Annotated Bibliography of Scientific Research Relevant to Oil and Gas Reclamation Best Management Practices in the Western United States, Published from 1969 through 2020

Open-File Report 2023–1068

U.S. Department of the Interior
U.S. Geological Survey

Cover. Hydroseeding for reclamation at an oil and gas well pad in the Uinta Basin, Utah. Photograph by Rebecca Mann, U.S. Geological Survey, 2020. (Photograph cropped from original version.)

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)
	Pressure	
pound per square inch (psi, lb/in^2)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)
	Radioactivity	
picocurie (pCi)	0.037	becquerel (Bq)
	Rate	
fluid ounce per acre (fl. oz/ac)	0.0730778	Liter per hectare (L/ha)
quart per acre (qt/ac)	2.33849	Liter per hectare (L/ha)
metric ton per acre (t/ac)	2,471.05	kilograms per hectare (kg/ha)
metric ton per acre (t/ac)	2.47105	metric tons per hectare (t/ha)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square millimeter (mm^2)	0.00155	square inch ($in.^2$)
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
square meter per hectare (m^2/ha)	4.356	square feet per acre (ft^2/ac)
	Volume	
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]
metric ton (t)	0.9842	ton, long [2,240 lb]
	Pressure	
kilopascal (kPa)	0.1450	pound per square inch ($lb/in.^2$)
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
gram per square meter (g/m^2)	0.000205	pound per square foot (lb/ft^2)
	Radioactivity	
becquerel (Bq)	27.027	picocurie (pCi)
	Rate	
kilogram per hectare (kg/ha)	0.892179	pound avoirdupois per acre (lb/ac)
milligram per hectare (mg/ha)	892.179	pound avoirdupois per acre (lb/ac)
liter per square meter (L/m^2)	3.26973	fluid ounces per square foot (fl. oz/ft^2)
megagram per hectare (Mg/ha)	5447.73	Mg per acre (lb/ac)
liter per hectare (L/ha)	0.427627	quart per acre (qt/ac)
liter per hectare (L/ha)	13.684	ounce, fluid per acre (fl. oz/ac)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Supplemental Information

Usage of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas.

Species Names

Tables for converting biological species scientific names to common names, and vice versa, can be found in appendix 1.

Abbreviations

ai	active ingredient
AC	activated carbon
AIC	Akaike information criterion
AIS	alien invasive species
AMF	arbuscular mycorrhizal fungi
ANOVA	analysis of variance
ART	Automated Reference Toolset
AWC	available water content
BD	bulk density
BES	biodiversity and ecosystem
BLM	Bureau of Land Management
BPSOU	Butte Priority Soils Operable Unit
Bq	becquerel
C	carbon
Ca	calcium
$CaCO_3$	calcium carbonate
CO_2	carbon dioxide
DART	disturbance Automated Reference Toolset
DNA	deoxyribonucleic acid
EC	electrical conductivity
ECB	erosion control blanket
EPA	U.S. Environmental Protection Agency
FFI	Flora and Fauna International
GIS	Geographical Information System
GPS	Global Positioning System
GS	Google Scholar search engine

IIRH	Interpreting Indicators of Rangeland Health
IS	imaging sensor
K	potassium
K_s	saturated infiltration rate
lidar	light detection and ranging
MANOVA	multivariate analysis of variance
MBC	microbial biomass carbon
MLRA	major land resource area
Mg	magnesium
Mn	manganese
N	nitrogen
Na	sodium
NDVI	Normalized Difference Vegetation Index
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
NMDS	nonmetric multidimensional scaling
NRCS	Natural Resources Conservation Service
P	phosphorous
ppm	parts per million
PAM	polyacrylamide
PCA	principal component analysis
PLFA	phospholipid-derived fatty acids
PLS	pure live seed
PM	peat-mineral soil mixture
RGB	red green blue
ROW	right-of-way, rights-of-way
S	sulfur
SO_2	sulfur dioxide
SAR	sodium adsorption ratio
SATVI	Soil Adjusted Total Vegetation Index
SMBC	soil microbial biomass
SMCRA	Surface Mining Control and Reclamation Act of 1977
SOM	soil organic matter
SOC	soil organic carbon
UAS	unmanned aerial systems

UAV	unmanned aerial vehicle
U.S. or USA	United States of America
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
VAM	vesicular-arbuscular mycorrhizal/mycorrhizae
VLSA	very-large scale aerial
WDEQ	Wyoming Department of Environmental Quality
WDEQ-LQD	Wyoming Department of Environmental Quality Land Quality Division
WOS	Web of Science search engine
Zn	zinc

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By Rebecca K. Mann,[1] Molly L. McCormick,[1] Seth M. Munson,[1] Hillary F. Cooper,[2] Lee C. Bryant,[2] Jared K. Swenson,[2] Laura A. Johnston,[1] Savannah L. Wilson,[1] and Michael C. Duniway[1]

Abstract

Integrating recent scientific knowledge into management decisions supports effective natural resource management and can lead to better resource outcomes. However, finding and accessing scientific knowledge can be time consuming and costly. To assist in this process, the U.S. Geological Survey has created a series of annotated bibliographies on topics of management concern for lands in the western United States (U.S.). Oil and gas development on public lands is a long-standing and substantial component of local and regional economies and has expanded in recent decades, particularly on public lands in the western U.S. This development is associated with extensive networks of pipelines, roads, and processing facilities, across which reclamation is Federally mandated following initial well pad development (“interim” reclamation) and once resource extraction is complete (“final” reclamation). Reclamation is critical for recovering ecological services to energy-affected lands, including vegetation productivity, wildlife habitat, water and air quality, and soil stability (for example, resistance to wind and water erosion). However, reclamation of oil and gas affected lands in the western U.S. has proved challenging due to an array of regulatory and environmental factors, such as minimally developed soils, short growing seasons, herbivory, high winds, invasive species, rugged terrain, and in particular, arid climates associated with low total precipitation, high evapotranspiration rates, and highly variable precipitation patterns. We compiled and summarized journal articles, government reports, technical reports, proceedings, and theses and dissertations relevant to oil and gas reclamation. We constrained our search to products published on or before December 31, 2020 but did not limit our search by a starting date; the earliest product resulting from this effort was published in March 1969. Second, we manually scanned the last 15 years (2005-2020) of tables of contents in journals, bibliographies, and proceedings of which we were aware would contain articles highly relevant to this bibliography. We carried out the search for these products through multiple means: (1) performing a structured search of two reference databases, (2) examining articles published since 2005 in highly relevant scientific journals and conference proceedings, and (3) reviewing additional material suggested by authors of products identified in steps 1 and 2. Our search was intentionally broad in order to identify as much relevant work as possible, much of which is professionally applied and tested within the industry of oil and gas reclamation, but which remains unpublished in scientific journals. We refined the initial list of products by removing: (1) duplicates, (2) products not written in English, (3) products that were not relevant to the arid ecosystems of western North America, (4) products that were not released as research, data products, or review articles in journals or as formal scientific reports, and (5) products with data which were not relevant to reclamation of oil and gas-affected lands, or for which the study did not present new data, findings, or syntheses relevant to reclamation of oil and gas-affected lands.

We summarized each product using a consistent structure (background, objectives, methods, location, findings, and implications) and assigned standardized management topics to each. Management topics are intended to aid online searching within the bibliography and are described in more detail in the Methods Section of this report; they include what type of disturbance the product addresses (well pads, mining, pipelines), what aspect of oil and gas reclamation they pertain to (practices, standards, monitoring), what type of data are present in the product (for instance soil or vegetation recovery data), and an indication if the product were from a source other than a published, peer-reviewed outlet (such as dissertations or unpublished professional reports – these are identified as grey literature). The review process for this annotated bibliography included an initial internal colleague review of each summary, requesting input on each summary from an author of the original product, and a formal peer-review. Our initial searches resulted in 3,197 total products, of which 290 met our criteria for inclusion. “Reclamation Practices” is by far the

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management topic most addressed, followed by "Reclamation Monitoring," for example, products assessing what and how monitoring methods are used to track and measure reclamation outcome. This document may be accessed at https://doi.org/10.3133/ofr20231068 or from the U.S. Geological Survey Publication Warehouse (https://pubs.usgs.gov/). The 1-page product summaries herein will also be used to create a bibliography at https://apps.usgs.gov/science-for-resource-managers that includes links to each original product, where available, and in which subject matter will be searchable by topic, location, and year. The studies compiled and summarized here may inform planning and management actions that seek to reclaim landscapes across the western U.S. which have been affected by oil and gas development.

Introduction

Reviewing the best available science relevant to land managers and resource planners is an important part of decision-making processes—helping to ensure that proposed resource management actions and decisions are as effective as possible in meeting their stated goals. However, the overwhelming number of scientific publications, the restrictive access to many publications and publication databases, and the time needed to execute a comprehensive search for the best available science on any given topic can hinder resource managers' ability to access and consider this science in their decisions. To facilitate the integration of science into decision making on lands influenced by oil and gas development in the western United States (U.S.), the U.S. Geological Survey (USGS) has carried out a program of work to compile and summarize recent scientific literature on a series of affected resources and topics of reclamation management concern.

Oil and gas development on public lands in the U.S. is substantial with a long history and provides revenue to local and regional economies and provisions important resources for the American people, for example, the Fiscal Year (FY) 2019 U.S. Department of the Interior economic contributions to the National economy (https://doi.sciencebase.gov/doidv/). Domestic oil and gas activity has expanded in recent decades (Allred and others, 2015; Copeland and others, 2017), particularly on public lands concentrated in the western U.S. Development of oil and (or) gas reserves entails surface disturbance and land clearing, including leveling lands for drilling, clearing vegetation and topsoil from well pads (Buto and others, 2010; Martinez and Preston, 2018), and constructing extensive networks of pipelines, roads, and processing facilities. Collectively, these activities result in a significant disturbance footprint that needs to be managed while in use and reclaimed after resource extraction is complete (U.S. Department of the Interior and U.S. Department of Agriculture, 2007; Allred and others, 2015; Moran and others, 2017).

Reclamation of areas disturbed by oil or gas activities is required by law for all well pads on Federally managed lands, the majority of which are under the jurisdiction of the Bureau of Land Management (BLM) Code of Federal Regulations 82 FR 2906. Reclamation mandates are further dictated by State-level BLM Field Office guidelines and Resource Management Plans (RMPs), as well as various State regulations (Curran and Stahl, 2015; Di Stéfano and others, 2021). Federal policy requires that operators carry out both "interim reclamation," a temporary stabilization of unused well pad surfaces and topsoil while the well is in production, and "final reclamation" of the entire well pad plus access roads or pipelines on the same use permit as the well pad, once resource extraction has been completed (Di Stéfano and others, 2021). Reclamation is critical to recovering the affected ecosystems, including water and air pollution, habitat degradation for protected wildlife (Sawyer and others, 2013; Hethcoat and Chalfoun, 2015; Green and others, 2017; Wyckoff and others, 2018), accelerated erosion (Duniway and Herrick, 2011; Allred and others, 2015; Duniway and others, 2019), and the spread of undesirable non-native invasive plant species (Villarreal and others, 2019; Gelbard and Belnap, 2003). Specific end goals of reclamation have varied widely depending on jurisdiction, current scientific knowledge, and management priorities, which can range from reinstating ecosystem services such as erosion control or forage production (Hobbs and Norton, 1996; Hobbs and others, 2006), to recovering historical ecosystem components and functions (Ruiz-Jaen and Aide, 2005; Prach and Hobbs, 2008; Wortley and others, 2013). The BLMs most current guidelines for reclamation goals and standards at the Federal level are described in the "Gold Book" (U.S. Department of the Interior and U.S. Department of Agriculture, 2007). Whatever the ultimate target, reclamation has proven to be extremely challenging in western U.S. landscapes (Nauman and others, 2017; Waller and others, 2018) due to environmental factors such as short growing seasons, ongoing herbivory, invasive species, topography, and in particular, challenging soils and harsh, arid climates (Duniway and others, 2019). In this annotated bibliography, we performed a search for written scientific products relevant to surface management of oil and gas on lands managed by the BLM and similar landscapes. We bound our search to products published on or before December 31, 2020 (the earliest product resulting from this effort was published in March 1969), and publicly available through December 31, 2020. We summarized the identified products using a standard 1-page format developed by the USGS (Carter and others, 2018, 2020) for use in the "Science for Resource Managers Bibliography" database.

Although this annotated bibliography does not replace the need to read the primary literature, we hope that this document will serve as a valuable reference for planners and managers responsible for making decisions about surface management of oil and gas in the western U.S. Each summary (and its associated product) is searchable in the online database by management topic using filters, or by using keywords to identify any term appearing in the title or body of the summary. We provide links to the original products to facilitate access to primary documents. Successful reclamation and management of oil and gas disturbances are topics of ongoing scientific interest and management concern. As such, information in this document can serve as a readily accessible resource for managers, planners, and policy makers who need a quick reference to recent peer-reviewed science and data about oil and gas reclamation and other aspects of surface management. Moreover, the products in this bibliography can be used to learn from previous reclamation efforts to better apply, refine, and improve management efforts on the ground.

Methods

Search Process

Previous reports (Carter and others, 2018, 2020) introduced a methodology for compiling annotated bibliographies to facilitate the integration of recent, peer-reviewed science into resource management decision-making. This and other annotated bibliographies (for example, Kleist and others, 2022; Poor and others, 2021) build on that method and apply it to additional species of interest and topics of management concern on western lands. Therefore, some relevant text and methodologies from Carter and others (2018, 2020) is reproduced herein to frame the presentation.

We used three search processes to collect original scientific work relevant to the practices, monitoring, and standards set for reclamation on landscapes affected by oil and gas development in the western U.S. First, we carried out a systematic search within two citation search engines: Web of Science, and Google Scholar using search phrases described below and in table 1. We developed the search phrases through consultation with an interagency team that had a background in oil and gas reclamation to help ensure that we would capture relevant products. We constrained our search to products published on or before December 31, 2020 but did not limit our search by a starting date; the earliest product resulting from this effort was published in March 1969. Second, we manually scanned the last 15 years (2005–2020) of tables of contents in journals, bibliographies, and proceedings that we were aware would contain articles highly relevant to this bibliography. These were:

- Journal of the American Society of Mining and Reclamation,
- International Journal of Mining, Reclamation, and Environment,
- OnePetro,
- Society of Petroleum Engineers American E&P Environmental and Safety Conference,
- Restoration Ecology,
- High Altitude Revegetation Workshop,
- Billings Symposia on Disturbed Land Rehabilitation,
- Wildland Shrub and Arid Land Restoration Symposia, and
- University of Wyoming Agricultural Experiment Station Field Days Bulletin.

Any articles in the tables of contents with titles and abstracts which appeared (even marginally) to meet the initial screening criteria described below were compiled. General handbooks and fact sheets, such as those from university U.S. Department of Agriculture Extension programs, were not included as part of the targeted search because they were considered informational compilations rather than original scientific work. Finally, our third search process involved compiling written products pertaining to oil and gas reclamation that was brought to our attention through other means. These "ad hoc" products were primarily those shared with us by the authors whom we contacted regarding the summaries of their products (see "Review Process" section), but also included highly relevant literature gleaned from the citation sections of the other products we reviewed. All products generated from these three processes (search engines, systematic scan of tables of contents, and ad hoc additions) were imported to a citation manager (EndNote X9) and metadata about these products were organized in a Microsoft 365 Excel database.

Systematic searches in Web of Science and Google Scholar were based on three tiers of search terms. Products were required to contain at least one term from the first tier, one term from the second tier, and no terms from the third tier. The first tier was designed to constrain results to products related to the subject of oil and gas; these terms included "oil and gas," "well pad," "well site," "oil pipeline," "gas pipeline," "oil pad," "gas pad," "coal bed methane," and "fluid minerals." The second tier of search terms (table 1) identified products related to the subject of reclamation; these were broken up into lists based on reclamation foci, to make searching manageable within the constraints of the search engines. The third tier was composed of exclusion terms specifically tailored to remove products containing commonly recurrent subject matter that was not pertinent to the reclamation bibliography, such as remediation of contaminants, physical and chemical properties of drilling equipment, air quality management, and studies carried out in non-target environments (that is, boreal forest, arctic, and tundra ecosystems; table 2).

In Web of Science, the search was applied to products from all databases, years, languages, and document types, and searching was limited to text appearing in the products' titles, keyword lists, or abstract text. A search single line was constructed to identify products containing any word from tier 1 terms, any word from one list of tier 2 terms, and no words from tier 3 terms; this process was iterated over all lists within tier 2. All products generated from the Web of Science search were exported to EndNote and the Excel database.

Google Scholar search engine uses a proprietary algorithm, which has been found to give higher ranking to articles which are highly cited and which have titles containing the search terms (Beel and others, 2010). This engine provided a more replicable list of results when using simpler search lines that limited the use of multiple operators; thus, we broke our search lines into multiple simple statements to identify products containing: one word from tier 1 terms, one word from tier 2 terms, and no words from tier 3 terms; this process was iterated over all combination tier 1 and tier 2 terms. Google Scholar also has a 256-character limit for search statements, so we constrained our exclusion terms to just those which produced the greatest reduction of products (table 2). We then manually scanned the titles of the first 100 articles resulting from each search statement and flagged any which appeared (even marginally) to meet the screening criteria described below. If at least one article appeared to meet

Table 1. Second tier search terms used to identify written products relevant to oil and gas reclamation in the western United States within search engines that were used to build the bibliography.

[Second tier search terms were broken up into lists on the basis of reclamation foci to make searching manageable within the constraints of the search engines. The search process required that products contain at least one term from a second-tier list. Search terms related to reclamation monitoring were broken into two lists ("Monitoring metrics" and "Monitoring methods and target areas"); search engines were required to include one word from each list, with all potential combinations explored. An asterisk (*) is a wild card indicating that any characters appending the search word are accepted. Quotations ("") are used to force the search engine to only identify exact phrases for multi-word terms. Within each list, search terms are separated by commas.]

Reclamation focus	Search terms
Reclamation practices	
General	reclaim*, restor*, revegetat*, remediat*, "natural recovery", "decision support tools", "ecosystem management"
Seeding	seed*, plant*, broadcast, drillseed, "drill seed"
Amendments	biochar, fertiliz*, mulch*, "wood chip", "soil amendment*"
Resurfacing	earthwork, resurface, stockpile, *contour*, "dirt work", "site preparation", "top soil", "topsoil", "spoils pile"
Weed control	weed, invasive, "exotic plants", "exotic species", "native plant", "native species"
Reclamation monitoring	
Monitoring metrics	runoff, erosion, habitat, ecological, forb*, grass*, shrub*, "bare ground", "functional group", "water infiltration", "plant cover", "plant density", "plant frequency", "vegetation cover", "species diversity", "species richness"
Monitoring methods and target areas	monitor*, benchmark*, "reference area", "reference site", "indicator", "monitoring methods", "remote sensing", "line point", "transect", "ocular"
Reclamation standards	
Overall goals	"bond release", "vegetation standards", "ecological sites", "final abandonment*", "ecological site groups"
Ecological setting	
Desired communities	rangeland*, grassland*, shrubland*, dryland*

Table 2. Third tier exclusion terms used to identify appropriate written products relevant to oil and gas reclamation in the western United States within search engines that were used to build the bibliography.

[Third tier exclusion terms were specifically tailored to remove products containing commonly recurrent subject matter that was not pertinent to the reclamation bibliography. The search process required that products not contain any of the terms from the third-tier lists. An asterisk (*) is a wild card indicating that any characters appending the search word are accepted. Quotations ("") are used to force the search engine to only identify exact phrases for multi-word terms. Due to character limitations, searches performed using Google Scholar excluded all the terms except those shown in italics.]

Wrong ecosystem	Chemistry or Physiology	Pollutants	Exploration
"off shore"	isotope	"dioxide capture"	seismic
offshore	physiology	carcinogen	distill*
arctic	chromatography	wastewater	spectrometry
boreal	consumption	"produced water"	injection
tundra	*kinetics*	"*CO2 capture*"	source rock

screening criteria within the final 20 articles of the output, we continued to scan an additional 50 articles (150 total). Complete output from all search lines were retained in records, and all flagged citations were exported to EndNote and the Excel database.

We purposefully included in this bibliography both peer-reviewed published publications and unpublished professional or university products that were not peer-reviewed, such as technical project reports, theses, dissertations, and publications from professional conference proceedings. These products, commonly known as “gray literature,” were intentionally included in this bibliography due to a limited pool of peer-reviewed publications specific to oil and gas reclamation and a correspondingly large amount of reclamation research taking place within professional industry that does not make it to the publication phase. Because gray literature has not been formally reviewed, and results of these products should be interpreted carefully, we flagged these products clearly within the list of Management Topics using the term “GrayLit.” Thus, readers who encounter this bibliography (whether via this report or through the online search engine), will be aware of any products that have not been formally peer reviewed. Further information about the type of product (for example, thesis, dissertation, report, conference proceedings) is indicated in the title of the product that is summarized. If the “GrayLit” term is not included in the Management Topics, then the product was from a peer reviewed outlet, which include published books, peer-reviewed government reports, or journal articles published in a credible scientific journal.

Product Screening

We organized the products gathered during the search processes within an Excel database to further characterization and identify just those which were relevant to the practices, monitoring, and standards for reclamation of western U.S. landscapes directly affected by oil and gas development. Research products were required to be based in water-limited (arid, semi-arid, and sub-humid) landscapes representative of the western U.S., unless their subject matter was transferable across environmental boundaries, such as general principles for developing reclamation standards, monitoring tactics, and reclamation success indicators. Although the search processes were structured to capture products directly pertinent to oil and gas, we included all products resulting from the searches if they had a scope of inference pertinent to oil and gas reclamation in terms of their on-the ground footprint, intensity of land disturbance, and reclamation goals. Thus, although this effort did not include a comprehensive search for products within the mining and road reclamation fields, our set contains research from those land disturbance types.

The screening process occurred in two phases. In a first pass screening, we scanned product titles and abstracts. Products were removed if they had no relevance to oil and gas reclamation, pertained to a region that was not ecologically comparable to the western U.S., were not associated with a complete report (for example, slideshows, posters, abstracts), were duplicates of a previously identified product or were not written in English (table 3). Products only pertaining to reclamation policy but not practices, standards, or monitoring,

Table 3. First pass product exclusion reasons and explanations of terms used to identify written products relevant to oil and gas reclamation in the western U.S. that were used to build the bibliography.

Exclusion reasons	Explanations
Ecosystem mismatch	Product represented areas outside the arid and semi-arid ecosystems of the western U.S.
Ecology focus	Conservation, biodiversity, land use planning: No direct reclamation inference.
Contaminant focus	Contamination, remediation, environmental health: No direct reclamation inference.
Operations focus	Drilling regulations, operations, safety: No direct reclamation inference.
Engineering focus	Chemical or structural engineering, tool development: No direct reclamation inference.
Exploration focus	Exploration, energy development, alternative energy: No direct reclamation inference.
Social focus	Social history, politics, development policy: No direct reclamation inference.
Wildlife focus	Wildlife response to well pad development: No direct reclamation inference.
Physical Science focus	Geology, hydrology, landscape response to development: No direct reclamation inference.
Agricultural focus	Agricultural focus with no application to oil and gas: No direct reclamation inference.
Restoration but not oil/gas	Restoration of areas with footprint or disturbance intensity not equivalent to oil and gas.
Duplicate product	Product is a duplicate of a previously accepted product in the database.
Inappropriate product type	Bibliographies, abstracts, slideshows, news articles, book reviews, editorials, handbooks, guidelines, best management practices, slideshows, government policy announcements.

and secondary sources of information (for example, news articles, bibliographies, book reviews, editorials, and interpretive materials such as guides or handbooks) were also removed. Scientific literature reviews targeting an original theme were considered primary work and were included. During this first pass screening, we broadly classified the accepted products according to several criteria (table 4), including the type of land disturbances addressed by the products (well pad, pipeline, mining, and [or] road disturbance), the types of data included in each product, the product types (for example, journal article, technical report, thesis or dissertation), and reclamation topics. Broad reclamation topics ("Reclamation Policy," "Reclamation Theory," "Reclamation Practices," "Reclamation Monitoring," "Reclamation Standards," and "Decision Support Tools") are fully defined in table 4 and are used to classify the primary focus of the products, in terms of their research intent and implications. For instance, the summarized publication by D.T. Booth, 2002, "Seed longevity and seeding strategies affect sagebrush revegetation," tested reclamation within the context of the "exclusion" and "pioneer plant" hypotheses, and it was thus assigned the topic of "Reclamation Theory"; other products that test reclamation tactics without explaining the results within the context of ecological or reclamation theories were not flagged with that term. Likewise, although most products mention that reclamation practices exist, only those which were testing the efficacy, outcome, cost, value, and so forth, of various techniques, were classified using the term "Reclamation Practices." Products retained during the first pass screening were subjected to a more in-depth second pass screening, in which we scanned the full text of each product and categorized them according to additional criteria, including information on the study location and kinds of reclamation treatments tested (for example, soil amendments, seed mixes, or seeding methods).

We parsed the final list of products among seven of the authors of this Open-File Report (L. Bryant, H. Cooper, L. Johnston, R. Mann, M. McCormick, J. Swenson, S. Wilson), in order to write the 1-page summaries. The authors calibrated their writing approach by meeting with the lead author (R. Mann) to review a set of priorities: (1) accuracy of the summarized content, (2) success in capturing key findings from the original product, and (3) maintenance of consistency in the level of detail reported. The writers also underwent a training period in which at least three of their summaries were closely read and reviewed by the lead author; this training process continued until the summaries written met the priority conditions. After the training period, the writers worked independently from the lead author. Products were disproportionally parsed among writers (one person wrote 200 summaries, and the remaining six people wrote an average of 15 products each). After their completion, all summaries were reviewed by the lead author to verify consistency and coherence of the summaries.

Written summaries have a structured format, with sections describing the background, objectives, methods, location, findings, and implications of the product, as well as a list of management topics the product addressed (see table 4). Location information included the country and state(s) where research occurred and, if available, the general area within each state or coordinates associated with study areas. All the information in the 1-page summaries is based on what was written by the original authors of the products and does not include any interpretations by the authors of this bibliography. Similarly, the summaries were written using the common and scientific names of species as they appear in the original texts; currently accepted taxonomic names can be found linked to the older synonyms in appendix 1. Considerable information was distilled from each product in developing the summary, and though we attempted to accurately represent each product, there may be additional information in the original product that is not included in each summary. The target length for summaries was short (350 words or less); as a result, the source documents should always be consulted directly for more specific information (links to the original product are provided for each summary whenever available).

Review Process

All 1-page summaries were sent to the corresponding lead authors of the products for their review and permission for printing in this bibliography. We gave each author two months to supply feedback after our initial email contact, sending a reminder one month and two months after initial contact. Of the 290 products we accepted for the bibliography, authors of 153 products responded, approving the inclusion of the summary in the bibliography. Authors of two products withdrew their work from the bibliography, authors of 74 products did not reply to emails, and we were unable to identify a method of contacting the authors of 63 products after a thorough online search. This process is consistent with USGS Fundamental Science Practices. After completion, this bibliography was formally peer reviewed by two independent reviewers and by the USGS Bureau Approving Official.

Results

A total of 3,197 products were identified by our initial search processes, including 1,697 identified from Web of Science, 1,046 from Google Scholar, 320 from targeted journals, and 134 from either author recommendations or conference proceedings. The first pass screening reduced the pool of products to 668, and the second pass screening, as well as feedback from the product authors and reviewers, resulted in the final set of 290 written products included in this bibliography. The final set of 290 product summaries will be posted on an online USGS-hosted searchable database the "Science for Resource Managers Bibliography"

Table 4. First pass article classification terms, with their definitions, which were used to classify the written products relevant to oil and gas reclamation in the western U.S that were used to build the bibliography.

[During the first pass screening, we broadly classified the accepted products according to several criteria, including the type of land disturbances addressed by the products, the types of data included in each product, the product types, and reclamation topics. Broad reclamation topics are fully defined here and are used to classify the primary focus of the products, in terms of their research intent and implications.]

Management category	Management topic	Definition
Land disturbance type	Well Pad	Study took place on an oil and gas well pad, used soils derived from an oil and gas well pad, or if the study was carried out in a greenhouse or lab, the authors of the study stated that results had direct inference to reclamation of oil and gas well pads.
	Pipeline	Study took place on oil and gas pipelines, used soils derived from an oil and gas well pipeline, or if the study was carried out in a greenhouse or lab, the authors of the study stated that results had direct inference to reclamation of oil and gas pipelines.
	Mining	Study took place on mining disturbances, used soils derived from mining disturbances, or if the study was carried out in a greenhouse or lab, the authors of the study stated that results had direct inference to reclamation of mining disturbances.
	Road	Study took place on road disturbances, used soils derived from road disturbances, or if the study was carried out in a greenhouse or lab, the authors of the study stated that results had direct inference to reclamation of road disturbances.
Data types	Vegetation Recovery Data	Product includes data on response of vegetation classes to reclamation tactics.
	Target Plant Recovery Data	Product includes data on individual plant species responses to reclamation tactics.
	Exotic Plant Data	Product includes data on exotic species abundance or response to control in reclaimed areas.
	Soil Data	Product includes data on soil amendments or soil properties in response to reclamation.
	Erosion Data	Product includes data on wind or water erosion in reclaimed areas.
	Hydrology Data	Product includes data on water movement patterns or hydrology in reclaimed areas.
	Wildlife Data	Product includes data on wildlife or wildlife habitat in response to reclamation.
Topics covered	Reclamation Policy	Product focuses on local or government policies on reclamation or reclamation economics.
	Reclamation Theory	Product focuses on scientific theories driving reclamation decisions or outcomes.
	Reclamation Practices	Product evaluates reclamation practices (review of techniques or outcomes of techniques).
	Reclamation Monitoring	Product evaluates monitoring methods used for tracking reclamation outcomes.
	Reclamation Standards	Product evaluates standards or benchmarks used to judge reclamation outcomes.
	Decision Support Tools	Product presents or evaluates decision processes or decision tools for reclamation planning.
Product class	GrayLit	Product was not rigorously peer reviewed. Includes technical professional reports, conference proceedings, professional magazine articles, theses, and dissertations.

(https://apps.usgs.gov/science-for-resource-managers). The set of summaries can be filtered by management topic (table 4), and the entire or filtered set of summaries can be queried using an open search function that identifies summaries from any user-defined search term. Links to the original products are included with each summary when available to direct users to the primary documents.

Within the final set of products (fig. 1), Google Scholar detected the greatest number (132, 46 percent); an additional 77 (27 percent) were from targeted journals or proceedings, 55 (19 percent) were added ad hoc (for example, author-recommended citations), and 26 (9 percent) were identified through Web of Science.

Even though our search was targeted to identify products related to oil and gas, the majority of products (165, 57 percent) focused on reclamation of land disturbances caused solely by mining. There was a steady increase in the number of written products related to oil and gas reclamation over time, with 118 total products (41 percent) directly related to oil and gas well pads and pipelines (fig. 2). A majority of the work (254, 88 percent) contained original data, which most commonly described vegetation response to reclamation practices, followed by response of soil parameters (for example, physical, chemical, or micro-organism response to reclamation practices), and response of targeted plant species.

The predominant topic of the products was reclamation practices, that is, those investigating interventional techniques (such as soil amendments, seeding, or earthwork) to create desired reclamation outcomes; this was discussed within 236 products (66 percent). Other topics were less common: “Reclamation Monitoring” (investigation into the methods used to measure reclamation progress) was discussed in 15 percent of the products, “Reclamation Standards” (evaluation of the standards or benchmarks used to justify reclamation success) was discussed in 9 percent of the products, “Reclamation Theory” (scientific theories driving reclamation outcomes in response to practices or influencing

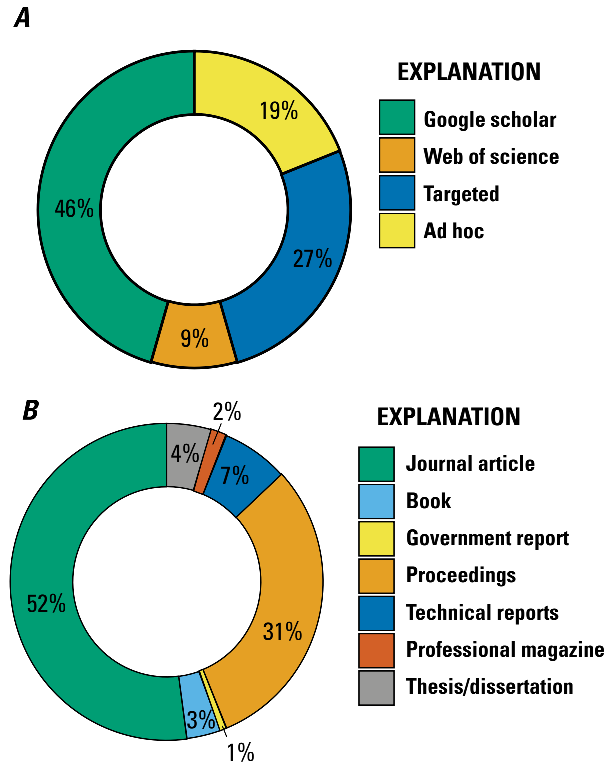

Figure 1. Diagrams of distributions of products included in the annotated bibliography of oil and gas reclamation best management practices in the western United States, 1969–2020. *A*, Distribution of products by method of identification (ad hoc refers to our search process regarding written products that were brought to our attention through other means); *B*, Distribution of products by type. A total of 163 products (56 percent) were from peer-reviewed journals, government reports, and books; and 127 products (44 percent) were professional reports, theses, dissertations, proceedings, and magazine articles that were not rigorously peer-reviewed.

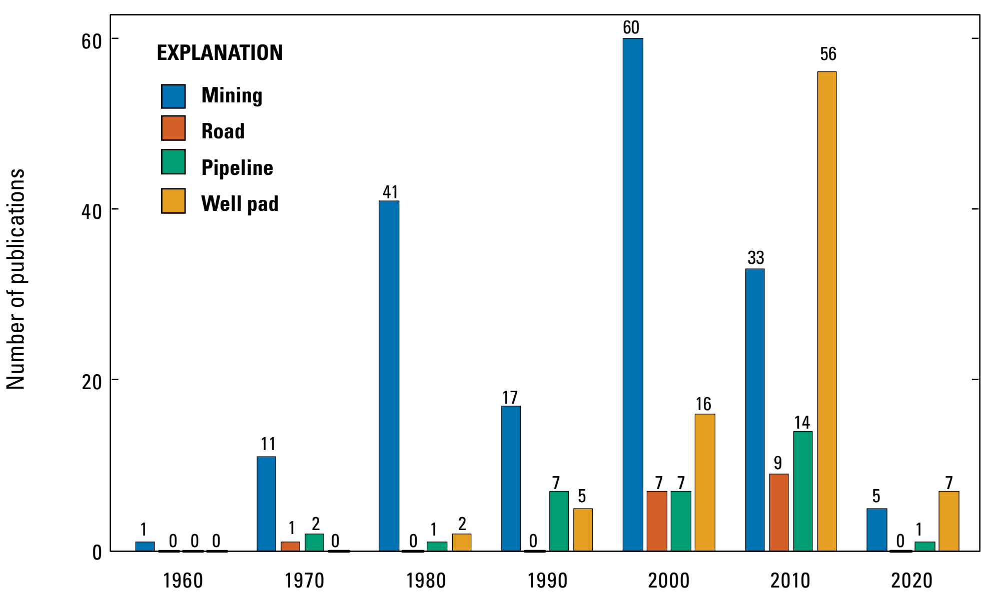

Figure 2. Histogram of products released per decade according to the types of disturbance they address that are included in the annotated bibliography of oil and gas reclamation best management practices in the western United States, 1969–2020. More than one disturbance type per product is possible.

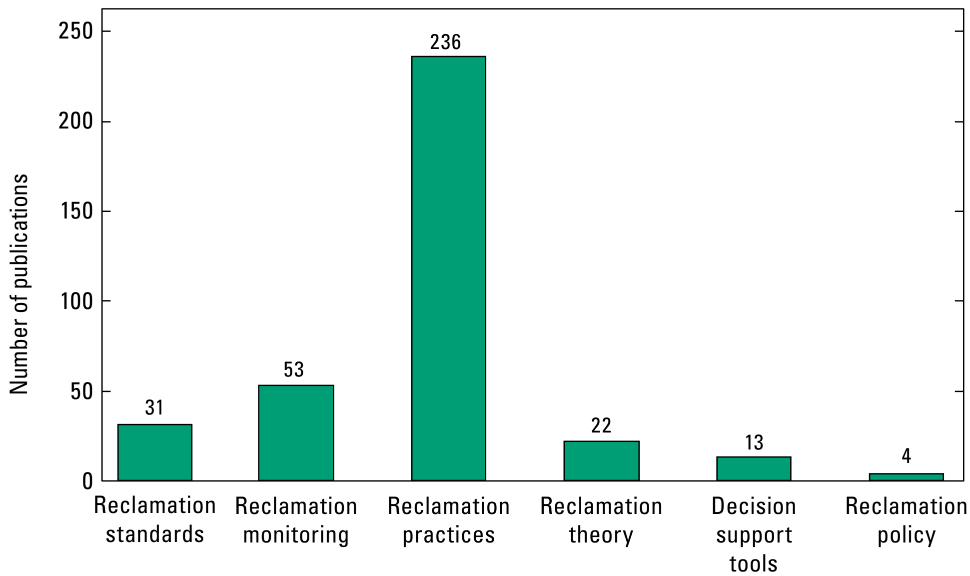

Figure 3. Graph of primary themes of written products that were included in the annotated bibliography of oil and gas reclamation best management practices in the western United States, 1969–2020. More than one theme per product was possible. The categories used to classify these products were reclamation standards (represented in 9 percent of all products), reclamation monitoring (15 percent), reclamation practices (66 percent), reclamation theory (6 percent), decision support tools (13 percent), and reclamation policy (1 percent); policy documents were excluded from the bibliography unless one of the preceding topics were also part of the subject matter. Numbers above columns indicates number of publications.

how reclamation decisions are made) were discussed in 6 percent of the products, and "Decision Support Tools" were discussed in 13 percent of the products. "Reclamation Policy" was discussed in 1 percent of the products, although this topic was not included unless one of the preceding topics were also part of the subject matter (fig. 3).

The products included in this bibliography represent scientific products and reports published from March 1969 through December 31, 2020, which are written in English and relevant to oil and gas reclamation in the western U.S. We present this annotated bibliography to help bridge the science-management gap by providing managers with a more easily accessible and synthesized set of scientific information relevant to surface management of oil and gas on western public lands.

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Aho, K., Weaver, T., and Regele, S., 2011, Identification and siting of native vegetation types on disturbed land—Demonstration of statistical methods: Applied Vegetation Science, v. 14, no. 2, p. 277–290.

DOI: https://doi.org/10.1111/j.1654-109X.2010.01110.x
Background: This paper attempts to better understand what vegetation types and communities exist in a particular area and the environmental characteristics that determine their distribution on the landscape. The authors located pre-disturbance native plant communities and developed a statistical approach for describing the niche space that they occupy to assist reclamation by setting site-appropriate reference areas or reclamation benchmarks.
Objectives: The authors (1) identified vegetation types appropriate for a particular project area, then (2) modeled the environmental characteristics where select vegetation types would most likely succeed after reclamation.
Methods: Vegetation data were collected along transects over a 3-year period to determine community composition and divisions between vegetation types. Reference vegetation type models using logistic general linear models and used regression tree analysis to determine which of several vegetation types would be best suited at a specific location in need of reclamation.
Location: Absaloka Mine in southeast Montana, USA
Findings: The models demonstrated that a continuum of vegetation communities exist including upland, bottomland, and old fields. Topography and slope were generally the best predictors in the models of vegetation presence. This process produced a relevé table for sites that included a species list, target cover levels, and a suggested seed mix for particular areas.
Implications: Reclamation efforts should consider the structure of the habitat and community types for target species. Sites planning reclamation must determine vegetation community classes and number of vegetation types suitable for the area. This methodology may work best for sites with minimal disturbance, such as cropland, rather than drilling or mining.
Topics: Mining, Reclamation Standards

Aird, J., 2012, Hydroseed challenges, hydroseed solutions: Erosion Control, v. 19, no. 1, p. 20–29.

Link (non-DOI): https://trid.trb.org/view/1127086
Background: Hydroseeding has been accomplished on difficult terrain and mediated across multiple jurisdictions while meeting tight timelines and logistical barriers.
Objectives: The author highlights different hydroseeding application techniques, seed mixes, and mulches by summarizing three reclamation projects on difficult terrain.
Methods: Reclamation methods, challenges, and concerns surrounding the Horsetooth Reservoir, Ruby Natural Gas Pipeline, and the Garden State Parkway Expansion projects were reviewed. Each site presented challenges (steep slopes, high erosion rates, dust, and hydrological management). A variety of methods were used at each site to address site-specific concerns.
Location: This is a review article that discusses reclamation at three project sites: (1) Soldier Canyon, Dixon Canyon, and Spring Canyon dams of Horsetooth Reservoir, 5 miles (mi) west of Fort Collins, Colorado, (2) Ruby Natural Gas Pipeline, 558 of 680 mi of the pipeline crossing southwestern Wyoming through Utah, Nevada, and southern Oregon, and (3) Garden State Parkway Expansion, a 13 mi stretch along the Garden State Parkway in New Jersey, USA
Findings: The Horsetooth Reservoir project required crews to respond to constantly changing conditions to successfully reclaim 100 acres of land. The Ruby Natural Gas Pipeline project required mulching by helicopter due to steep slopes and erosion prone soils. Flexibility and consideration for land management goals along each section of the pipeline enabled successful reclamation of 558 mi of the pipeline. In the Garden State Parkway Expansion, easements, shoulders, medians, and on and off ramps along 13 mi of expanded highway were reclaimed to manage for erosion and dust control, as well as stormwater management. Staging and traffic logistics were the most difficult aspects of reclamation for the latter.
Implications: Hydroseeding areas with steep slopes are made more difficult by boulders, strong winds, and limited access. Determining what mulch, seed mix, and application technique to use depends on the project. Considerations for logistical complications, erosion, slope severity, land ownership and restoration goals, worker safety, soil quality, and nearby communities are essential for successful reclamation. The examples provided in this article can guide land managers restoring vegetation on difficult terrain.
Topics: Pipeline, Road, Reclamation Practices

Aldon, E.F., 1981, Long-term plant survival and density data from reclaimed southwestern coal mine spoils: Great Basin Naturalist, v. 41, no. 3, p. 271–273.

Link (non-DOI): https://www.jstor.org/stable/41711816
Background: Revegetation of previous coal strip mines is especially difficult in arid environments with little precipitation. Though research has shown such reclamation is possible, it is still unknown if revegetated ecosystems will assume full function and perform at pre-mine performance. Monitoring revegetation on coal strip mines is important for assessing reclamation success and determining which species are best suited for future reclamation projects in similar arid environments.
Objectives: The author assessed revegetation success and long-term survival of alkali sacaton and fourwing saltbush on reclaimed coal strip mines in an arid environment.
Methods: Four plot treatments were assessed: (A) direct seeding fourwing saltbush with no irrigation, (B) transplanting three-month old fourwing saltbush seedlings with drip irrigation, (C) broadcast seeding alkali sacaton on rototilled plots with sprinkler irrigation during the first growing season, and (D) broadcast seeding alkali sacaton in furrows with sprinkler irrigation during the first growing season. All plants were seeded on untreated spoil material with no additional topsoil. Monitoring included vegetation establishment and survival; treatments were compared five years after initiation.
Location: Navajo Mine, northwestern New Mexico, USA
Findings: Treatment (A) plots had 62 percent survival of fourwing saltbush. Competition likely leads to shorter plants over time. Treatment (B) plots had 88 percent survival of fourwing saltbush and plant height increased over time. Treatment (C) plots had an average of 36.8 surviving alkali sacaton plants, 5.3 percent cover, and a density of 0.06 plants per square meter (plants/m^2). Treatment (D) plots had a 2.6 percent alkali sacaton cover and a density of 0.04 plants/m^2. Alkali sacaton density did not differ from those found on undisturbed land in a similar study.
Implications: Alkali sacaton and fourwing saltbush showed some reestablishment over time, however the driving mechanisms were not fully understood. This study illustrates that revegetation of coal strip mines in arid environments is possible but needs further research.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices

Alexander, R.R., 2006, Standard upland revegetation specifications for the Butte Priority Soils Operable Unit Silver Bow Creek/Butte Area Superfund site Butte, Montana, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 25–48.

DOI: https://doi.org/10.21000/JASMR06010025
Background: Deep underground mining in the Silver Bow Creek/Butte Area Site near Butte, Montana, began with gold in 1864 followed by deep mining of copper, zinc, and silver. In 1955, this area transitioned to open pit mining that continues today. One of seven units within the Silver Bow Creek/Butte Area Site is the Butte Priority Soils Operable Unit (BPSOU), which the U.S. Environmental Protection Agency (EPA) designated as a Superfund site in the late 1980s. Since then, reclamation has involved revegetation efforts using soil-caps as a long-term cleanup method.
Objectives: The author reviewed the process of developing and implementing standards for revegetating the BPSOU in Butte, Montana.
Methods: The history of mining on the BPSOU within the Silver Bow Creek/Butte Area Site was outlined. The development and specifications of reclamation standards for the BPSOU were reviewed with regards to limestone stabilization, cover soil requirements, organic amendment, seeding, and fertilization.
Location: BPSOU of the Silver Bow Creek/Butte Area National Priorities List Site in southwestern Montana, USA
Findings: Reclamation standards were developed from several sources including the State of Montana abandoned mine reclamation specifications, reclamation practices established by the EPA and local county government, technical standards developed by the Reclamation Research Unit at Montana State University, and input from various site stakeholders. Early failed revegetation efforts were attributed to poor cover soil texture and water-holding capacity. The standards struck a balance between overly rigid requirements that would have slowed down the cleanup and weaker requirements that would have been environmentally unsatisfactory. More testing would improve the reclamation plan.

Implications: A clearly defined plan that meets industry, State, and Federal standards can help facilitate more successful reclamation and revegetation of mine lands. The process and standards used for revegetating the BPSOU serves as a case study and model for similar sites. Open discussion across all involved parties was a key component of the reclamation process.
Topics: Mining, Reclamation Practices, Reclamation Standards, GrayLit

Allen, E.B., and Allen, M.F., 1980, Natural re-establishment of vesicular-arbuscular mycorrhizae following stripmine reclamation in Wyoming: Journal of Applied Ecology, v. 17, no. 1, p. 139–147.

Link (non-DOI): https://www.jstor.org/stable/2402969
Background: Vesicular-arbuscular mycorrhizae (VAM) are found on many plants on reclaimed and naturally colonized stripmines and play an important role in vegetation health. In Wyoming, reclamation protocol mixes topsoil with subsurface soils, which may decrease VAM spore count, impacting plant communities and revegetation efforts. Understanding the response of mycorrhizal communities to reclamation is important for revegetation success.
Objectives: The authors evaluated the effects of topsoil mixing on VAM spore counts and root infection following stripmine reclamation in an arid environment and compared data to undisturbed and disked native prairies.
Methods: Sites were identified representing native undisturbed prairie sites and reclaimed stripmine sites, including three same-aged sites in their first growing season and three different-aged sites in the first, second, and third growing seasons. *Agropyron smithii* was collected from all sites, *Agropyron intermedium* was collected from the different-aged sites, and seven colonizing annuals were collected from sites where they were most abundant. The root system and adhering soil was collected from five individuals of each species. Five soil samples were collected from each site from the top 6 centimeters (cm) and were analyzed for pH, total nitrogen (N), extractable phosphorous (P) and potassium (K), and texture. Percent mycorrhizal infection from collected roots was determined and mycorrhizal spores were isolated from soil samples by sucrose flotation and counted. Data were analyzed using a one-way analysis of variance (ANOVA) and least significant differences.
Location: Three coal mines and surrounding shortgrass prairie in the Powder River Basin of northeastern Wyoming, USA
Findings: Natural prairies had higher P and N than reclaimed sites. The undisturbed prairie site had the highest mycorrhizal root infection (95 percent), followed by the disked prairie (62 percent), though spore count did not differ between the two sites. The same-aged, reclaimed sites had significantly lower spore counts than undisturbed sites. Root infection of *A. intermedium* and spore count increased with time in the different-aged sites but overall infection and counts on the 2- and 3-year-old sites were <50 percent of the native sites. Trends in spore count and root infection varied by site and over time and were likely impacted by high soil moisture in 1978 (second year of sampling).
Implications: After 2–3 years, mycorrhizal infection on reclaimed sites was up to 50 percent of undisturbed prairies; however, spore counts still lagged and were not correlated with infection. This suggests that spore presence likely depends on additional environmental factors, such as high clay content that reduces sporulation. Some reclamation methods, such as applying hay mulch, may increase VAM spores due to presence of a small number of spores in the material, although more research is needed to investigate these potential source materials.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Allen, E.B., and Allen, M.F., 1986, Water relations of xeric grasses in the field—Interactions of mycorrhizas and competition: New Phytologist, v. 104, no. 4, p. 559–571.

Link (non-DOI): https://www.jstor.org/stable/2433031
Background: In arid soils, Vesicular-arbuscular mycorrhizae (VAM) fungi may assist with nutrient and water uptake. Disturbance of arid soils disrupts mycorrhizal fungi and revegetation during reclamation could be delayed by reduced mycorrhizal spores. Additionally, succession may be impacted by pioneer species that do not form mycorrhizal relationships. However, few field studies have been conducted to better understand these complex relationships.
Objectives: The authors tested the combined effects of (1) mycorrhizal inoculation, and (2) colonization by non-mycorrhizal annuals on grasses in an inoculum-poor arid soil.
Methods: A study site was selected which had been regraded following mining but had no topsoil application; the resurfaced parent material was composed of sedimentary sandy clay, contained no propagules (seeds, spores, or hyphae), and was considered primary successional. In 1981, the site was drill seeded with a native species mix then colonized by a number of

species, namely *Salsola kali*. On a 30 × 68-meter (m) experimental area three blocks were established, and each was divided into four treatment combinations: (1) annuals present with mycorrhizal inoculum, (2) annuals present with no inoculum, (3) annuals removed with inoculum, and (4) annuals removed with no inoculum. Mycorrhizal inoculum was applied in early spring 1982. Vegetation percent cover and density by species were recorded within twelve 0.5 × 1 m quadrats per treatment combination. *Agropyron smithii* and *Agropyron dasystachyum* phenology was monitored, and in select *A. smithii* and *A. dasystachyum* plants, additional data were collected, including xylem pressure potential, soil water potential, stomatal resistance, and phosphorus (P) and nitrogen (N) concentrations. Soil samples were also collected for mycorrhizal analysis.
Location: Kemmerer Coal Mine (elevation 2,200 m) near Kemmerer, Lincoln County, in southwestern Wyoming, USA
Findings: *A. smithii* plants with mycorrhizae had decreased stomatal resistance and increased leaf water potential compared to non-inoculated plants (but only in the driest part of the growing season). Mycorrhizae may have reduced the effects of competition on stomatal resistance between annuals and *A smithii* with inoculated plants. There was no significant relationship of annuals or inoculum on water relations in *A. dasystachyum*. Both species had delayed phenology with inoculum, but N and P concentrations and percent cover were not impacted.
Implications: VAM and plant interactions are complex and likely sensitive to environmental conditions such as precipitation. More research is needed to fully understand the role of reclamation in reestablishing disturbed mycorrhizal communities and their impact on successful revegetation.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Allen, E.B., and Allen, M.F., 1988, Facilitation of succession by the non-mycotrophic colonizer *Salsola kali* (Chenopodiaceae) on a harsh site—Effects of mycorrhizal fungi: American Journal of Botany, v. 75, no. 2, p. 257–266.

Link (non-DOI): https://www.jstor.org/stable/2443892.
Background: Vesicular-arbuscular mycorrhizae (VAM) fungi improve plant growth and may influence community processes such as succession, competition, phenology, and nutrient transport. Non-mycotrophic annuals, which do not form mycorrhizae, colonize sites with and without mycorrhizal fungi; in sites with low mycorrhizal fungi, these annuals may alter community succession. While greenhouse experiments have shown the growth of non-mycotrophic plants like annual *Brassica* spp. and *Salsola kali* are affected by VAM fungi, interactions among mycorrhizal fungi, non-mycotrophic plants, and mycotrophic plants in the field are unclear.
Objectives: The authors assessed the direct and interactive effects of VAM inoculation in a community with both non-mycotrophic pioneer annuals and mycotrophic later successional species over a 4-year period.
Methods: A study site was selected which had been regraded following mining but had no topsoil application. The resurfaced parent material was composed of sedimentary sandy clay, contained no propagules (seeds, spores, or hyphae), and was considered primary successional. In 1981, the site was drill seeded with a native species mix then colonized by a number of species, namely *S kali*. On a 30 × 68-meter (m) experimental area, three blocks were established, and each was divided into four treatment combinations: (1) annuals present with mycorrhizal inoculum, (2) annuals present with no inoculum, (3) annuals removed with inoculum, and (4) annuals removed with no inoculum. Mycorrhizal inoculum was applied in early spring 1982. Vegetation percent cover and density by species were recorded within twelve 0.5 × 1 m quadrats per treatment combination. In select *S. kali* plants, additional data were collected, including xylem pressure potential, soil water potential, stomatal resistance, and phosphorus (P) and nitrogen (N) concentrations. Soil samples were collected for mycorrhizal analysis. Wind speed and snow depth were recorded in 1984.
Location: Kemmerer Coal Mine (elevation 2,200 m) near Kemmerer, Lincoln County, in southwestern Wyoming, USA
Findings: Uninoculated quadrats had higher percentage cover and density of *S. kali* and both metrics decreased after mycorrhizal inoculation. Inoculation did not significantly affect density or cover of *Agropyron* spp. Where *S. kali* had the greatest density, annual *Agropyron* spp. had the greatest density, possibly due to *S. kali* litter creating beneficial growing conditions given the harsh environmental conditions of the site. When *S. kali* density decreased following inoculation, annual *Agropyron* spp. density decreased as well.
Implications: Early mycorrhizal inoculation may slow primary succession during the first few years in harsh semiarid and arid environments. Interactions among *S. kali*, *Agropyron* spp., and VAM fungi are complex and affect plant community dynamics more than the individual components alone.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Allen, E.B., Chambers, J.C., Connor, K.F., Allen, M.F., and Brown, R.W., 1987, Natural reestablishment of mycorrhizae in disturbed alpine ecosystems: Arctic and Alpine Research, v. 19, no. 1, p. 11–20.

Link (non-DOI): https://www.jstor.org/stable/1550995
Background: Vesicular-arbuscular mycorrhizae (VAM) fungi are important for plant growth and may influence community processes like succession. In fragile alpine environments, which are slow to recover after disturbance and have few colonizing annuals, the role of VAM fungi is poorly understood. Additionally, the impacts of disturbance on VAM fungi in alpine ecosystems of various successional stages are largely unknown.
Objectives: The authors evaluated the occurrence of VAM spores and root infection in undisturbed, seral, and revegetated alpine environments disturbed by mining activities.
Methods: Eleven study areas were selected, which included active and abandoned mines with sections of manually revegetated, seral naturally colonized vegetation, and undisturbed areas. Five randomly located soil samples were collected from each study area and analyzed for pH, organic matter, cation exchange, texture, phosphorous (P), total nitrogen (N), and N as nitrate. Fifteen plots within each study area were randomly established; within them, aboveground vegetation was clipped to measure production by species. For comparisons across seral stages, ten species present in areas of varying ages were sampled to assess VAM infection and rhizosphere spore counts. Roots and soils were sampled yearly and seasonally to determine mycorrhizae variations. Data were analyzed with multiple regression and analysis of variance (ANOVA).
Location: Glengary and McLaren mines on Fisher Mountain (45°04′ N., 109°57′ W.; elevation 2,975 meters [m]) in the Beartooth Mountains and an undisturbed native area and barrow pit near Twin Peaks on the Beartooth Plateau (45°00′ N., 109°30′ W.; elevation 3,050 m) in Montana, USA
Findings: VAM fungi were found in plant roots in undisturbed (up to 60 percent infection) and revegetated (up to 46 percent infection) areas. Mycorrhizal spore counts and infection varied across plant species, areas, and collection date. Soil N, pH, and P were significant in predicting spore counts and percent infection. There were unclear yearly and seasonal fluctuations in spores and infection, especially in 1984. The youngest seral (revegetated) areas had low mycorrhizal diversity (1 species) compared to older areas (up to 11 species). Overall, plant colonization was slow but, once established, mycorrhizal fungi colonized quickly.
Implications: Mycorrhizal presence may depend on spore dispersal, host presence, host response, and soil and environmental conditions, all of which are highly variable spatially and temporally. More research examining the impacts and interactions of these factors is needed before models of mycorrhizal functions in alpine communities can be developed.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Allred, J., 2020, Soil health assessment on arid rangeland soils impacted by oil and gas exploration, development, and extraction: Logan, Utah, master's thesis, Utah State University, 109 p.

Link (non-DOI): https://digitalcommons.usu.edu/etd/7815/
Background: Soils on the Pariette Bench in Utah's Uintah Basin are highly arid. When disturbed, salinity and sodicity of the surface soils are intensified, which complicates native revegetation following disturbance and allows for invasive plant establishment. Oil and gas exploration is a major soil disturbance in the region and reclamation efforts have proven challenging and unsuccessful. A better understanding of the effects of oil and gas development on soil health on the Pariette Bench can help inform more effective reclamation techniques.
Objectives: The author assessed and compared soil health of plugged and abandoned well pads to that of undisturbed rangelands in the Uintah Basin.
Methods: Six plugged and abandoned oil well pads and paired adjacent undisturbed rangeland sites (12 total sites) were selected for the study. A grid system was used to collect 20 soil samples from the top 120 millimeters (mm) of each pad and rangeland location (240 total samples). Soil health (physical, chemical, and biological indicators) was assessed using the undisturbed sites as the scorecard for desired health conditions given successful reclamation. Soil health indicators were mapped using ArcGIS and paired *t*-tests were used to compare soil health indicators of well pads and undisturbed sites. Additional field measurements included soil carbon dioxide (CO_2) respiration using a dynamic gas flux chamber, and plant species (categorized as beneficial or invasive) counts and percent cover using the soil sampling grid and a 1 square meter (m^2) frame. Electromagnetic induction measurements were also collected and analyzed with multiple regressions.
Location: Pariette Bench in the Uintah Basin south of Vernal, Utah, USA

Findings: Well pads had significantly higher clay percentage (on average 30 percent more) and sodicity (2–12.5 times, measured by sodium adsorption ratio [SAR]) and significantly lower beneficial plant cover compared to undisturbed sites. Maps indicated soil health hotspots at each site where further soil testing could occur. While soil health varied across sites, all well pads had lower soil health compared to undisturbed sites; the clay texture and increased sodicity likely contributed to reduced revegetation, specifically of native beneficial species.
Implications: Reclamation of arid, saline-sodic soils should focus on techniques that reduce sodicity and improve soil texture, encouraging native species revegetation and reducing invasive species establishment. Electromagnetic induction measurements can provide useful information on soil health though it is important to identify the specific soil health indicators driving any detected effects.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Ament, R., Cuelho, E., Pokorny, M., and Jennings, S., 2017, Evaluation of effectiveness and cost-benefits of woolen roadside reclamation products, Final report: Western Transportation Institute Report no. FHWA/MT-17-009/8223-001, Prepared for the State of Montana Department of Transportation, 100 p.

Link (non-DOI): https://www.mdt.mt.gov/other/webdata/external/research/docs/research_proj/wool_test/FINAL_REPORT.pdf
Background: In Montana, woolen products could be used in roadside reclamation, either along with or as a replacement for existing products such as erosion control blankets (ECBs). Wool has high nitrogen (N) value and water holding capacity, both necessary for revegetation of disturbed lands. Potential woolen materials must meet existing standard best management practices of the Montana Department of Transportation and Federal Highway Administration. Laboratory testing and evaluation of these materials, followed by field testing, is necessary before any implementation in reclamation projects.
Objectives: The authors wanted to research, evaluate, and report on the efficacy of using various woolen products in roadside reclamation projects in Montana.
Methods: Wool ECBs were developed and tested with Ramy Turf Products, LLC, in Mankato, Minnesota. First, potential woolen products were identified via an internet search and categorized them as wool products produced abroad (7 products), wool products currently used for horticulture and landscaping in the U.S. that may have roadside applications (2 products), or U.S. wool mill products with the potential for new roadside reclamation uses (7 products). The 16 total products were assessed on construction and potential for reclamation use. The authors then worked with Montana mills to develop 11 new woolen products for field trials to assess the effects of weight, color, and production method on seedling germination and growth. Within 1 square meter (m^2) test plots, a perennial grass seed mix was hand broadcasted and monitored.
Location: Near Bozeman, Montana, USA
Findings: Color did not noticeably affect seedling development therefore darker colors were selected for further testing (as they more resembled soil and cost less). Weight did affect seedling development; heavier materials did not allow for seedling penetration and were lifted from the soil surface as seedlings grew. There was no statistical difference in mean seeded grass species mean canopy cover between the compost control treatment and compost with cut wool; further research is needed to evaluate what ratio of cut wool to compost (if any) enhances plant establishment and growth. The rolled 100 percent wool ECB and 50 percent wool/50 percent straw ECB were the highest performing treatments (greatest seeded grass establishment). These ECBs were comparable to the specifications of short-term (Type II B and C) standard ECB used by the Montana Department of Transportation and are commercially viable options for roadside reclamation.
Implications: Woolen products, especially 100 percent wool or 50 percent wool/50 percent straw ECBs, are a cost-effective method for controlling erosion and increasing plant establishment in roadside reclamation. Additional research is needed to improve shearing strength at high flows to meet Type III specifications.
Topics: Road, Vegetation Recovery Data, Erosion Data, Reclamation Practices, GrayLit

Ament, R., Jennings, S., and Blicker, P., 2011, Steep cut slope composting—Field trials and evaluation, Final report: Western Transportation Institute Report No. FHWA-MT/10-008/8196, prepared for the State of Montana Department of Transportation, 113 p.

DOI: https://doi.org/10.21949/1518361
Background: Revegetating steep slopes, like those along highways, can be difficult due to increased erosion risk. Determining cost-effective best practices for erosion control and revegetation is necessary for achieving project goals. This study builds on previous research by Jennings and others (2007; https://doi.org/10.21949/1518165). Both studies were sponsored by the Montana Department of Transportation.
Objectives: The authors evaluated several compost application depths and retention techniques for improving vegetation of steep highway cut slopes in Montana.
Methods: Twenty-two test plots of differing sizes were constructed on steep north- and south-facing roadside cut slopes (64–71 percent grade) along Montana Highway 84. The soil texture was classified as a silt loam with low levels of organic matter, nitrogen (N), and phosphorous (P). A mix of six native bunchgrass species appropriate for the study site's environmental conditions and geologic materials was broadcast seeded on all 22 test plots. The effect of compost was tested at three depths (0.32, 0.64, and 1.27 centimeters [cm]) on one north-facing and two south-facing plots; compost was applied with a blower truck. To evaluate retention methods, 1.27 cm of compost was applied to an additional 10 south-facing plots followed by one of five retention methods: coconut straw fiber erosion control blanket (ECB), lightweight plastic netting, and three commercially available tackifiers (polymer emulsion liquid, guar-based water dispersible formulation, and *Plantago*-based seed husk powder); there were two replicates of each treatment. Percent live perennial grass cover was compared among treatments and seeded control plots.
Location: Montana Highway 84 roughly 25 kilometers (km) west of Bozeman in southwest Montana, USA
Findings: Low compost application rates (0.32 and 0.64 cm) resulted in <10 percent live perennial grass cover and negligible erosion control. Compost application of 1.27 cm and 2.54 cm, based on Jennings and others 2007, are recommended as best practices and can be expected to result in 16–26 percent live perennial grass cover on south-facing slopes with a semiarid climate in Montana. Both coconut straw fiber ECBs and lightweight (preferably biodegradable) plastic netting are effective at retaining compost; however, recommendations regarding tackifier treatments could not be given due to confounding results that varied widely with plot location. For best results and reduced wind exposure, seeding, compost application, and retention treatments should occur in the spring immediately before the growing season. Recommended compost application rates range from $41,160–82,171 per hectare (ha), though cost may vary by location. Compost application at 1.27 cm with plastic netting is estimated at $65,069/ha.
Implications: Vegetation establishment on steep highway cut slopes can be achieved with compost application and retention treatments. Results from this study can be applied to reclamation and revegetation of other steep slopes in semiarid environments, like those created by natural resource extraction, facilities and access construction, and mine tailing disposal.
Topics: Road, Vegetation Recovery Data, Erosion Data, Reclamation Practices, GrayLit

Anderson, D.C., 1990, Habitat restoration on naval petroleum reserves in Kern County, California, *in* Planning, rehabilitation, and treatment of disturbed lands, Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, Mont., March 25–30, 1990, Proceedings: Bozeman, Mont., Montana State University, Reclamation Research Unit Publication no. 9003, v. 3, p. 1–14.

Link (non-DOI): https://archive.org/details/fifthbillingssym00bill/page/n1/mode/2up
Background: In 1976, a new program was mandated by law to increase national oil production on Elk Hill in California. In 1979, the Secretary of the Interior notified the Department of Energy that the energy extraction activities on Elk Hill could be impacting endangered species. These impacts were confirmed by the Fish and Wildlife Service, stating that overall impacts anticipated on Elk Hill may jeopardize the existence of the San Joaquin kit fox, the blunt-nosed leopard lizard, and their habitats. To continue energy extraction activities, a proposed alternative to prevent further impacts to these species was presented and included restoration of disturbed land. This task had many unique challenges and early attempts were rarely successful. Identifying best-practices for reclamation in this region may aid in future restoration efforts.

Objectives: Field trials were started to: (1) test which species were adapted to Elk Hill conditions, (2) evaluate reclamation methods and find which were best for Elk Hill, (3) evaluate the use of native seed species on Elk Hill, and (4) evaluate reclamation equipment needs.
Method: Information was gathered to document similarities between reclaimed disturbed sites and adjacent undisturbed sites. Sites were selected using aerial photography and mapping techniques to locate land disturbances. Overall, about 586 sites were evaluated by 1989. Site preparation consisted of ripping compacted soil, spreading straw/hay, and drill seeding; after seeding, the area was mulched with straw and crimped into the soil. Native seed mixes were not widely used early in this study because well-performing species were unknown and natives were not commercially available; after several years, a list of preferred species was created and included in seed mixes. Signs of wildlife and visual estimates of vegetative cover, rocks, litter, bare ground, shrub, forb, and grass cover were made during the first two growing seasons following reclamation. Estimates for grass and forbs were made using 0.25 square meter (m^2) quadrats, and shrub density was determined in 1 m^2 plots. Erosion was classified into five categories and photos were taken of the site for a year for comparison. After five years, all sites were evaluated for vegetation cover and species diversity.
Location: Naval Petroleum Reserve No.1 in southern Kern County, California, USA
Findings: In 1985 and 1986, there was low species diversity and shrub density. Sites that were hydroseeded had less cover than those drill seeded. Red brome abundance, although excluded in 1987 and 1988 seed mixes, was the same across all measurement years.
Implications: Reclamation efforts should remain flexible and adapt procedures based on monitoring data. In this study, the seed mixes were altered after low species diversity and shrub density were observed. Altering the seed mix increased the number of shrub species and overall vegetative cover in subsequent years. This research presented useful ways to track reclamation success and evaluate reclamation technologies.
Topics: Well Pad, Vegetation Recovery Data, Reclamation Practices, GrayLit

Anderson, J.D., Ingram, L.J., and Stahl, P.D., 2008, Influence of reclamation management practices on microbial biomass carbon and soil organic carbon accumulation in semiarid mined lands in Wyoming (revised May 21, 2008): Applied Soil Ecology, v. 40, no. 2, p. 387–397.

DOI: https://doi.org/10.1016/j.apsoil.2008.06.008
Background: Mining and reclamation procedures result in losses of soil organic carbon (SOC) and soil organic matter (SOM), which have major consequences for the recovery of a functioning arid or semiarid ecosystem. Microbial soil communities may take up to 20 years to recover after reclamation. Reclamation efforts can assist in increasing SOC, and studies have illustrated that in some cases, SOC can accumulate in reclaimed areas above that of reference soils. In Wyoming, mining can be followed by several potential reclamation treatments. Specifically, topsoil can be directly hauled or stockpiled, the soil can then be mulched using hay crimping or grass stubble mulched, seeded with different seed mixes, and eventually grazed. Each of these practices can have various effects on SOC accumulation and turnover, although their effects in the context of mining reclamation have not been well studied to date.
Objectives: This study aimed to assess and compare different management practices on SOC and microbial biomass carbon (MBC) on reclaimed surface coal mines, which ranged from a shortgrass sagebrush steppe at 1,220 meters (m) elevation (216 millimeters [mm] mean annual precipitation) to a northern mixed grass prairie at 1,375 m elevation (390 mm mean annual precipitation). The secondary objectives were to compare the SOC concentrations in reclaimed versus disturbed soils and to estimate carbon (C) accumulation rate and concentration after reclamation.
Methods: Each of the five surface coal mine sites was matched with a nearby undisturbed reference site. Four reclamation practices, each with two levels, were compared on the reclaimed sites: grazed versus ungrazed, direct hauled versus stockpiled topsoil, stubble versus hay mulched, and grass versus shrub seed mix. Not all mines received a test of each treatment; effects of the practices (compared to other practices and to undisturbed sites) were examined at the mines on which they were represented. Three 100 m transects with four sampling points per transect were established in each treatment or control area. Soils were collected from three depths and analyzed for SOM and MBC.
Location: Five surface coal mines in semiarid Wyoming: Mine 1 (43°01′37″ N., 105°49′44″ W., shortgrass sagebrush steppe, 1,646 m elev.), Mine 2 (43°41′57″ N., 105°14′27″ W., northern mixed grass prairie, 1,371 m elev.), Mine 3 (41°44′02″ N., 108°47′14″ W., shortgrass sagebrush steppe, 1,220 m elev.), Mine 4 (44°05′56″ N., 105°21′55″ W., northern mixed grass prairie, 1,375 m elev.), and Mine 5 (41°54′10″ N., 106° 30′47″ W., shortgrass sagebrush steppe, 2,067 m elev.)

Findings: Soil texture, pH and electrical conductivity (EC) were similar in paired reclaimed and undisturbed soils within mines. For a majority of the cases, the undisturbed reference sites had a higher concentration of SOC than the reclamation sites, although total mass of SOC in reclaimed areas was greater than the undisturbed soil among half of the mines. Within reclamation treatments, there were no significant differences in SOC between factor levels (for example, no differences between grazed versus ungrazed, nor direct hauled versus stockpiled topsoil, stubble versus hay mulched, or grass versus shrub seed mix), although there were differences among the treatments themselves. The difference in SOC between the reclaimed soils and the undisturbed soils differed by mine site; for instance, there was no difference between grazed and undisturbed soils at Mine 1, but at Mine 2, SOC concentration in reclaimed sites with either grazing treatment was significantly lower than it was in the undisturbed soil. Shrub seeded soils had higher MBC than grass seeded, and equal to or greater than undisturbed soils. There was no difference in MBC between the topsoil handling techniques. Stubble mulched soils and undisturbed soils had greater MBC than hay crimped soils. Grazed sites had higher MBC compared to ungrazed sites.
Implications: In most cases, reclamation practices did not affect SOC, however undisturbed soils consistently had greater SOC than reclaimed soils. There was a linear relationship between age of reclamation and SOC. The paired treatments examined usually had different MBC levels, as well as treatment versus undisturbed soils. This suggests that SOC has not recovered 11–26 years post mine reclamation, whereas MBC had recovered in most reclaimed soils. Shrub seed mixes may facilitate more microbial activity.
Topics: Mining, Soil Data, Reclamation Practices

Arnold, R.N., Smeal, D., O'Neill, M.K., Lombard, K., Heyduck, R.E., Henke, S., Wirth, D., Zent, J., Wirtanen, R., Craddock, D., Katirgis, S., and Lepich, M., 2009, Revegetation of disturbed well sites with selected cool season native and non-native grasses for stand establishment in the intermountain region of northwest New Mexico: New Mexico State University, Research Report 768.

Link (non-DOI): https://contentdm.nmsu.edu/cdm/ref/collection/AgCircs/id/68832
Background: In San Juan, New Mexico, there are an estimated 20,000–30,000 acres of oil and gas development sites that will need reclamation in the next 10 years. However, semi-arid and arid ecosystems are among the most difficult biomes to revegetate after disturbance due to sporadic and low annual rainfall. Often, reclamation may require multiple rounds of seeding, and identifying cultivars of grasses—a primary component of seed mixes that can withstand these extreme conditions—may improve reclamation efforts.
Objectives: Researchers identified particular native and non-native grass cultivars adapted to the region of study and tested their establishment at well sites.
Methods: All reserve pits on each well site were covered with topsoil and leveled. Each plot was seeded with a tractor driven cone seeder that planted native and non-native cool season seed mixes 0.5 inch (in.) deep. A rating scale to evaluate native and non-native grasses was developed; the scale ranged from 1 (no stand establishment) to 9 (100 percent stand establishment or survival). Rain gauges were installed to track precipitation.
Location: San Juan Oil and Gas Production Basin in the intermountain region of San Juan and Rio Arriba counties in northwest New Mexico, USA
Findings: Annual rainfall from 2003 through 2005 ranged from 8.7 in to 13.2 in; the lowest cumulative precipitation received in a year was 7.8 inches, and the highest was 18.3 inches. Stand establishment was low across all sites, but particular cultivars performed better than others. Two years after planting native grasses at the Pure Resources Rincon 202M well site, stand establishment for "Arriba" western wheatgrass, bottlebrush squirreltail, and Anatone bluebunch wheatgrass had ratings of 2.0, 2.5, and 2.1, respectively. Non-native grasses, Canada wild ryegrass and Bozoisky Russian wild ryegrass, had ratings of 2.2 and 3.4, respectively. XTO Energy Com 2E site had the worst stand establishment of all grasses after year two. After three years the following species had an average score of 2 or better: Arriba western wheatgrass, Paloma Indian ricegrass, San Luis Slender wheatgrass, and needle and thread grass and the non-native grass Canada wild ryegrass. Researchers found that the Williams Production Rosa 159A had the best stand establishment of Arriba western wheatgrass, Canada wild ryegrass, bottlebrush squirreltail, Paloma Indian ricegrass, San Luis slender wheatgrass, and needle and thread grass as compared to the other grasses planted at other locations. In addition, XTO Energy Kutz 11E site showed that native grasses Paloma Indian ricegrass and needle and thread grass and non-native grass Canada wild ryegrass had the best stand establishment with ratings of 4.0, 2.9, and 3.0, respectively.

Implications: Stand establishment of native grasses had better overall rates compared to non-native grasses. The species that best survived under limited and seasonally delivered rainfall in the semi-arid intermountain region and which were adopted by the Bureau of Reclamation Farmington Field Office for rangeland seeding include Arriba western wheatgrass, bottlebrush squirreltail, Paloma Indian ricegrass, San Luis slender wheatgrass, and needle and thread grass.
Topics: Well Pad, Target Plant Recovery Data, Reclamation Practices, GrayLit

Arthur, D.T., 2006, Review of the effects of calcium carbonate-rich soils on plant establishment during restoration, *in* Keammerer, W.R., ed., High Altitude Revegetation Workshop No. 17, Fort Collins, Colo., March 7–9, 2006, Proceedings: Colorado Water Resources Research Institute Information Series no. 101, p. 89–97.

Link (non-DOI): https://watercenter.colostate.edu/wp-content/uploads/sites/33/2020/03/IS101.pdf
Background: Revegetation of disturbed soils can be limited by several soil factors, such as the presence of calcium carbonate ($CaCO_3$). $CaCO_3$ is a common salt that can precipitate and accumulate in lower soil profiles in arid and semi-arid environments, forming calcic horizons or calcareous soils. After disturbance, if soils high in $CaCO_3$ accumulations are brought to the surface and used as an agriculture soil medium, in landfill cover construction, or for post mining or oil and gas reclamation, then revegetation success could be severely impacted. $CaCO_3$ can be detrimental to vegetation germination and establishment because soil with higher levels of $CaCO_3$ have reduced plant available nutrients, a higher potential for soil crust development (which can reduce soil moisture), and decreased soil microbial community health. Reclamation managers for disturbed lands should consider $CaCO_3$ soil content when planning and implementing reclamation/revegetation of disturbed lands.
Objectives: The author discussed the impacts of $CaCO_3$ on soil health and revegetation.
Methods: This provides a description of how $CaCO_3$ forms and its impacts on nutrient availability, plant productivity and soil physical changes. Previous research is reviewed, and recommendations are made for suitable soil $CaCO_3$ percentage concerning restoration and reclamation sites.
Location: This is a review article and does not involve a specific field site location
Findings: $CaCO_3$ is a salt formed by the reaction of CO_2 and calcium oxide. CO_2 (produced by root and soil microorganism respiration) in the presence of water forms carbonic acid. This formation tends to be most active in the upper soil where biological activity is highest. The salt generally stays in the water solution and then migrates to deeper soil profiles where less water is present, which drives the solution equilibrium toward precipitation of the $CaCO_3$. The precipitation of the $CaCO_3$ can accumulate at lower soil profiles in arid and semiarid regions. The presence of $CaCO_3$ can decrease the availability of plant nutrients, reduce plant productivity, and can produce physical changes to soil, limiting water infiltration and root penetration. $CaCO_3$ reduces plant nutrient uptake by the formation of unavailable plant nutrient forms through a reaction with $CaCO_{3.}$ This includes reductions in both macronutrient (phosphorous) and micronutrients (boron, zinc, iron, copper, and manganese) limiting plant growth. Ideally, soil $CaCO_3$ content should be 10–15 percent to reduce negative impacts on vegetation and soil communities.
Implications: Reclamation and land managers should sample for $CaCO_3$ levels in soils slated for use on disturbed lands for reclamation/revegetation. Recommended soil $CaCO_3$ content for successful revegetation is 10–15 percent.
Topics: Well Pad, Soil Data, Reclamation Practices, GrayLit

Ashcroft, N.K., Fernald, A.G., VanLeeuwen, D.M., Baker, T.T., Cibils, A.F., Boren, J.C., 2017, The effects of thinning trees and scattering slash on runoff and sediment yield within dense piñon-juniper woodlands in New Mexico, United States: Journal of Soil and Water Conservation, v. 72, p. 122–130.

DOI: https://doi.org/10.2489/jswc.72.2.122
Background: Due to fire suppression in the southwest, piñon-juniper woodlands have expanded and altered the region's hydrology, flora, and fauna. The inter-canopy between dense growth is characterized by bare soil and sparse vegetation that may be a major source of runoff. The vegetation structure and increased disturbance from oil and gas development may further disrupt hydrology in these areas. Within the San Juan Basin in New Mexico, the Bureau of Land Management (BLM) estimates

by 2023 there will be an additional 10,000 oil and gas wells established. This situation provides the opportunity for managers to restore ecological functions while reclaiming sites after resource extraction. Specifically, thinning piñon-juniper woodlands during well construction could benefit landscapes by restoring ecological functions and hydrology.
Objectives: Researchers simulated rainfall to compare and estimate the effects of thinning treatments on piñon-juniper woodlands in undisturbed areas, along pipelines, and along roadways to (1) assess runoff and runoff per unit of precipitation, (2) infiltration, and (3) suspended sediment and sediment yield in conjunction with oil and gas development within piñon-juniper ecosystems.
Methods: Eight sites adjacent to pipeline locations were selected within Twick Silver, Travessilla-Weska Rock, or Penistaja soils. The sites were limited to those with slopes less than 15 percent, which were under Federal or State government management, which were easily accessible and (or) visible, and which were dominated by piñon-juniper vegetation. On each site, one research block was established. Blocks consisted of a 91.4 meter (m) × 12.2 m plot thinned to result in a residual basal area of a 1.2 square meters per hectare (m^2/ha) (BA5), a 91.4 m × 10.7 m plot thinned to result in a residual basal area of 2.3 m^2/ha (BA10), a 91.4 m × 22.8 m un-thinned control plot, and a 180 m × 15 m pipeline plot adjacent to the control and treatment plots. To achieve the desired basal areas, wood >7.6 centimeter (cm) diameter was removed, a portion of the trees >30.5 cm diameter were cut with a chainsaw and removed (slash scattered across the site), a portion of the trees <30.5 cm diameter were masticated, sagebrush was mowed as close to the ground as possible, and all other shrubs were mowed to a height of 50.8 cm; a Hydro-Axe was used for mowing shrubs. All block treatments were completed by September 2004. Litter depth and surface cover of grass, forbs, litter, bare soil, and slash were estimated within each plot. soil cores were extracted to characterize soil properties for each plot. During July 2005, rain simulation subplots were randomly placed within each treatment, in both canopy and inter-canopy microsites. Simulated rain was applied in subplots when the soil was most erodible on each treatment and condition. After each simulation, runoff was collected through a down-slope catchment bucket for measurement. and a 1-liter (L) water sample was used to estimate suspended sediments.
Location: Pump Canyon and Navajo Reservoir watersheds in San Juan County, New Mexico, USA
Findings: Runoff was analyzed as a ratio because characteristics effecting runoff, suspended sediment, and sediment production varied among plots. Litter depth, litter cover, and bare ground between canopy and inter-canopy differed among plots. There was a significant difference in soil moisture between pipeline (0.7 percent) and control (5.0 percent) plots. Thinning treatments had significantly less overall runoff and the runoff ratio differed between treatments (except with the control and pipeline). Sediment suspension differed statistically on roads compared to other treatments. Mean sediment yield was significantly less with both thinning treatments compared to the control.
Implication: Reducing runoff in piñon-juniper woodlands is important, especially following additional disturbances, because gully formation can occur quickly in the interspaces between canopies. Thinning treatments can positively affect hydrology by reducing total runoff. Modifying piñon-juniper woodland adjacent to pipeline construction can help to retain water in the ecosystem, capturing runoff and sediment yield from disturbed sites.
Topics: Road, Pipeline, Erosion Data, Hydrology Data, Reclamation Practices

Atwood, L.B., 2000, Monitoring restoration of the Vaseux-Bighorn National Wildlife Area following pipeline construction, *in* Darling, L.M., ed., A Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, British Columbia, Canada, Feb. 15–19, 1999, Proceedings: British Columbia Ministry of Environment, Lands and Parks, v. 2, p. 815–819.

Link (non-DOI): https://www.env.gov.bc.ca/wld/documents/so10atwood1.pdf
Background: Understanding how various techniques promote reclamation is important, especially in lands managed for wildlife habitat. This project describes a revegetation experiment that occurred on a natural gas pipeline scar in a wildlife area in Canada.
Objectives: The study sought to describe the outcome of four treatments and make recommendations for future reclamation based on their results. The four treatments included: (1) hand broadcasting native herb and shrub seed; (2) transplanting native perennial grasses, herbs, and shrubs; (3) hydroseeding of native grasses; and (4) applying a microbiotic crust.
Methods: Along the pipeline, reclamation prescriptions and seed mixes were created based on seven geographic areas the pipeline intersected, which were defined based on vegetation surveys and soil characteristics described within the National Wildlife Area. Reclamation treatments were installed after diffuse knapweed (*Centaurea diffusa*) was controlled using herbicides. Broadcast seeding and hydroseeding used wild-collected seeds and was done in November 1994. Plant salvage included 7,600 plants that were potted and stored over winter and planted in March 1995. Study sites were monitored once in 1996. In broadcast seeded areas, 3, 1-square meter (m^2) quadrats were systematically placed along three 18 meter (m) transects

which crossed the disturbed portion of the right of way; seeded species density and cover of seeded species, litter, and bare ground were recorded. Survival was also assessed for transplanted species. Microbiotic crust was tested in subplots and applied at one of four rates: no crust (control), 0.55 liter per square meter (L/m^2), 0.7 L/m^2, and 0.9 L/m^2, with three replicates each, spread over two geographic areas. Percent cover of crust and plant species was recorded in subplots. All data were analyzed with analysis of variance (ANOVA).
Location: Vaseux-Bighorn National Wildlife Area, British Columbia, Canada
Findings: From 360 kilograms (kg) of collected and broadcast seed, only seven of the 23 species established in >25 percent of their sown area; 5 species were established at all locations. Average survival of salvaged plants was 77 percent for shrubs, 76 percent for bunchgrasses, and 61 percent for forbs. The hydroseed/herbicide treatments varied by ecoregion and seed mix. The highest cover of hydroseeded species was 35.6 percent and the lowest was 5.6 percent. Pre-seeding herbicide treatments had reduced competition from diffuse knapweed only in the short term, and cheatgrass (*Bromus tectorum*) was found to be prevalent at all study areas; competition from these two invasive species is suspected to have limited establishment of seeded and transplanted plants. Microbiotic crust seeding increased the cover of crust species by 92 percent and was associated with higher densities of three grasses (two native species and cheatgrass), all of which had awned seeds, potentially enabling their retention in the microbiotic crust.
Implications: Seeding success requires better seed handling practices (that is, collecting, cleaning, storying, seed treatments, and viability) and an understanding of how to best propagate native species. Transplanting actively growing plants (such as C3 grasses) reduces survival for that functional group. However, salvaged plants should be used for species that don't establish by seed because they had high survival in this study. Even though costs to salvage plants is high compared to seeding, salvage could be important in areas managed for wildlife habitat. Microbiotic crust inoculation can help plants establish by providing quality seed beds, however, nonnative species may also benefit.
Topics: Pipeline, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices, GrayLit

Avirmed, O., Burke, I.C., Mobley, M.L., Lauenroth, W.K., and Schlaepfer, D.R., 2014, Natural recovery of soil organic matter in 30–90-year-old abandoned oil and gas wells in sagebrush steppe: Ecosphere, v. 5, no. 3, p. 1–13.

DOI: https://doi.org/10.1890/ES13-00272.1
Background: Soil organic matter (SOM) makes up most of the carbon (C) in these arid systems and exhibits a heterogeneous spatial pattern. The historical and current effects of oil and gas development on SOM are not well studied.
Objectives: The study aimed to (1) describe the importance of historical (non-reclaimed) oil and gas wells on SOM relative to other drivers such as shrub cover and soil texture, and (2) determine how fast SOM recovers in the absence of reclamation.
Methods: Twenty-nine oil and gas well sites that were plugged and abandoned between 1918 and 1980 and which had no field evidence that they had been reclaimed were identified. Three transects were established around each well site, each with two plots representing the disturbed area at 4 meters (m) from the well center and an undisturbed area 24 m from well center. Soil profiles underneath shrub canopy and between shrubs were sampled, for a total of 12 profiles/site. The soils were analyzed for bulk density, texture, and SOM in the lab.
Location: Carbon and Sweetwater Counties (41°23′ to 42°23′ N., and 107°34′ to 107°89′ W.), Wyoming, USA
Findings: There was no difference in soil bulk density, texture, or SOM pools on non-reclaimed sites (30–90-year-old abandoned oil and gas wells) compared to adjacent undisturbed sites. The results were surprising in light of other research on more recently disturbed mine sites, showing up to 75 percent loss of SOM compared to undisturbed areas. Natural variation in soil texture and fine-scale environmental heterogeneity (differences in soil properties between soil under shrubs versus soil from interspaces) were the most important variables to soil C and nitrogen (N), in which the majority of SOM forms were higher under shrub canopies than interspaces and higher on finer textured loams than sandy soils. Fine-scale heterogeneity of total soil organic C was ~2-fold higher on the finer-textured (loamy) sites and was equivalent to undisturbed sites after about 45 years, compared to the coarse-textured soils, which showed no increase in heterogeneity over age of well pad.
Implications: This study showed no significant effects of oil and gas disturbance on SOM pools, but there was an effect within the well pads on loamy soils in that heterogeneity of total C (representing a more recalcitrant form of SOM) increased with time since disturbance. This study found higher SOM under shrub canopies compared to interspaces and suggests that the recovery of SOM may be dependent on the recovery of shrubs, although there may be a lag in recovery on for some (for example, recalcitrant) forms of SOM. Eliminating the practice of soil removal and stockpiling could reduce losses in SOC that occur in modern reclamation practices because stockpiling eliminates shrub cover and exposes SOM to decomposition.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices

Arivmed, O., Lauenroth, W.K., Burke, I.C., and Mobley, M.L., 2015, Sagebrush steppe recovery on 30–90-year-old abandoned oil and gas wells: Ecosphere, v. 6, no. 7, p. 1–10.

DOI: https://doi.org/10.1890/ES14-00175.1
Background: The sagebrush steppe in the western U.S. is dominated by *Artemisia tridentata* and once covered ~60 million hectares. This ecosystem has been reduced by almost a half due to land use changes including oil and natural gas extraction. Current literature suggests that big sagebrush takes at least 30 years to recover, however the rate of recovery differs based on the disturbance type.
Objectives: This study measured natural recovery of sagebrush steppe using a chronosequence of 29 oil and gas well sites that were abandoned without reclamation 1923–1980. The authors assessed the recovery of big sagebrush and other plant groups after 30–90 years of growth on unrestored gas and oil sites to understand if adjacent undisturbed sites affect recovery of disturbed sites.
Methods: In summer 2012, big sagebrush cover, density, and biomass was measured, and cover of other shrubs, grasses, and forbs was estimated on the 29 well pads and adjacent undisturbed areas. A recovery ratio for each well pad-undisturbed pair was generated for each parameter (cover, density, biomass) by dividing the value attained on the well pad to the value attained on the undisturbed area (a value of 1 was considered fully recovered). Recovery indices were regressed over well pad age for each parameter.
Location: Carbon and Sweetwater counties (41°23′ to 42°23′ N., and 107°34′ to 107°89′ W.), southcentral Wyoming, USA
Findings: Undisturbed sites had higher cover and biomass than all ages of well pads, and regression of these parameters suggested that it can take up to 70 years for Wyoming big sagebrush density to recover and at least 87 years for Wyoming big sagebrush cover to the levels found in undisturbed sites. Sagebrush cover was independent of distance from the undisturbed areas within well pads. Grasses and other shrubs recovered much more rapidly, but forb recovery was limited. Age of wellsite was positively related with big sagebrush cover although the relationship was not strong (R^2=0.22). Adjacent undisturbed sites did not influence big sagebrush recovery. Annual exotic grasses were not present on these well pads. Grass cover and other shrubs (Greene's rabbitbrush and rubber rabbitbrush) had high cover on well pads, but forbs had the lowest recovery index among all plant groups.
Implications: Big sagebrush density may recover more quickly than its cover and biomass, which can take 90 years or more. This is likely not due to seed dispersal, but to other factors. Forbs had not recovered on well pads after 87 years, potentially due to low propagule availability and competition with grasses. Grasses and non-sagebrush shrubs recovered rapidly on these sites, and even performed better on well pads than in undisturbed areas. Because big sagebrush significantly recovered but its recovery was slow, and forbs were much lower on well pads than undisturbed sites, these two plant groups should be the target of reclamation efforts.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Standards

Azeria, E.T., Santala, K., McIntosh, A.C.S., and Aubin, I., 2020, Plant traits as indicators of recovery of reclaimed well sites in forested areas—Slow but directional succession trajectory (revised April 21, 2020): Forest Ecology and Management, v. 468, p. 1–13.

DOI: https://doi.org/10.1016/j.foreco.2020.118180
Background: Succession following natural disturbances is fairly well studied; however, the same cannot be said of succession following severe anthropogenic disturbances, such as oil and gas development and reclamation. Understanding succession following these disturbances is necessary to ensure reclamation methods are successful and ecologically relevant. In Alberta, Canada, oil and gas disturbance in the boreal forest ecozone has resulted in >239,000 well sites, of which only 24 percent have been reclaimed. Reestablishing a viable and functioning understory community is vital to forest health. Studying the trajectory of restoration over time in these disturbed forests may shine light on reclamation best practices and management improvements.
Objectives: The authors used a chronosequence to (1) determine the difference in trait composition of young and old reclaimed well sites compared to natural and harvested forests; (2) determine if the post-reclamation changes of understory community functional traits on well sites followed a directional trajectory; and (3) evaluate any relationships between functional traits and environmental variables.

Methods: Eighty-nine approximately 1-hectare sites were selected, representing (a) 30 well pads ranging in age from 7 to 48 years post-reclamation, (b) natural or harvested forest sites adjacent to each of the 30 well pads, and (c) 29 non-adjacent, young harvested forest sites. In 2014, vascular plant composition was sampled in the 30 well pads and their adjacent site pairs following McIntosh and others (2019; https://doi.org/10.21000/JASMR19030091). Data for the 29 non-adjacent, young reference sites were collected in 2010 and 2012 following a similar protocol. Ten plant traits and metrics associated with colonization ability and performance were compiled from the Traits of Plants in Canada database and evaluated. Geographic Information System (GIS) landcover types were compiled with fine scale field data habitat characteristics and soil chemical and physical properties for each site. Species richness and relative abundance for each site was summarized and analyzed with one-way analysis of variance (ANOVAs). Multivariate analyses were used to assess community differences and community-weighted traits at each site.
Location: Central Mixedwood and Lower Foothills Natural Subregions (ranging from 54°12′–56°22′ N., and 110°39′–118°7′ W.) in central Alberta, Canada
Findings: Plant richness differed significantly only between young reclaimed and young harvested sites; abundance varied more widely across site types. Community-weighted principal component analysis (PCA) analysis discriminated between species with fast-resource acquisition traits and those with resource-conservation traits. Community-weighted traits differed among all site type pairwise comparisons but overall functional composition similarity between reclaimed well sites and all reference types increased with time since reclamation, though the oldest reclaimed sites still differed significantly from references sites.
Implications: Reclamation of oil and gas development is important but should not be expected to return Alberta's disturbed boreal forests to pre-disturbance conditions. Additionally, there is a lag affect in recovery which, if not properly monitored, could lead to unsuccessful reclamation.
Topics: Well Pad, Vegetation Recovery Data, Reclamation Practices, Reclamation Monitoring

Baethke, K.A., Ploughe, L.W., Gardner, W.C., and Fraser, L.H., 2020, Native seedling colonization on stockpiled mine soils is constrained by site conditions and competition with exotic species: Minerals, v. 10, no. 4, p. 1–16.

DOI: https://doi.org/10.3390/min10040361
Background: Mining, while economically important, leads to degraded ecosystems that require reclamation or restoration to reestablish functioning processes. Historically, Australian mine restoration efforts have used agronomic seed mixes to speed up revegetation. However, the desire to plant native species is a growing concern, and with it comes the need to develop methods to increase seedling emergence and colonization success. Raking, and hydroseeding (or hydroslurry, which contains a mixture of water, mulch, and other binding materials but not necessarily seeds) are techniques that may be useful, but additional research is needed to better understand these methods' effects on seedling development.
Objectives: The authors evaluated the effects of raking and hydroseeding on native seedling emergence and colonization on stockpiled mine spoils to see if these methods could be implemented to increase native species revegetation following mine disturbance.
Methods: Seeds were purchased and collected locally from species based on their commonality to the interior grasslands of British Columbia, cultural importance, and access to large quantities of seed. Eighty 2 square meter (m^2) bare soil plots were established on a leveled ~2-year-old stockpile. Native seed (seeded or unseeded) and site preparation (none, raking, hydroslurry, or raking and hydroslurry) treatments were applied in a fully factorial experiment with 10 replications each. Seeds not included with hydroslurry applications were hand-broadcast. Using a 1 m^2 grid, vegetation surveys were conducted to calculate species richness, the Shannon-Weaver diversity index, and evenness values. Species were categorized as native or exotic and using Grime's C-S-R theory. Data were analyzed using mixed-model analysis of variance (ANOVA) in R 3.6.1.
Location: New Gold's New Afton Mine west of Kamloops (50°38′54.92″ N., 120°29′59.67″ W.; elevation 775 meters [m]), British Columbia, Canada
Findings: Raking treatments increased colonization compared to no site preparation regardless of seeding treatment. Raking and seeding produced the greatest species richness, though most seedlings established were exotic; only 7 percent of established seedlings were native species. The most dominant functional group was forbs, though it decreased with the hydroslurry treatment. Overall, exotic species outcompeted native species in establishment and colonization regardless of seeding or site preparation treatment.
Implications: While tilling and raking can assist native species establishment, more research is needed to understand native seed viability under harsh environments. Native species should be sown in large enough numbers to reduce exotic species competition and species should be carefully selected for site-specific suitability. Exotic species' presence should be minimized by making sure topsoil does not contain an abundance of exotic species in the seedbank.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Reclamation Practices, Reclamation Standards

Baker, P., and Kunzler, L., 2006, Controlling cheatgrass with herbicides to establish perennial species, in Keammerer, W.R., ed., Altitude Revegetation Workshop No. 17, Fort Collins, Colo., March 7–9, 2006, Proceedings: Colorado Water Resources Research Institute, Information Series no. 101, p. 125–129.

Link (non-DOI): https://watercenter.colostate.edu/wp-content/uploads/sites/33/2020/03/IS101.pdf
Background: Cheatgrass infestation hinders successful establishment of perennial vegetation at heavily disturbed mining sites. Using herbicides to control cheatgrass before seeding desired vegetation species may increase the success of revegetation. Soil type (for example, clayey or sandy) may also impact perennial vegetation establishment and cheatgrass presence.
Objectives: The authors assessed the effect of herbicide application after grading but before seeding on cheatgrass presence and perennial vegetation establishment.
Methods: Contractors ripped and graded 185 acres of previously mined oolitic sands. Plateau herbicide was applied at 3 fl. Ounces per acre (oz/ac) with 1 quart per acre (qt/ac) methylated seed oil on 76 acres prior to ripping and grading; another 109 acres owned by the Bureau of Land Management (BLM) did not receive herbicide application. The entire 185-acre area was drill seeded with a perennial vegetation mix. The point-intercept method was used to measure perennial vegetation cover and estimate cheatgrass cover within three designated parcels across the 185-acre study site, including clayey playas, raised sandy areas, and regraded slopes between the two soil types. A Student's t-test was used to compare perennial vegetation cover in raised sandy areas and clayey playas with and without herbicide application.
Location: U.S. Magnesium Rowley Plant, Utah, USA
Findings: In raised sandy areas with herbicide application, perennial vegetation cover was significantly higher and cheatgrass appeared suppressed when compared to similar areas without herbicide application. In clayey playas, where cheatgrass is less common, there was no difference in perennial vegetation cover. There appeared to be an increase in perennial cover on regraded slopes, but no statistical analysis was performed. A noted decrease in various annual species in herbicide-treated areas and the unexpected presence of shrubs in seeded areas could have been attributed to individual species herbicide tolerance.
Implications: Plateau herbicide application improved perennial vegetation establishment but did not completely eradicate cheatgrass presence in raised sandy areas and had little effect in clayey playas. Overall, herbicide application can be a cost-effective method for managing cheatgrass infestation and increasing revegetation success. Soil type, herbicide application rate, and timing of herbicide application should be considered on a site-by-site basis as these factors can impact the success of perennial vegetation germination.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Bateman, A., Lewandrowski, W., Stevens, J.C., and Muñoz-Rojas, M., 2018, Ecophysiological indicators to assess drought responses of arid zone native seedlings in reconstructed soils: Land Degradation & Development, v. 29, no. 4, p. 984–993.

DOI: https://doi.org/10.1002/ldr.2660
Background: Limited rainfall, poor soil nutrients, and high temperatures complicate restoration of disturbed lands in arid landscapes, especially where mining operations have removed the top layer of soil and replaced it with waste or overburden materials. Early seedling development and establishment is crucial for successful revegetation, but topsoil removal also reduces the soil nutrients that seedlings require. Understanding seedling response to reconstructed soils in arid landscapes is necessary for designing appropriate restoration protocol.
Objectives: The authors conducted two glasshouse experiments to (1) assess the drought thresholds of 21 native plants of Western Australia and (2) identify the effects of reconstructed soil substrates on plant responses to drought.
Methods: Twenty-one perennial species native to the Pilbara region commonly used in mine restoration were identified and classified as herbs, shrubs, trees, and grasses based on their photosynthetic pathway. Stockpiled topsoil and mine waste overburden were also collected from an active mining site in the Pilbara region and analyzed for physiochemical properties. Two greenhouse experiments were conducted; in the first, seeds of the study species were planted in topsoil and either exposed to a drought treatment or watered to maintain soil at field capacity. Physiological responses of the seedlings exposed to the treatments were measured. In the second experiment, four species representing a diverse range of physiological responses (determined in the first experiment), were grown in topsoil, overburden, or a combination of both, exposed to the same

treatments as in the first experiment (imposed drought or watered to field capacity), and physiological responses of the seedlings was again assessed. For each species in the experiment, there were 10 replicates of 20 centimeter (cm) tall pots planted with 20 seeds each. Physiological response to drought was assessed using non-linear modelling; analysis of variance (ANOVA) was used to assess differences in soil properties and differences species responses to soil treatments.
Location: Glasshouse facilities at the University of Western Australia and Kings Park Botanic Garden in Perth, Australia
Findings: Trees were significantly less tolerant to drought-related conditions compared to shrubs and herbs. Seedlings grown in overburden declined in overall growth and drought tolerance, likely due to the soil substrate's depleted nutrients and reduced water retention capacity.
Implications: Early seedling development is crucial for revegetation of disturbed arid landscapes. Nutrient rich soil is necessary for successful seedling germination and establishment. In arid landscapes, shrubs and herbs may more readily establish compared to trees; the latter may require irrigation and soil amendment for successful development.
Topics: Mining, Vegetation Recovery Data, Soil Data, Target Plant Recovery Data, Reclamation Practices

Bay, R., Erickson, W., and Carlson, K., 2008, Promoting plant diversity with low broadcast seeding rates applied to amended overburden mine soils at a limestone quarry in Tijeras, New Mexico, *in* Brummer, J.E., ed., High Altitude Revegetation Workshop No. 18, Fort Collins, Colo., March 4–6, 2008, Proceedings: Colorado Water Resources Research Institute Information Series no. 107, p. 310–328.

Link (non-DOI): http://hdl.handle.net/10217/69248
Background: The Rio Grande Portland Cement Corporation was mandated to implement a reclamation study at the Tijeras Cement and Limestone Quarry. The corporation contracted Habitat Management, Inc. to design and monitor test plots and ensure quality data collection. Topsoil was not salvaged for use during reclamation, so test plot treatments involved various organic amendment types and amounts, different broadcast seeding rates, and woody species transplants on top of redbed geologic material as growth medium.
Objectives: The authors evaluated reclamation methods, including soil amendments and seeding density, for enhancing reclamation efforts at a cement and limestone quarry in New Mexico.
Methods: The authors inventoried site vegetation, sampled soil for suitability, assessed runoff and erosion, and evaluated organic amendment to select the most appropriate location for test plots. Test plots were prepared with respect to water control and slope to reduce confounding environmental variables. A full factorial design was used to apply several treatments: control (0 tons [article did not indicate whether this was metric tons or US ton] per acre [t/ac]), hay mulch (2 t/ac), manure (20 and 30 t/ac), and broadcast seeding, with planting densities of 5, 10, and 20 pure live seed per cubic foot (PLS/ft^2). This resulted in a total of 16 treatment combinations; each had three replicates. Following New Mexico Mining and Minerals Division guidelines, plots were monitored annually from 2003 to 2006 for vegetation ground cover, plant diversity, vegetation health, seedling germination and establishment, woody plant density, and transplant survival from 2003 to 2006. Data were analyzed using a two-way analysis of variance (ANOVA) with a Tukey Honestly Significant Difference correction.
Location: Tijeras Cement Plant and Limestone Quarry in Tijeras, New Mexico, USA
Findings: Vegetation ground cover increased significantly from 2005 to 2006 but was not statistically significantly different among amendment treatments. Overall vegetation diversity also increased from 2005 to 2006; plots receiving 2 t/ac hay mulch had higher overall grass diversity than untreated plots or plots treated with 20 t/ac compost; there was no significant difference between hay mulch and plots treated with 30 t/ac compost. The highest seeding rate (20 PLS/ac) also resulted in the greatest species diversity, but only significantly greater when compared to the lowest rate (5 PLS/ac). There were no significant differences in interactions among amendment type and seeding density. However, 20 pure live seed per hectare (PLS/ha) with 30 tons organic amendment and 5 PLS/ha with 2 tons native hay mulch resulted in the greatest means for the most parameters.
Implications: Seed mix application rate is dependent on the desired vegetation cover diversity. Because no one amendment/seeding density treatment was statistically more productive, site-specific conditions and desired outcomes should guide reclamation efforts.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Bayramov, E., 2013, Optimization of environmental monitoring principles along oil and gas pipelines using GIS and remote sensing, *in* 7th International Conference on Application of Information and Communication Technologies, Baku, Azerbaijan, Oct. 23–25, 2013: Institute of Electrical and Electronics Engineers (IEEE), p. 291–293.

DOI: https://doi.org/10.1109/ICAICT.2013.6722681
Background: Revegetation and erosion control measures were implemented to mitigate disturbance due to the construction of Baku-Tbilisi-Ceyhan Oil and South Caucasus gas pipelines. This study aimed to evaluate vegetation restoration progress and predict erosion-prone areas along pipeline right-of-way (ROW).
Objectives: In 2007, the authors used geographic information systems (GIS) and remote sensing analysis to evaluate the progress of vegetation recovery along a ROW corridor between pipelines that had been reclaimed through revegetation and erosion control measures in 2005. They also compared two erosion prediction models to quantitatively predict erosion-prone areas along oil and gas pipelines.
Methods: The study area is a 44-meter (m)-wide ROW corridor between two parallel, 442-kilometer (km)-long pipelines. The study evaluated change between 2005 (when pipeline construction ceased, and the ROW was reclaimed) and 2007. Percent cover of vegetation was determined by comparing field-based estimates using Normalized Difference Vegetation Index (NDVI) with values from high-resolution satellite imagery. Erosion prone areas were identified using Universal Soil Loss Equation (USLE) and Morgan-Morgan-Finney erosion prediction. Model predictions were compared to 316 in situ measurements of erosion, from erosional events occurring between 2005 and 2012.
Location: A ROW corridor of the Baku-Tbilisi-Ceyhan Oil and South Caucasus gas pipelines section in Azerbaijan
Findings: Roughly 10.7 million square meters (m^2) of vegetation cover was restored; environmental acceptance criteria required an additional 8.9 million m^2 to be recovered. The USLE and Morgan-Morgan-Finney models resulted in significantly different predictions of erosion. USLE predicted spatially distributed erosion and Morgan-Morgan-Finney predicted clustered patterns of erosion classes. USLE performed better and identified 192 of 316 erosion occurrences along the pipelines; Morgan-Morgan-Finney only identified 117.
Implications: The area of restored vegetation can be determined by analysis of NDVI and in situ estimations of vegetation cover percentage. USLE predicts soil loss rates more reliably than Morgan-Morgan-Finney.
Topics: Pipeline, Erosion Data, Reclamation Monitoring, GrayLit

Bayramov, E., Buchroithner, M., and McGurty, E., 2012, Quantitative assessment of vegetation cover and soil degradation factors within terrain units for planning, monitoring and assessment of renaturation along oil and gas pipelines: Geocarto International, v. 27, no. 7, p. 535–555.

DOI: https://doi.org/10.1080/10106049.2011.648662
Background: Successful reclamation following pipeline construction is hindered by erosion. Erosion can remove soil above a buried pipeline and reduce vegetative cover. Controlling and assessing erosion over time is necessary to adequately reclaim pipeline disturbances.
Objectives: The authors (1) determined when satellite images reflect peak vegetation, (2) assessed regrowth and vegetation cover two years after reclamation, (3) quantified areas vulnerable to erosion and prioritized those areas, (4) modeled erosion in high-risk areas, (5) assessed the accuracy of soil erosion models, and (6) described how these methods can be applied to other contexts.
Methods: Vegetation cover data were gathered in the middle of each month using Normalized Difference Vegetation Index (NDVI), which correlated with field-based vegetation cover measurements. Calculations were performed using the data to determine which areas along the pipeline had returned to 70 percent pre-disturbance vegetation cover. A variety of metrics, including vegetation cover, site suitability analysis, soil erodibility factor, and soil erosion model outputs, were used to determine erosion classes and erosion vulnerability in particular terrain units. The erosion model's classes and vulnerability scores were compared to field surveys of existing erosion.
Location: Baku-Tbilisi-Ceyan oil pipeline and South Caucasus gas pipeline in Azerbaijan

Findings: Peak vegetation cover was variable in 2006 but spanned from the middle of April to the end of July. Normalization of NDVI data required the omission of 28 of the 96 transects with high likelihood of mismatch (13 percent root mean square error), after which a high correlation was achieved (0.94 R^2 value) between NDVI values and field collected vegetation cover. Based on vegetation cover more than half of the project (10.7 square kilometers [km^2]) was adequately restored, but 8.9 km^2 did not meet criteria for adequate reclamation (criteria defined in: Baku-Tbilisi-Ceyhan [BTC] and BOTAS, 2004, Biorestoration field guide, monitoring biorestoration and erosion risk. Azerbaijan, Georgia, and Turkey, BTC & BOTAS). The soil erosion models identified 40 percent of erosion sites and provided a detailed analysis of erosion vulnerability. Soil erosion models overpredicted erosion at an additional 395 sites.
Implications: Field surveys of vegetation cover are better correlated with satellite images when field surveys are more numerous and distributed across a site. Site suitability analysis and soil erosion models can predict sites vulnerable to erosion. Mapping erosion vulnerability should be included in reclamation monitoring.
Topics: Pipeline, Erosion Data, Reclamation Monitoring

Beggy, H.M., and Fehmi, J.S., 2016, Effect of surface roughness and mulch on semi-arid revegetation success, soil chemistry and soil movement: Catena, v. 143, p. 215–220.

DOI: https://doi.org/10.1016/j.catena.2016.04.011
Background: Preventing erosion and encouraging revegetation are important for successful long-term management of disturbed slopes like those associated with mining operations. The specific type of erosion cover (for example, straw mulch, plant litter, rocks) used will vary based on site-specific and environmental conditions. Some slopes may require surface microtopography alterations such as contour furrowing, pitting, imprinting, or soil ripping. Understanding which of these methods, or which combinations of them, are best suited for slope revegetation efforts in semiarid environments is important for future reclamation success.
Objectives: The authors evaluated the effects of mulch application and soil roughness treatments on erosion and vegetation growth on sloped surfaces in a semiarid grassland environment.
Methods: Two naturally sloped sites were selected and regraded each to a 3:1 slope. Each slope was capped to 30.5 centimeters (cm), one with a sedimentary mix from the Willow Canyon Formation and the other with a conglomerate from a late Tertiary alluvium. Surface treatments: ripping to 20 cm or smoothed, were applied to rows of plots and mulch treatments (4.5 milligrams per hectare [mg/ha] wheat straw incorporated into soil pre-ripping, 4.5 mg/ha straw applied then tackified using polyacrylamide to soil surface after seeding, or no mulch) were applied in a random, factorial design to six plots within each roughness treatment in each soil type at each elevation. Sites were broadcast seeded with a 10-species mix of native plants at 523 seeds per square meter (seeds/m^2). Aboveground biomass was quantified by species in nine 40 square centimeters (cm^2) quadrats per plot and collected soil samples for organic matter and nitrogen (N) content. Erosion was estimated using 20 cm nails installed flush with ground surface in seven random locations per plot. Data were analyzed using nested linear mixed effect models.
Location: Two sites (1,646 and 1,403 meters [m] above sea level) 45 kilometers (km) south of Tucson, Arizona, USA
Findings: No treatment or interaction of treatments significantly affected total aboveground biomass, but the seeded grass component did show a positive significant response to mulch treatment. Plant species richness was highest in the no mulch+smooth treatment, although no treatment or treatment combination had a statistically significant effect. Analyses of soil chemistry showed that the only significant change was that surface mulch lowered pH towards a more neutral value; no significant differences were found in soil organic matter or soil nitrogen (N). There were visible trends in erosion values in response to treatment although analysis did not detect significant differences; in general, smoothed plots had less erosion than roughened plots, and mulch, particularly surface-applied, also reduced erosion (but not significantly). There was a significant but weak (adjusted R^2=0.08) relationship between erosion and seeded grass biomass. Insignificant findings were likely due to high variability among blocks.
Implications: Application of surface mulch can reduce weeds and volunteer species but may alter species composition by favoring grasses. However, the polyacrylamide tackifier applied with the surface mulch was not independently tested in this study; it has had mixed effects in other research. In this study, soil microtopography appeared to create initiation sites for downhill erosions within the depressions, and if microtopography is used, it should be applied precisely and perpendicular to the slope contour to avoid unintended erosion effects. Although insignificant, the visible reduction of erosion associated with mulch application is promising. This study suggests that optimal combinations of treatments can both reduce erosion and favor vegetation establishment in slope reclamation scenarios.
Topics: Mining, Vegetation Recovery Data, Soil Data, Erosion Data, Reclamation Practices

Berg, W.A., 1975, Revegetation of land disturbed by surface mining in Colorado, *in* Wali, M.K., ed., Practices and problems of land reclamation in western North America: University of North Dakota Press, p. 79–89.

DOI: https://doi.org/10.1016/0016-2361(76)90020-X
Background: Gold and silver mining were Colorado's original economic drivers. Today, coal, uranium, and oil shale mining operations are expanding across the state. While surface (strip) coal mining is concentrated in the northwestern portion of Colorado, it will likely spread to additional areas, bringing with it concerns regarding landscape disturbance and revegetation needs. Observations of existing strip coal mining operations, and potential revegetation problems, may provide useful for future reclamation efforts.
Objectives: The author reviewed mining operations in Colorado and discussed potential future problems associated with surface mining expansion across the state.
Methods: The author reviewed literature and research on the spoil characteristics, herbaceous vegetation, and land use alternatives associated with surface (strip) coal mining in northwestern Colorado. They briefly discussed additional areas and forms of mining in the state (that is., southwest coal, south central coal, Denver Basin coal, limestone spoils, uranium spoils, and oil shale open pit mining).
Location: This is a review article and does not involve a specific field site location
Findings: Past strip coal mining spoils produced fine-texture soils with reduced nitrogen (N) content, which is expected to continue with expansion. Alfalfa was the dominate species for spoil revegetation in northwestern Colorado; however, it is a poor species to use when livestock grazing is the post-mine land use designation. Southwest Colorado has extensive potential surface mineable coal deposits though revegetation has been unsuccessful and limited by low precipitation; the same problems occur in southern Colorado. Limestone, uranium, and oil shale open pit mining soils all need considerable amounts of added nutrients via fertilizer or other amendments. Future mining operations should consider conserving topsoil for reclamation purposes as it is higher in N and other nutrient contents.
Implications: This article provides a useful overview of Colorado mining in the 1970s and provides suggestions for increasing revegetation success.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Bjugstad, A.J., 1983, Establishment of trees and shrubs on lands disturbed by mining in the west, *in* New forests for a changing world, 1983 Society of American Foresters National Convention, Portland, Oregon, October 16–20, 1983, Proceedings: Society of American Foresters, p. 434–438.

Link (non-DOI): https://www.fs.usda.gov/rm/pubs_other/rmrs_1984_bjugstad_a001.pdf
Background: The Surface Mining Control and Reclamation Act (SMCRA) passed in 1977 placed new focus on revegetating mine spoils. In semiarid environments, such as those in the western United States and northern Great Plains, moisture and underlying landscapes are major limiting factors in successful revegetation. New stipulations of the SMCRA necessitate new methodologies and approaches to mine spoil revegetation in these regions.
Objectives: The author reviewed efforts to reestablish vegetation (trees and shrubs) on disturbed mine land in the western United States, specifically the northern Great Plains.
Methods: The difficulties of revegetating mine spoils in the semiarid western United States and northern Great Plains were outlined and previous research results, specifically dry land tests at the Belle Ayr Mine near Gillette, Wyoming, were reviewed. General suggestions for successful revegetation methods were summarized.
Location: This is a review paper and does not involve a specific field site location, but a case study considered for the paper is centered on the Belle Ayr Mine near Gillette, Wyoming, USA
Findings: Survival varied by species and planting year (due to precipitation variables). One study showed that irrigation improved survival for all species. In another study, response to container or bare root planting varied by species. A third study showed that examination of mulch, fertilizer, and irrigation affected shrub survival for some species: Rocky Mountain juniper had successful survival regardless of treatment, winterfat performed poorly across all treatments, and big sagebrush responded positively to mulch combined with irrigation and fertilizer combined with irrigation.

Implications: This review provides useful suggestions for land mangers looking to revegetate mine spoils in semiarid environments, though results may vary greatly among species. Site specific characteristics and needs will determine to what degree land managers can apply this research to their revegetation and reclamation plans. In any case, cultural treatments and intensive management will likely be required for revegetation success.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Blicker, P.S., Jennings, S.R., and Goering, J.D., 2006, Native plant reestablishment on highway cut slopes using compost application, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Mont., June 4–8, 2006, Proceedings: Billings Land Reclamation Symposium and the American Society of Mining and Reclamation, p. 68–103.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2006-Billings/0068-Blicker.pdf
Background: Highway corridor revegetation in Montana is complicated by steep slopes. Successful reclamation requires early reestablishment and survival of seeded plants. The accepted methods of broadcast seeding and hydromulching bare slopes produce marginal results due to rocky, nutrient poor soil conditions, which leads to increased maintenance costs. Understanding appropriate compost application rates and what equipment can apply the material on 2H:1V slopes could improve highway and steep slope revegetation reclamation.
Objectives: The authors sought to (1) reduce erosion and enhance successful vegetation on steep highway cuts by using compost amendment, (2) develop protocols for future similar situations, and (3) monitor, evaluate, and communicate project findings.
Methods: The authors designed a two-phase project. In phase I, a literature review was carried out, assessing the use of compost amendment to assist vegetation growth, equipment necessary for successful application, and feasibility of this method in Montana. Phase II (still ongoing at the time this article was published) involved construction of five test plots at each of four research sites, applying either incorporated or blanket compost amendment at varying depths, broadcast seeding, monitoring erosion, vegetation reestablishment and growth, and soil properties. The authors evaluated the ongoing results from these various tests.
Location: Mile Posts 77 (Middle Thompson Lake) and 69 (Loon Lake) on U.S. Highway 2, 60 kilometers (km) east of Libby, Montana, and the junction of I-94 and U.S. Highway 12, 4.8 km east of Miles City, Montana, USA
Findings: Applying compost to steep slopes is a viable method for revegetation in Montana using pneumatic blower trucks. Erosion and soil chemistry did not differ between blanket or incorporated compost application. Vegetation growth on all composted plots was greater than non-composted control plots and erosion on composted plots was reduced compared to controls.
Implications: Steep slopes produced during road construction from energy development could benefit from this study's results. Reclamation land managers should consider compost application to increase revegetation success.
Topics: Road, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Bony, L., 2020, Salt affected soils and their relationships with plant communities on reclamation well sites: Edmonton, Alberta, University of Alberta, master's thesis, Department of Renewable Resources, 66 p.

DOI: https://doi.org/10.7939/r3-e0bs-pf98
Background: Salt affected soils can occur naturally or be produced by disturbance, such as oil and natural gas extraction. In Alberta, Canada over 300,000 wells and over 430,000 kilometers (km) of pipelines have drastically disturbed saline-sodic soils, which has complicated reclamation and revegetation efforts. Electrical conductivity (EC) and sodium absorption ratio (SAR) are widely measured as indicators of salinity; however, they may not be the most appropriate parameters for all salt contaminated soils. Assessing these parameters, and their impact on plant communities, may improve reclamation methods and help tailor protocols to salt-specific soil conditions.

Objectives: The author evaluated whether EC and SAR are the most scientifically appropriate indicators of salt affected soils and assessed the effects of saline and sodic soil on plant communities.
Methods: Twenty-two well sites were selected, 16 in the Dry Mixed Grass ecosystem and six in the Central Parkland ecosystems. EC and SAR readings were collected using a ground conductivity meter and soil samples (augering to 1.5 meter [m] by 15 centimeter [cm] increments) from one to three randomly selected areas at each site known to have high EC and SAR values. A 20 × 50 cm quadrat frame was placed adjacent to each auger hole and was used to visually assess total vegetation canopy cover, canopy cover and mean height of each species, and ground cover by categories. Soil chemical and physical data were analyzed with non-metric multidimensional scaling and regression modeling and vegetation data were analyzed with Redundancy Analysis and Akaike information criterion.
Location: Dry Mixed Grass and Central Parkland ecoregions of Alberta, Canada
Findings: Soil parameters differed by ecoregion; all ion concentrations, notably sulfate, were higher in the Dry Mixed Grass ecoregion. Non-metric multidimensional scaling of all parameters revealed no relationship between EC and SAR. EC and SAR were each correlated with varying ions though not the same or all; measuring EC and SAR does not indicate which specific ions are present in the soil. Overall, ground cover was similar between the two ecoregions though Central Parkland had more total vegetation canopy cover due to land use (ungrazed cultivated crops). Relationships between vegetation and EC and SAR varied by soil depth and at some depths other parameters (for example, potassium, magnesium, and pH) were better indicators of vegetation response to sodic soil conditions.
Implications: Land managers should consider using more specific analyses than just EC and SAR to determine the specific ions (and ratios) present in the soil and design more specific and targeted reclamation planning. It should be noted that this research assessed only two ecoregions in Alberta, and relationships among EC, SAR, and vegetation response in saline-sodic soils may vary in other ecoregions.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices, Reclamation Monitoring, Reclamation Standards, GrayLit

Booth, D.T., 2002, Seed longevity and seeding strategies affect sagebrush revegetation: Journal of Range Management, v. 55, no. 2, p. 188–193.

DOI: https://doi.org/10.2307/4003355
Background: Sagebrush (*Artemisia tridentata*) is a mandated species for reclamation of coal-mined rangelands in Wyoming due to its importance to ecosystem function. Two competing, locally discussed sagebrush revegetation hypotheses existed at the study's inception. The first, the "exclusion" hypothesis, suggested that sagebrush establishment would be precluded in communities dominated by a different species of shrub, and such, seeding fourwing saltbush (*Atriplex canescens*) at 2.2 kilograms pure live seed per hectare (kg PLS/ha) or greater would form monotypic stands that outcompeted sagebrush. The second, the "pioneer plant" hypothesis, suggested that sagebrush establishment was precluded due to poor soil conditions and low soil mycorrhizal inoculum potential, therefore that the soil on reclaimed mines was responsible for poor sagebrush revegetation.
Objectives: The author tested the "exclusion" and "pioneer plant" hypotheses for sagebrush revegetation on reclaimed coal mines.
Methods: "Steptoe" barley was seeded over the entire study site to produce stubble mulch then mowed to remove seed heads. A randomized complete block design was used with three replicates per treatment. Split plots were either half-filled with stored topsoil or half-filled with fresh-stripped topsoil. One of four treatments were applied within split plots: (1) sagebrush (*A. tridentata* ssp. *wyomingensis*) seeded in 1992 and 1993, (2) fallow in 1992 with sagebrush seeded in 1993, (3) fourwing saltbush seeded in fall 1991 and sagebrush seeded in 1993, and (4) no seeding (control). Shrub development was monitored and photographed in 1 square meter (m^2) quadrats (9 per plot in 1992 and 15 per plot in 1993 and onward). Seed efficiency, shrub density, and height were calculated and compared among treatments. Data were analyzed using a mixed effects linear model.
Location: North Antelope coal mine (43°31′41″ N., 105°17′04″ W.) in the Powder River Basin of Wyoming, USA
Findings: New sagebrush seedlings were detected during all study years (1992–1996) and all treatments had significantly more seedlings than the unseeded control. Treatment 1 yielded the most sagebrush individuals. Treatment 3 had the greatest seed efficiency and results suggest saltbush did not affect 1993 (study's wettest year) sagebrush establishment. Topsoil, handled as in this study, did not affect seed efficiency. Shrub density and height were not related to treatment or topsoil. Treatment 2 produced significantly more surviving shrubs than treatment 1.
Implications: Leaving reclaimed land fallow with stubble mulch for a season before seeding shrubs may be more cost effective for meeting shrub density standards than seeding two years in a row. Using high seeding rates of partially dormant seed spreads seedling establishment potential over multiple years. Results did not support either of the hypotheses tested.
Topics: Mining, Target Plant Recovery Data, Reclamation Theory, Reclamation Practices

Booth, D.T., and Cox, S.E., 2009, Dual-camera, high-resolution aerial assessment of pipeline revegetation: Environmental Monitoring and Assessment, v. 158, p. 23–33.

DOI: https://doi.org/10.1007/s10661-008-0562-5
Background: Reclaiming land after energy extraction is required by law in several states across the west. However, according to U.S. General Accounting Office reports from 1999 and 2005, government agencies have difficulty meeting monitoring requirements. Very-large scale aerial (VLSA) surveys may be a more efficient method for monitoring reclaimed sites.
Objectives: The authors assessed reclamation success of right-of-way (ROW) disturbances using aerial images while simultaneously evaluating the utility of VLSA imagery at high and low resolution for reclamation monitoring.
Methods: Flyovers were conducted at two reclaimed pipelines (Howell and Lost Creek) in 2006 and 2007 using aircraft with a U.S. Federal Aviation Agency “Sport Airplane” designation, 10.5-meter (m) wingspan, and two-person capacity. An externally mounted dual-camera equipment module consisting of two digital single-lens reflex (SLR) cameras set for 1/4,000 second (s) shutter speed, a Trackair navigation system, laser rangefinder, light meter, and a Global Positioning System (GPS) receiver were used to collect imagery. During flyovers, location data, altitude above ground level (AGL), and light intensity values were collected. Images were lined up with GPS coordinates, altitude AGL, light intensity, and ground speed using a merge software. Slope, aspect, and elevation for each image location were obtained using ArcGIS 9.0. The aerial survey for the Howell pipeline was conducted at 240 m AGL, rather than the 150 m AGL altitude at the Lost Creek pipeline, to increase the field of view to span the full width of the disturbed area. High- and low-resolution images were acquired during flyovers at the Howell pipeline. SamplePoint software was used to quantify vegetation cover, and images were classified based on life form and ground cover inside and outside the ROW. Images were compared between sites at both resolutions to determine if resolution affected accuracy of vegetation cover.
Location: A 32-kilometer (km) ROW segment crossing the Arapahoe Use Area in the Green Mt Common Allotment along the Lost Creek pipeline south of Jeffrey City in southern Wyoming (42°14′ N., 107°54′ W.) and a 35 km ROW segment crossing the Salt Creek watershed along the Howell pipeline norther of Casper in central Wyoming (43°23′ N., 106°26′ W.), USA
Findings: For the Lost Creek pipeline, shrub and forb cover were lower inside the pipeline ROW relative to the adjacent, undisturbed land. However, grass and litter cover were higher. Inside the ROW, total vegetation cover was 22 percent. Adjacent to the pipeline, on undisturbed lands, vegetation cover was 55 percent. No weeds were detected in the images or by on-ground surveys. For the Howell pipeline, 38 percent vegetation cover was present inside the ROW and 51 percent in adjacent land. In addition, the Howell pipeline had greater shrub establishment with ROW establishment 74 percent of that seen in adjacent land, compared to the Lost Creek ROW establishment only 7 percent of that seen adjacent. Only 14 percent of the Lost Creek pipeline ROW had bare ground, but 72 percent of the Howell pipeline ROW had more bare ground than adjacent undisturbed sites. Researchers calculated this survey project cost $5,700 including image analysis and data summary.
Implication: VLSA pipeline surveys can adequately facilitate environmental monitoring on energy extraction sites. By using VLSA surveys, large sample numbers and ground cover measurement can be attained. This enables fact-based decision making by land managers for protecting or rehabilitating affected ROW surface resources. Additional imagery directly over the ROW, and a second acquisition flight targeted for 30 m adjacent to the ROW can aid in monitoring reclamation efforts. Low resolution images provide no benefit and only high-resolution images should be collected. While weedy species are currently not a threat at these sites, the amount of bare ground at each site may enable future invasion.
Topics: Pipeline, Vegetation Recovery Data, Reclamation Monitoring

Booth, D.T., Gores, J.K., Schuman, G.E., and Olson, R.A., 1999, Shrub densities on pre-1985 reclaimed mine lands in Wyoming: Restoration Ecology, v. 7, no. 1, p. 24–32.

DOI: https://doi.org/10.1046/j.1526-100X.1999.07103.x
Background: Native shrub reestablishment is required after mining companies extract mineral resources. As of 1996, shrub density must be 1 shrub per square meter (shrub/m^2) on 20 percent of the affected area after reclamation. Examining the effectiveness of shrub reclamation techniques (by measuring shrub density on mines reclaimed before 1985) is important for designing best practices and helping various stakeholders reach reclamation goals.
Objectives: Researchers (1) evaluated the long-term effects of various reclamation practices on shrub revegetation at mines reclaimed prior to 1985, and (2) provided recommendations to increase shrub density during reclamation.

Methods: Fourteen mines >10-years-old were selected within three geographic regions to examine the long-term effects of shrub revegetation, avoiding sites with steep slopes and grazing activities. All sites were seeded by 1985 and shrub density was measured in the summer of 1994. Plots (20 × 50 meter [m]) were oriented to the long axis of each site in a perpendicular fashion. The number of rooted living and standing-dead shrubs were counted in a 200 m^2 area, and shrub seedlings were counted in a strip 4-m-wide along the transect. Both standing dead and living shrubs were used to determine average shrub height. Field survey data were compared to land mandates (1 shrub/m^2 for 20 percent or extrapolated to 0.2 shrubs/m^2 on 100 percent of the land) to determine if reclaimed sites had significantly lower shrub density than was required.
Location: Mines in the southwest region (Bridger Coal Company mine 53 kilometers [km] northeast of Rock Springs, and Kemmerer Coal Mine 23 km southwest of Kemmerer), northeast region (Black Thunder Coal Mine 20 km east of Wright, Belle Ayr Coal Mine 28 km south of Gillette, and WyoDak Coal Mine 4 km east of Gillette), and the central region (Pathfinder Uranium Mine in the Shirley Basin 78 km southeast of Casper, Dave Johnston Coal Mine 40 km east of Casper, and Seminoe I Mine 28 km northwest of Hanna) of Wyoming, USA
Findings: Shrub density was significantly greater than 0.2 shrubs/m^2 on one of five saltbush communities and seven of nine sagebrush communities. The highest shrub density was at the Bridger Coal Company sites with 0.22 and 0.90 shrubs/m^2 at Bridger #1 and #2, respectively. There was a correlation between shrub density and seeding rates in sagebrush, but not saltbush, sites. Seeding rates between 60 and 1,000 seeds/m^2 and shrub density up to 0.6 shrubs/m^2 were positively correlated (when shrubs were part of the seed mix). There was no correlation between shrub density and grass-seeding rates, but sagebrush densities were greater when seeded without grass. In three of four saltbush communities, natural sagebrush immigration occurred and there was evidence that over-seeding easily established saltbush stands with sagebrush, possibly an effective means of increasing shrub density and diversity. A non-local seeded subspecies (basin big sagebrush) established significant stands in three sagebrush habitat sites.
Implication: Over half of pre-1985 reclaimed study sites met the Wyoming standard for shrub density using an extrapolated standard of 0.2 shrub/m^2 for 100 percent of the land from 1 shrub/m^2 for 20 percent of the land. However, the extrapolated standard ignores that the original requirement is for patches with greater density, not overall density, and increasing shrub densities above 0.2 shrub/m^2 can be difficult and costly. Seeding with diverse shrub seed mixes at high seeding rates may enable reclamation to meet the new requirements.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Bowen, C.K., Olson, R.A., Schuman, G.E., and Ingram, L.J., 2002, Long-term plant community responses to topsoil replacement depth on reclaimed mined land, *in* Barnhisel, R., and Collins M., eds., Reclamation with a purpose, American Society of Mining and Reclamation 19th Annual National Conference, Lexington, Ky., June 9–13, 2002, Proceedings: American Society of Mining and Reclamation, p. 130–140.

Link (non-DOI): https://www.asrs.us/Publications/Conference-Proceedings/2002/0130-Bowen.pdf
Background: Topsoil is often applied on reclaimed mine lands to encourage plant reestablishment and growth and increase reclamation success. Varying topsoil depth may impact the efficacy of this practice. Long-term assessment of plant growth under different topsoil depths can demonstrate best practices for successful reclamation.
Objectives: The authors evaluated plant species growth, diversity, richness, cover, and production under varying topsoil depths applied 24 years post-mine reclamation.
Methods: During reclamation, topsoil was spread in a wedge over spoil at depths of 0–600 millimeters (mm). A completely randomized experimental design was used with ten replicate plots of mulch treatments (straw or stubble mulch). Five plots were seeded with barley for stubble mulch establishment and five plots were left fallow for straw mulch application. All plots were drill seeded with perennial grass and shrub mix. Within quadrats, plant biomass, cover (estimated using Daubenmire method), diversity, and frequency were measured 24 years post-reclamation. In addition, all live plant matter was clipped at ground level in quadrats and dried for biomass measurements. A Shannon-Weiner diversity index was calculated for each species and data were analyzed using a three-way analysis of variance (ANOVA).
Location: Pathfinder Mines Corporation Shirley Basin uranium mine, south-central Wyoming, USA
Findings: Topsoil depth treatment had a significant effect on canopy cover, species diversity, species richness, and plant biomass. However, in general, species diversity and species richness decreased as topsoil depth increased. Canopy and ground cover and biomass increased as soil depth increased.

Implications: Topsoil depth applied in mine land reclamation clearly affects plant species diversity and richness. However, applying shallow topsoil may not ensure future soil stability. Long-term studies are necessary for accurately assessing the effect of topsoil depth on plant communities post-mine reclamation.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, GrayLit

Bowles, B., 2011, Development of a sagebrush steppe plant community 33 years after surface disturbance: Fort Collins, Colo., Colorado State University, master's thesis, 24 p.

DOI: https://mountainscholar.org/handle/10217/47304
Background: Understanding long-term recovery of reclamation efforts after treatment is rare and critical for adopting effective strategies that lead to long-term ecological recovery.
Objectives: The author of this study revisited a reclamation experiment 33 years after completion to assess plant production and composition on plots that had been seeded with different seed mixes.
Methods: In 1976, the site was disturbed by removing about 4 centimeters (cm) of topsoil and vegetation to replicate an oil and gas well pad. Sites were drill seeded with six different seed mixes and received a mulch or fertilizer treatment. Hydro-mulch was applied to a different set of 54 plots in the original 1976 study. A 1981 study determined that the effects of hydro-mulch was insignificant. Therefore, the hydro-mulch plots were not included in this study and no conclusions were made on the effects of mulch. In 2008 and 2009 above-ground biomass, litter, and soil samples were collected to compare the reclaimed and nearby undisturbed land.
Location: Piceance Basin (39°54′13″ N., 108°24′02″ W.) 60 kilometers (km) northwest of Rifle, Colorado, USA
Findings: Results varied by year. Plots seeded with only native seed mixes had the greatest diversity (Shannon-Weiner diversity index). Regardless of the seed mix used, introduced species (crested wheatgrass and others) had greater biomass than native species. However, nonnative species did not establish in the undisturbed plots. Seed mixes that contained introduced species had lower biomass of weedy annual species. Sagebrush did not recruit from the nearby undisturbed area into any of the plots. Fertilizer did not influence long-term production or composition.
Implications: This study illustrated that seed mixes containing only native species can lead towards a trajectory of recovery better than mixes with introduced species and fertilizer applications. In areas of high invasion by weedy annual grasses, managers should consider seeding with specific introduced species to resist noxious invasive species establishment. However, it should be noted that the removal of about 4 cm of topsoil effectively removed competition within the seedbank, and that seed mixes containing introduced species were better at resisting invasion of annuals when there was no prior seedbank.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Bradshaw, A.D., 1983, The reconstruction of ecosystems—Presidential address to the British Ecological Society, December 1982: Journal of Applied Ecology, v. 20, no. 1, p. 1–17.

DOI: https://doi.org/10.2307/2403372
Background: Ecosystem disturbance takes many forms, including energy resource mining. Reclamation can help reestablish a functioning self-sustaining ecosystem post-mining, and natural successional processes can play a large role in the reclamation process. Some mining disturbances require more intense reclamation methods before natural successional processes can occur. Ecologists have a unique opportunity to inform reclamation for long-term ecosystem health.
Objectives: The author discussed natural successional processes and their capacity to assist reclamation following mining disturbance.
Methods: The author reviewed research and literature on the natural processes of colonization and ecosystem development on disturbed land. They discussed artificial reconstruction of ecosystems including physical factors, nutrients, toxicities, plants, and animals. They concluded with suggestions for ecologists on how to contribute to reclamation and the importance of collaboration.
Location: This is a review article and does not involve a specific field site location
Findings: Healthy soil is necessary for functioning ecosystems. Colonization and ecosystem development require nutrient-rich soil, with nitrogen (N) levels up to 1,000 kilogram per hectare (kg/ha) for plant establishment and growth. Once established, various plant species can facilitate further revegetation and plant community development. Human-initiated reclamation may

be necessary to reestablish soil structure, physical factors, and adequate nutrient levels; reduce or remove toxic heavy metals; reseed plants via hydraulic seeding; and reestablish some animal populations (for example, earthworms) before natural successional processes can become self-sustaining.
Implications: Natural successional processes can play a role in reclamation if healthy soil and minimal vegetation is reestablished. Ecologists should collaborate with land managers and regulatory bodies to ensure reclamation results in long-term self-sustaining function ecosystems.
Topics: Mining, Reclamation Theory, Reclamation Practices

Bradshaw, A.D., 1997, Restoration of mined lands—Using natural processes: Ecological Engineering, v. 8, no. 4, p. 255–269.

DOI: https://doi.org/10.1016/S0925-8574(97)00022-0
Background: Mine land reclamation destroys soil and plant communities and requires reclamation to reestablish functioning ecosystems. However, reclamation is costly and alternative means may be necessary when funding is limited or completely lacking. Natural succession processes have the potential to reclaim mine lands in the absence of funding, though some amount of reclamation may be needed to reestablish productive soil conditions after extremely toxic and (or) destructive mining operations.
Objectives: The author discussed the merits of natural processes, focusing on soil, as cost-effective means of mine land reclamation.
Methods: The author presented soil as a separate ecosystem to consider during reclamation and discussed natural and assisted soil development methods. They reviewed research on how to overcome physical, nutritional, and toxicity problems associated with mined soils to reestablish functioning and healthy soil ecosystems.
Location: This is a review paper and does not involve a specific field site location
Findings: While some aspects of soil development take thousands of years, biological process of soil development can take only decades and can be aided, if necessary, by reclamation methods. Nitrogen (N) content is the leading nutrient necessary for plant development, and plants in turn assist with soil formation. Assisted soil development may involve organic amendment, fertilizer application, and revegetation methods to address physical, nutritional, and toxicity issues before allowing natural processes to continue.
Implications: When possible, land managers should take advantage of natural soil development processes when reclaiming mine lands to reduce costs and encourage self-sustaining development. Under certain conditions, some reclamation intervention may be needed to reestablish suitable soil conditions for revegetation success in the long-term.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Bressler, A.W., 2008, Weed management in Albert's oil and gas industry, *in* Darbyshire, S.J., and Prasad, R., eds., The view from the north, Weeds Across Borders 2008 Conference, Banff, Alberta, May 27–30, 2008, Proceedings: Alberta Invasive Plants Council, p. 201–210.

Link (non-DOI): https://d1ied5g1xfgpx8.cloudfront.net/pdfs/31658.pdf
Background: Weed management and control is an important part of minimizing negative environmental impacts from oil and gas development. Reclaimed sites can fail to receive certification if noxious weeds are present. Obsidian Energy (formerly Penn West Energy Trust), with Wood (formerly AMEC Earth & Environmental), maintains a weed management database for Canadian oil and gas companies to take proactive steps towards tracking and reducing weed presence. This database is a "living" document that incorporates up-to-date data and lessons learned and evolves in response to new techniques and technologies.
Objectives: The author described the weed management system developed by Wood as a tool for Canadian oil and gas developers to successfully control weeds.
Methods: The author outlined the need for weed control on oil and gas drilling sites and consequences (for example, failing reclamation certification) associated with poorly managed site weed data over time and insufficient control methods. They discussed current assessments, and an example situation oil and gas developers may run in to. They introduced the weed management database, its offerings, and future developments.
Location: Alberta, Canada

Findings: Weed management on oil and gas drillings sites is often poor due to transfer of land management and lacking historical records of weed presence. The Wood weed management program can develop status and progress reports, maintain data consistency, inventory weeds at the species level, evaluate contractor performance, conduct cost analyses, manage historical data, and plan future weed management.
Implications: Oil and gas developers in Canada should consider consulting the Wood weed management program to ensure their weed control meets industry and reclamation standards.
Topics: Well Pad, Reclamation Monitoring, Decision Support Tools, GrayLit

Brown, S.L., and Paschke, M.W., 2002, Native shrub establishment in Colorado, *in* Barnhisel, R., and Collins M., eds., Reclamation with a purpose, American Society of Mining and Reclamation 19th Annual National Conference, Lexington, Ky., June 9–13, 2002, Proceedings: American Society of Mining and Reclamation, p. 163–177.

Link (non-DOI): https://www.asrs.us/Publications/Conference-Proceedings/2002/0163-Brown.pdf
Background: Colorado coal mines are often located in high quality wildlife habitat and reclamation strives to reestablish native vegetation to support wildlife populations. However, reclamation efforts often yield variable and unpredictable results due to reclamation methods and natural processes. Evaluating native shrub establishment is necessary to design best-practices for reclamation of coal mine disturbance.
Objectives: The authors provided information on how to improve wildlife habitat at coal mine reclamation sites by assessing shrub reestablishment under several conditions.
Methods: A literature review was conducted on the biology, ecology, and propagation of seven primary shrub species important for Colorado wildlife habitat. Large-scale demonstration plots were established to test commercially used shrub establishment methods, incorporating literature review findings. Stockpiled or live handled topsoils were applied, and plots were strip-seeded with native seed mix, broadcast seeding when necessary. Browsing in plots was evaluated in light of two treatments: a non-palatable seed mix or fencing in the plot. Soil roughening was applied to a subset of plots as an additional treatment. Soil samples were collected and using a line-point intercept method, measurements were taken for vegetation cover, surface cover (bare ground, rock, litter), and shrub establishment and height.
Location: Colowyo, Seneca, and Trapper mines in northwestern Colorado, USA
Findings: Topsoil samples from all three mines had satisfactory physical and chemical properties to sustain plant growth, though two mines had low phosphorus levels. Shrub establishment varied by site, with dry conditions possibly contributing to the presence of invasive Russian thistle.
Implications: Native shrub establishment after coal mine reclamation varies by site, even if soil characteristics are favorable for plant growth. Long-term monitoring will help identify factors affecting shrub establishment and assist in developing methods to reestablish primary wildlife habitat in Colorado lands disturbed by coal mine activity.
Topics: Mining, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Buchanan, B., Owens, M., Mexal, J., Ramsey, T., and Musslewhite, B., 2005, Long-term effects of cover soil depth on plant community development for reclaimed mined lands in New Mexico, *in* Barnhisel, R.I., ed., 22nd National Meeting of the American Society of Mining and Reclamation, Breckenridge, Colo., June 19–23, 2005, Proceedings: American Society of Mining and Reclamation, p. 115–126.

DOI: https://doi.org/10.21000/JASMR05010115
Background: Revegetation of mine land depends on multiple variables, including soil depth. Several studies have suggested ideal soil depth for maximum plant growth, though no such studies were specific to New Mexico. Such a study is necessary to develop soil depth recommendations for mine reclamation in northern New Mexico.
Objectives: The authors evaluated the long-term effect of soil depth on vegetation parameters to determine a recommended soil depth for mine reclamation in northern New Mexico.

Methods: A 1 hectare (ha) double wedge plot was constructed with suitable spoil and cover soil oriented at 90° to ensure simultaneous comparison of varying depths of both mediums. The spoil has a 0 centimeter (cm) to 120 cm depth range, and the cover soil a 0 meter (m) to 60 cm depth range. In 1993, the wedge was uniformly seeded with a native seed mixture and 49 gridded locations were identified as sampling points to determine precise soil depths and to sample vegetation. Shrub density, vegetation cover, and production were sampled in 1994, 1995, 2003, and 2004. Vegetation metrics were plotted by soil depth and assessed for correlations.
Location: An active coal mine in San Juan County in northern New Mexico, USA
Findings: There were no strong relationships between vegetation metrics and soil depths though there were general trends. Total and perennial vegetation cover and production increased with cover depth. The relationship between shrub density and cover soil depth varied by species, though overall shrub cover was not related to cover soil depth, however when species were assessed individually, *Ericameria nauseosa ssp. nauseosa* had a significant negative relationship with cover soil depth and *Krascheninnikovia lanata* a significant positive relationship with cover soil depth (*Atriplex canescens* was not affected). A predicted five species/sample location would have been achieved with soil depths of 25–65 cm (shallower or deeper soil depths would have less than five species).
Implications: Optimal soil depth depends on the desired plant community. For this study, deeper soil promoted forbs and shallower soil promoted shrubs. Land managers should consider post-mine land use and seeding mixes when deciding soil depths or consider varying soil depth to promote an overall more diverse plant community.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Buckner, D.L., 1985, Point-intercept sampling in revegetation studies—Maximizing objectivity and repeatability, *in* Bridging the gap between science, regulation, and the surface mining operation, 2nd Annual Meeting the American Society for Surface Mining and Reclamation, Denver, Colo., October 8–10, 1985, Proceedings: American Society of Mining and Reclamation, p. 110–113.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/1985/0110-Buckner.pdf
Background: Following the Surface Mining Control and Reclamation Act (SMCRA) passed in 1977, the use of quantitative performance standards became increasingly important to examine revegetation success on sites disturbed by mineral extraction. Commonly, plant cover, annual biomass production, and woody plant stem density are used to gauge revegetation success, but techniques for collecting cover data can be highly variable. Ocular estimation, line intercept, and point-intercept sampling are three commonly used methods to detect and quantify vegetation cover and abundance.
Objective: The researcher examined the strengths and weaknesses of ocular estimation, line intercept, and point-intercept sampling and determined how best to apply each in the context of reclamation.
Methods: The use of cover data was considered and compared for different applications such as rangeland health assessments and revegetation following mining activities. Three commonly used cover sampling methods were summarized and their strengths and weaknesses were reviewed; they included (1) ocular estimation, which involves visually estimating the amount of area individual species occupy within a gridded rectangular or circular frame, resulting in a cover value for each species, (2) the line-intercept method, which involves measuring the length of vegetation that intersects a linear tape stretched across vegetation, and (3) the point-intercept method, which involves counting vegetation that intersects particular points, often in 1 square meter (m^2) sampling areas, along a vertical transect and as either "hits" or "non-hits" to reduce subjectivity or partial coverage.
Location: This is a methods paper and does not involve a specific field site location
Findings: Accuracy and repeatability of plant cover data for revegetation after mining is important, whereas the accuracy of relative abundance of a species is more important when describing an ecological community or community composition. The point-intercept method is best suited for mine permit baselines and assessing revegetation success because it can reduce subjectivity or partial coverage. In these applications, confidence in absolute cover and repeatability is crucial and information on the full range of individual species' cover values is not. In contrast, ocular estimation is best for descriptive plant ecological purposes, in which complete information on species is important but confidence in absolute cover values and repeatability is not.
Implications: Using the appropriate method for quantifying vegetation is dependent on the stakeholders' objectives. If a stakeholder wants to describe an ecological community and structure of a site, ocular estimation should be the preferred method. The point-intercept method should be used to develop plant cover baseline estimates and used to monitor revegetation success after reclamation. Line-intercept method falls somewhere in between the other two methods in terms of suitability for various applications.
Topics: Mining, Reclamation Monitoring, GrayLit

Buckner, D.L., 2006, Correlation of plant cover and production with annual climate parameters—An example with implications for bond release technical standards, *in* Barnhisel, R.I. ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Mont., June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 150–155.

DOI: https://doi.org/10.21000/JASMR06010150
Background: The Surface Mining Control and Reclamation Act of 1977 (SMCRA) set regulatory requirements for reclamation of mined lands. Revegetation metrics are often based on surrounding undisturbed reference areas. Occasionally reference areas become disturbed, so technical standards are granted as reference metrics. However, these standards do not take into account climate variation and may result in too high (or too low) standards of revegetation requirements. To incorporate climate variation into technical standards, long-term multiyear data collection of undisturbed reference sites is needed.
Objectives: The author presented a 9-year dataset as a basis for testing predicted levels of revegetation based on climate conditions for reclamation technical standards.
Methods: A Cover-Point Model 5 optical point projection device was used to collect cover data along transects from 1997–2004, at the same 20 randomly located sites within the sagebrush grassland steppe habitat of the Belle Ayr Mine Extended Reference Area. Climate data were collected from the National Oceanic and Atmospheric Administration (NOAA) Gillette 9 ESE station 12 miles (mi) from the Extended Reference Area. Climate and vegetation data were assessed for correlations.
Location: A sagebrush grassland steppe of the Extended Reference Area for Belle Ayr Mine in Campbell County, Wyoming, USA
Findings: For 1997–2004, total live vegetation cover and precipitation in months preceding vegetation sampling were highly correlated (preceding four months: r=0.97; preceding six months: r=0.95; preceding twelve months: r=0.89). Also in this timeframe, forage production and species density were highly variable, both in value and correction with precipitation. When 2005 data were included, all correlations decreased, and correlations between forage production or species density with precipitation decreased notably.
Implications: Long-term datasets can be used to build models that incorporate climate variation into reclamation technical revegetation standards. However, these models may still be inaccurate, especially in years with unusual precipitation. Longer monitoring programs (>30 years) may be needed to fully capture climate variation and predict vegetation standards.
Topics: Mining, Vegetation Recovery Data, Reclamation Monitoring, Reclamation Standards, GrayLit

Burnett, D.B., McDowell, J., Scott J.B., and Dolan, C., 2011, Field site testing of low impact oil field access roads—Reducing the environmental footprint in desert ecosystems, *in* Society of Petroleum Engineers (SPE) Americas Exploration and Production (E&P) Health, Safety, Security, and Environmental Conference, Houston, Tex., March 21–23, 2011: Society of Petroleum Engineers.

DOI: https://doi.org/10.2118/142139-MS
Background: Energy development in ecologically sensitive desert locations can negatively affect the environment along lease roads and around well pads. To address environmental concerns, new materials for low impact access roads were tested to reduce the surface footprint of drilling operations. These could potentially reduce environmental restrictions and be less expensive than conventional roads.
Objectives: The authors assessed the effectiveness of new road technologies and evaluated and reported the success of different road types to accelerate the commercial development of new road technologies.
Methods: Three road alternatives were tested: (1) removable composite mats as temporary road and pad materials, (2) recycled well site waste as base roads, and (3) roll-out roads and mats. Performance of each alternative was monitored with respect to the durability and strength of roads and the environmental impact on soils.
Location: Proving Grounds Research Facility at Texas A&M Transportation Institute in Jeff Davis County, Texas, USA

Findings: The road base made from recycled well material and the rigid mat design performed well, however the roll out road requires modification.
Implications: Alternative "disappearing roads" have great potential for use in energy development. However, further field testing is necessary in more rigorous conditions of existing designs, and remediation needs under these alternative roads need to be assessed.
Topics: Road, Reclamation Practices, GrayLit

Cairns, J., Jr., 1983, Management options for rehabilitation and enhancement of surface-mined ecosystems: Minerals and the Environment, v. 5, p. 32–38.

DOI: https://doi.org/10.1007/BF02092249
Background: Surface-mined land can be managed post-mining following four basic options: (1) restoration to the pre-mine condition, (2) rehabilitation of certain desired land characteristics, (3) development of functional and preferred alternative ecosystems that do not match pre-mine conditions, or (4) neglect or natural reclamation in the case unaided management would be satisfactory. These options require careful consideration to ensure long-term ecosystem function. Developing a framework for selecting the most appropriate land management option is important for post-mine land management success.
Objectives: The author discussed and compared the four basic management options for surface-mined land through a systematic selection approach.
Methods: The author provided an overview of the four basic post-disturbance management options: (1) restoration, (2) rehabilitation, (3) development of alternative ecosystems, and (4) neglect or natural reclamation. They discussed perturbation-dependent/independent ecosystems and how that affects option selection. They presented a data-based checklist for management option and additional checklists (with discussion) for each option. They finished the paper with suggests for future surface-mined reclamation decision making and possible obstacles.
Location: This is a methods paper and does not involve a specific field site location
Findings: Perturbation dependent and independent ecosystems require differing land management techniques to ensure desired productivity and species diversity are attained. Restoration is the preferred option for novel and threatened ecosystems, but rehabilitation can be equally successful for less sensitive ecosystems. Developing an alternative ecosystem provides land managers and ecologists more creativity when restoration and rehabilitation are too costly, time intensive, or may not be successful in the long-term due to mining activities. Natural reclamation may be most appropriate if current methods of human reclamation could be more environmentally detrimental.
Implications: Perturbation dependency is a crucial factor for land managers to consider before selecting a post-mining management option. Management option selection should be based on data and site-specific needs. Cooperation among land managers and Federal and environmental agencies is necessary for successful long-term management results.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, Reclamation Standards, Decision Support Tools

Cannon, K.R., and Landsburg, S., 1990, Topsoil stripping in potentially arable forested luvisols—A literature review: Alberta Gas Transmission Division (AGTD) Environmental Research Monographs 1990-2, 38 p.

Link (non-DOI): https://era.library.ualberta.ca/items/092fcf67-cd69-4adf-8c98-6c256033706d
Background: Alberta, Canada has rich oil and natural gas reserves highly sought after for economic profit. Pipeline construction is widely accepted, but the effects of such construction on agricultural, forested, and arable soil quality is unknown. Few studies have documented the effects of pipeline construction methods (stripping or not stripping) on Luvisolic soils, especially given the marginal quality of such topsoil. Understanding these effects on luvisols is important for reclamation and post-mine land use success.
Objectives: The authors reviewed literature on the effects of stripping and not stripping topsoil in currently forested Luvisolic soils with the potential for cultivation.
Methods: A literature review was conducted covering Luvisolic soil characteristics and cultivation, pipeline construction methods, and soil conservation methods. The review also covered the impacts of pipeline construction on soil mixing, soil compaction, soil chemistry, water properties, erosion, weeds, and crop yield. The potential impacts of pipeline construction on Luvisolic soils were discussed.
Location: This is a literature review and does not involve a specific field site location

Findings: Topsoil conservation of Luvisolic soils may not be necessary as it could result in horizon characteristics similar to the plough depth of cultivated Luvisols, which tend to crust, have low water holding capacity, and exhibit low productivity. By not stripping topsoil, and allowing it to mix with the subsoil, soil conditions could improve in these situations. However, more research is needed to support these hypotheses and determine in-field effects of pipeline construction on Luvisolic soil physical and chemical properties and soil quality.
Implications: This review is a useful reference for land managers looking to reclaim Luvisolic soils. Understanding the potential consequences of pipeline construction may inform reclamation planning.
Topics: Pipeline, Soil Data, Reclamation Practices, GrayLit

Carlson, K.E., Radil, A.C., and Romig, B.R., 2006, Biosolid applications at the Climax Mine—Revegetation and soil results, *in* Keammerer, W.R., ed., High Altitude Revegetation Workshop No. 17, Fort Collins, Colo., March 7–9, 2006, Proceedings: Colorado Water Resources Research Institute Information Series 101, p. 75–88.

Link (non-DOI): https://watercenter.colostate.edu/wp-content/uploads/sites/33/2020/03/IS101.pdf
Background: Successful reclamation of mine tailings requires neutralizing acidic conditions and adding organic amendments to create an environment more conducive for revegetation. Reclamation can be complicated by climatic and additional environmental conditions, such as rocky, nutrient poor soil. Using biosolids as amendments is a cost-effective method for restoring nutrients to mine tailings while facilitating sound disposal of sewage waste. The Phelps Dodge Climax Molybdenum Company, in collaboration with Habitat Management, Inc., utilized biosolids and lime to assist with revegetation of molybdenum mine tailings.
Objectives: The authors tested, monitored, and evaluated the effects of a one-time application of biosolids, lime, and seed mixtures on revegetation and soil conditions of molybdenum mine tailings.
Methods: Seven biosolid application units were established on capped mine tailings and treated with 20–30 dry metric tons (t) biosolids per acre (ac) and 30 t/ac of lime. They were seeded in accordance with the site's reclamation permit. Vegetation cover, shrub density, and production along five randomly placed 50 meter (m) transects in each unit was sampled. Soil samples were collected at 0–6 inches (in) and 6–12 in depth intervals at the start of each vegetation transection and analyzed for general properties. Data were analyzed with analysis of variance (ANOVA).
Location: Climax Molybdenum Mine near Leadville, Colorado, USA
Findings: In general, total vegetation cover and production increased with time since biosolid application and was dominated by grasses. Vegetation nutrient content also increased over time. Soil pH and harmful mineral content decreased over time.
Implications: A one-time biosolids application can aid in revegetation and improve soil quality on reclaimed molybdenum mine tailings. Biosolids should be considered in respect to site-specific conditions as a tool that could increase successful reclamation outcomes.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Carr, R.S., III, Sewell, H.J., Davison, A., and Steinbacher, J., 2008, Restoring sage grouse habitat in the Pinedale Anticline gas field, WY—A Shell/BLM revegetation pilot project, *in* Brummer, J.E., ed., High Altitude Revegetation Workshop No. 18, Fort Collins, Colo., March 4–6, 2008, Proceedings: Colorado Water Resources Research Institute Information Series no. 107, p. 329–359.

Link (non-DOI): http://hdl.handle.net/10217/69248
Background: One of the more controversial issues involved with current natural gas exploration and development in the Green River basin of western Wyoming is the destruction of the native sagebrush-grassland ecosystem and the associated sage grouse and ungulate habitat. Reclamation using the required Bureau of Land Management (BLM) seed mix has resulted in patchy grass-dominated areas interspersed with older sage-dominated rangelands; disturbed areas are still highly visible,

and reestablishment of healthy sagebrush communities is several decades away. In 2004, Shell Rocky Mountain Production Company in collaboration with the Wyoming BLM Pinedale Field Office initiated the "Shell/BLM Pinedale Anticline Revegetation Pilot Project" to improve reclamation efforts and sage grouse habitat across the Pinedale Anticline gas field.
Objectives: The authors reintroduced native plant species to interim reclaimed drill locations across the Pinedale Anticline gas field to improve sage grouse and ungulate habitat. An additional project goal included testing the cost-effectiveness of hydroseeding drill pad slopes to reduce erosion (results not discussed in this article).
Methods: From 2004–2007, a total of 13 well pads across 20 miles of the Pinedale Anticline gas field were seeded for reclamation. Seven were newly reclaimed, all seeded in 2004; three were hydroseeded, and four were drill seeded. Two of the drill-seeded pads received no soil amendment, one received an organic soil amendment, and one was split, with half receiving an organic soil amendment and half not. An additional six previously reclaimed locations were reseeded in 2005, 2006, and 2007, three of which received added soil amendment, and two of which were fenced in. Quattro Environmental, Inc. provided the soil amendments used in the study. They created three amendment blends containing various ratios of "Fertil-Fiber," "Kiwi Powder," "Cliffhanger Tak," humic shale, gypsum, agricultural lime, and organic compounds containing nitrogen (N), phosphorous (P), magnesium (Mg), sulfur (S), zinc (Zn), and manganese (Mn); the blend used at a specific site were based on the soil data available for that location. Vegetation emergence and growth was monitored annually from 2005 to 2007 along randomly placed transects and 50 square centimeters (cm^2) quadrats. Permanent 1 square meter (m^2) photo plots were established for annual comparisons. Seeded additional locations in 2005, 2006, and 2007.
Location: Pinedale Anticline gas field in the Green River basin in western Wyoming, USA
Findings: This article summarizes results for the sites seeded in 2004 only as this was an ongoing project at time of publication. Record high precipitation the year following seeding resulted in highly successful seeding, including sagebrush and forbs, important species for wildlife; specific species establishment varied by site. Soil amendment benefits are not clear; seeding was successful at two sites without amendments (likely due to existing high-quality soil conditions). Fencing resulted in more successful native plant establishment. Overseeding on previously reclaimed grass-dominated sites has had little impact. Pellet counts revealed habitat use by sage grouse, rabbits, small rodents, and ungulates.
Implications: While still ongoing at the time of publication, preliminary results suggest that critical sagebrush habitat can be reestablished despite grass-dominated reclamation results.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Carrick, P.J., and Krüger, R., 2007, Restoring degraded landscapes in lowland Namaqualand–Lessons from the mining experience and from regional ecological dynamics: Journal of Arid Environments, v. 70, no. 4, p. 767–781.

DOI: https://doi.org/10.1016/j.jaridenv.2006.08.006
Background: Diamond mining has surpassed other mineral mining, livestock grazing, and cereal cropping as the leading cause of land degradation in Namaqualand, South Africa. Restoration was limited prior to 1992 but has since become more common. However, climatic (for example, low rainfall, high winds) and environmental (for example, poor soil nutrients, poor seed bank) conditions, and the interactions among them, greatly complicate restoration efforts. A high number of drought tolerant and succulent species may provide opportunities for successful restoration.
Objectives: The authors discussed the history of mining in Namaqualand, South Africa, and presented future possibilities for improved restoration and mining practices.
Methods: The authors summarized a brief history of mining in Namaqualand. They discussed autogenic recovery as it relates to vegetation and rainfall, and restoration as it relates to soil relocation, landscaping, and the impact of wind. They outlined the importance of topsoils, mined soils, and soil processes and their interactions with seedbanks, seeding, and transplanting. Finally, they highlighted possible future research avenues to improve restoration and mining practices.
Location: This is a review of mining in Namaqualand, South Africa and does not involve a specific field site location
Findings: While mining of copper has occurred in Namaqualand since 1850, the recent increase in diamond mining has taken a toll on the land. Low annual rainfall leads to failure of plant reestablishment, and the use of nonnative species requires resource-intensive irrigation. Wind greatly influences the landscape, making topographical restoration difficult. Poor topsoil with a limited seedbank increases the need for soil amendments and transplanting.
Implications: Research into the dynamics of Strandveld and Succulent Karoo ecosystems would increase the potential for successful restoration. Mine operators can improve mining reclamation practices by including a commitment to restoration standards and by engaging in open communication with environmental organizations.
Topics: Mining, Reclamation Theory, Reclamation Practices

Chambers, J.C., 2000, Seed movements and seedling fates in disturbed sagebrush steppe ecosystems—Implications for restoration: Ecological Applications, v. 10, no. 5, p. 1400–1413.

DOI: https://doi.org/10.1890/1051-0761(2000)010[1400:SMASFI]2.0.CO;2
Background: This study examined the soil surface characteristics and seed morphology on seed entrapment and retention, and the effects of soil surface characteristics on soil water potential and seedling emergence and survival. An experiment with various manipulations to soil surface was installed at a reclamation site in Wyoming.
Objectives: The author investigated a variety of treatments and soil types for trapping and retaining seeds at a highly degraded site. In addition, the author investigated how various treatments affect soil moisture.
Methods: At a coal mine reclamation site, several treatments were installed which examined the effects of soil, mulch, small and large holes, and shrub mimics. Data were collected on soil water potential, seed entrapment and retention, seedling emergence, and species survival.
Location: Kemmerer, Wyoming (41°43′ N., 110°37′ W.; elevation 2,240 meters [m]), USA
Findings: Large holes or pits were better than small holes, gravel layer, or shrub mimics. Soil and a layer of sand had the smallest effect on seed retention, and surface mulch neither gained nor lost seeds. Treatments that retained seeds also increased soil moisture. Gravel mulch was ineffective, shrub mimics and small holes accumulated fine-textured soils and had low soil moisture. If a seedling emerged, the probability of survival was just over 50 percent after 2 years of monitoring.
Implications: Seed entrapment and survival is highly dependent on soil surface characteristics and seed morphology. Soil surface characteristics that improve seed entrapment and retainment don't necessarily increase soil moisture. The effects depend on seed morphology: appendages and size. These results show that retaining seeds and increasing soil moisture create favorable conditions for seed germination and seedling establishment.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices

Chambers, J.C., Brown, R.W., and Williams, B.D., 1994, An evaluation of reclamation success on Idaho's phosphate mines: Restoration Ecology, v. 2, no. 1, p. 4–16.

DOI: https://doi.org/10.1111/j.1526-100X.1994.tb00037.x
Background: Assessing reclamation success requires determining if the structure and function of the reclaimed ecosystem are on a trajectory toward reclamation goals. One common method of assessment is comparing reclaimed sites to undisturbed reference sites nearby. While these comparisons are often made within short timeframes (3–10 years after reclamation), monitoring over longer periods of time (>10 years after reclamation) may be more informative as vegetation and soil structures take time to develop and stabilize.
Objectives: The authors assessed reclamation success on the Wooley Valley phosphate mine by comparing data collected 4 and 14 years after reclamation and evaluated differences between the short- and long-term monitoring timeframes.
Methods: Reclamation of the Wooley Valley phosphate mine was initiated in 1977 and involved two soil types (spoil and topsoil) and three treatments (seed+mulch, seed only, and no seed or mulch [control]) that were randomized within soil types and replicated twice. In 1991, a reference area approximately 200 meters (m) from the reclaimed area was selected for comparison. In 1981 and 1991, 0.25 square meter (m^2) quadrats were used to measure species composition and standing crop biomass in the reclaimed and reference (1991 only) areas. In 1991, soil samples were collected at 0–2 centimeters (cm) and 10–20 cm depth intervals from the reclaimed and refence areas and evaluated chemical, physical, and elemental properties. Data were compared among the reclaimed treatments and between the reclaimed and reference areas using analysis of variance (ANOVA).
Location: Wooley Valley phosphate mine (42°48¢ N., 111°22¢ W.; elevation 1,624 m) in southeastern Idaho, USA
Findings: Four years after reclamation, biomass did not differ between soil types or treatments. After 14 years, biomass did not differ between soil types but there were significant differences among treatments (though across all treatments perennial grasses and the perennial legume *Medicago sativa* were important biomass components). Biomass did not differ significantly between sampling times and was higher on the reclaimed compared to reference area (in 1991). In 1991, vegetation cover was highest in the reference area and higher on topsoil compared to spoil plots in order of control, seed only, and seed+mulch treatments; there was no difference in cover between the seed+mulch treatment and reference area. After 14 years, the topsoil control treatment

and reference area had the most similar vegetation. Soil characteristics were similar between reclaimed soil types and differences were influenced more by treatment. The reclaimed area had lower organic carbon (C) and total nitrogen (N) compared to the reference area (except the seed+mulch treatment).
Implications: Reclamation methods used at the Wooley Valley phosphate mine resulted in reclaimed areas that were not similar to a native reference area, differences that are apparent even 14 years after reclamation. Reclaimed areas had higher biomass, but fewer native species compared to reference areas. Land managers should carefully consider reclamation methods, and how they may interact with native and non-native species, to ensure desired outcomes are achieved.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Chenoweth, D., Schneider, J., and Reid, C., 2012, Kern River natural gas pipeline expansion—A case study in overcoming adversity on a mountainous lineal reclamation project, *in* Barnhisel, R.I., ed., the American Society of Mining and Reclamation 29th Annual National Conference, Tupelo, Miss., June 8–15, 2012, Proceedings: American Society of Mining and Reclamation, p. 82–94.

DOI: https://doi.org/10.21000/JASMR12010082
Background: Pipeline reclamation projects can pose difficult obstacles because of their size, the rugged terrain they cross, and short project timelines. This is a report that outlines reclamation goals and management decisions for a challenging pipeline reclamation project.
Objectives: The short-term reclamation objectives were to reestablish landscape contours and hydrologic patterns, minimize on-site erosion and off-site sedimentation, reestablish vegetative communities, replace or enhance wildlife habitat, and establish vegetation monitoring stations. The long-term objectives were to stabilize soil, establish sustainable vegetative cover, monitor sites for three years, maintain and repair sediment and erosion controls, and restore water resources.
Methods: Reclamation techniques were delineated by steepness of slope. On slopes less than 30 percent, techniques included soil preparation, drill seeding, straw mulch, and crimping. On slopes 30–50 percent, techniques included hand broadcast seed, hand raking, and installation of straw erosion control blankets (ECBs) with photodegradable netting. On slopes greater than 50 percent, techniques included hand broadcast seeding, hand raking, and installation of straw coconut ECB with photodegradable netting. Four seed mixes were used based on ecological community: Great Basin sagebrush, riparian and canyon woodlands, wet meadow, and Douglas Fir.
Location: Wasatch Mountain in Morgan, Davis, and Salt Lake counties 28 miles (mi) north of Salt Lake City to 6 mi south of Henefer, Utah, USA
Findings: The project area was 390 acres and cost $2,500,000. One-hundred seventy-five acres were covered with an ECB and 215 acres were covered in straw mulch; this required two helicopters, six all-terrain vehicles, and up to 100 employees a day. The project was completed on time over the course of four months.
Implications: It is important to ground validate access to a pipeline prior to reclamation. Flying, driving, and hiking a pipeline before beginning operations is essential for understanding transportation needs. Working with union workers requires additional administration but is worthwhile after some time investment. Communication between managers is essential to meet rigid timelines and troubleshoot problems early on.
Topics: Pipeline, Reclamation Practices, GrayLit

Chesapeake Energy Corporation and Douglas Core Area Restoration Team, 2014, Plan for the development of oil and gas resources within a sage-grouse core population area: Wyoming Game and Fish Department, Douglas Core Area Restoration Team, Annual Report, 37 p.

Link (non-DOI): https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Sage%20Grouse/SG_DCAREPORT_2014.pdf
Background: In 2008, the State of Wyoming implemented a Core Population Area Strategy to preserve greater sage-grouse (*Centrocercus urophasianus*) populations and habitat. In 2013, the Chesapeake Energy Corporation (Chesapeake) implemented plans for energy resource development within the Douglas Sage-Grouse Core Population Area (Area). To ensure oil and natural

gas operations did not threaten sage-grouse populations, a plan was drafted and approved by the State of Wyoming in 2013 to provide for energy development while protecting and restoring sage-grouse habitat for long-term species health. Chesapeake voluntarily implemented the plan in 2013.
Objectives: The authors presented Chesapeake's 2013–2014 progress on commitments in the 2013 plan to mitigate negative consequences of energy development on sage-grouse populations and habitat.
Methods: This report outlines Chesapeake's plan compliance regarding avoiding key habitat areas, minimizing impacts, and mitigating/restoring suitable habitat. Performance monitoring was reviewed, including baseline vegetation surveys, habitat restoration monitoring, sage-grouse lek monitoring, and adaptive management strategies. Fund investments, expenditures, and additional expenses were also summarized.
Location: Douglas Sage-Grouse Core Population Area, Wyoming, USA
Findings: During 2013–2014, disruption density across the Area increased by only 0.04 (+2.0 percent surface disturbance), most of which occurred in Area B and none in Area A (the highest quality sage-grouse habit). Male sage-grouse were detected in the Area followed patterns observed state-wide, indicating there was no apparent negative effect on sage-grouse due to energy development in the Area. Native sagebrush seed was harvest and propagated for future restoration project use. About 1.34 acres of sagebrush habitat was being restored at the time of publication with an additional 4 acres slated for fall 2014.
Implications: This report is a useful case study for land managers and conservation groups and highlights how energy development can successfully mitigate negative impacts to sensitive wildlife species and encourage species conservation.
Topics: Well Pad, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Claassen, V., 2000, Organic amendments for revegetation of drastically disturbed soils, *in* Keammerer, W.R., ed., High-Altitude Revegetation Workshop No. 14, Fort Collins, Colo., March 8–10, 2000, Proceedings: Colorado Water Resources Research Institute Information Series no. 91, p. 146–156.

Link (non-DOI): http://hdl.handle.net/10217/3160
Background: Topsoil horizons are a necessary source of nutrients for vegetation, but these horizons are removed during disturbances, such as road construction. As a result, disturbed sites like roadsides lack nutrients (for example, long-term nitrogen [N] sources) required for successful revegetation. Composted materials are a potential source of N and other nutrients and may serve as a topsoil replacement at disturbed sites during revegetation efforts.
Objectives: The author (1) evaluated the effectiveness of California green materials compost as a primary erosion control material and nutrient source for sustainable revegetation of highly disturbed and degraded soils, and (2) reported these findings to the California Department of Transportation for developing specifications for compost use in roadside revegetation.
Methods: Twenty-three commercially produced green compost materials were sampled in December 1998–January 1999, including yard waste, co-composted materials (for example, yard waste and biosolids), agriculture byproduct composts, and grape pomace/prunings; one sample was also from un-composted green material. One composite sample was created from four, 4 L subsamples taken throughout each pile. A standard collection protocol was followed, that included subsamples be collected a minimum of 50 meters (m) apart, at 1 m depths, and 1–3 m from the base of the pile. The temperatures of the piles were measured at the time of sampling to determine if they were respiring or cooled off. Collected samples were submitted for commercial compost analysis of nutrient content, nutrient availability, total exchangeable cations, percentage of water equal to half of the saturated capacity, electrical conductivity, and physical characteristics. Sample analysis results were summarized by compost source material category (green material compost, biosolids/green material co-composts or agricultural byproduct composts).
Location: Twenty-three composting, recycling, and refuse centers across California, USA
Findings: Green compost had lower salinity than co-composted materials or agriculture byproducts. Total N and extractable N were highest in co-composted materials, though N assay variability among sources was moderate to high. Agriculture byproduct had the highest potassium and sodium content. All sample categories had below legal limits for copper and zinc. Overall, total N for green compost should be sufficient for revegetation efforts, but further analysis is necessary.
Implications: Green or co-composted materials can serve as potential topsoil replacement for revegetation of disturbed roadsides; however, further analysis and improved methods are needed.
Topics: Road, Reclamation Practices, Soil Data, GrayLit

Claassen, V., 2006, Soil compaction effects on slope stability and root growth—An article review, *in* Keammerer, W.R. ed., High Altitude Revegetation Workshop No. 17, Fort Collins, Colo., March 7–9, 2006, Proceedings: Colorado Water Resources Research Institute, Information Series no. 101, p. 98–100.

Link (non-DOI): https://watercenter.colostate.edu/wp-content/uploads/sites/33/2020/03/IS101.pdf
Background: Revegetation of slopes and banks following energy development reclamation is affected by soil compaction. Depending on profession and training, standards of ideal soil compaction parameters may differ. Understanding varying research perspectives can assist land managers in selecting soil compaction parameters that best fit their reclamation objectives.
Objectives: The author reviewed several differing research perspectives on soil compaction to provide land managers a resource when deciding how to balance slope stabilization and revegetation goals.
Methods: The authors reviewed and summarized previous research on the effects of varying degrees of soil compaction on plant growth and slope stabilization. They discussed methods of achieving a balance among soil compaction, slope stabilization, and revegetation.
Location: This is a review article and does not have a specific field site location
Findings: In general, geotechnical engineers aim for the highest soil compaction possible, agronomists aim for the least soil compaction necessary, and bioengineers strive for a middle ground by using plant materials for slope stabilization. Excessive soil compaction (82–91 percent of standard Proctor densities) can limit root growth, however moisture level can be used to mitigate negative impacts on plants while still achieving desired soil densities. Roughing the soil surface or adding coarse textured materials can also increase plant growth while achieving soil densities.
Implications: Soil compaction parameters vary by scientific discipline. Methods have been suggested for balancing desired soil density and revegetation, though more research is needed how these methods actually affect plant growth and survival. Land managers should research best practices based on their site-specific needs.
Topics: Mining, Reclamation Practices, Soil Data, GrayLit

Cockrell, J.R., Schuman, G.E., and Booth, D.T., 1995, Evaluation of cultural methods for establishing Wyoming big sagebrush on mined lands, *in* 12th Annual Meeting of the American Society of Mining and Reclamation, Gillette Wyo., June 3–8, 1995, Proceedings: American Society of Mining and Reclamation, v. II, p. 784–795.

Link (non-DOI): https://www.osti.gov/biblio/98686
Background: Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) is a widely adapted subspecies throughout the state and western U.S. and its reestablishment is required for successful mine site reclamation. Unfortunately, a number of factors complicate reestablishment. Testing various reclamation methods can be useful in determining the most effective practices for sagebrush restoration.
Objectives: The authors evaluated the role of competition in sagebrush establishment, and the effects of different reclamation methods, including direct-applied topsoil, stock-piled topsoil, vesicular-arbuscular mycorrhiza (VAM) inoculum, and mulch types.
Methods: One of three treatments were applied to coal mine spoil: (1) topsoil management, (2) mulch type, and (3) two levels of competition: drill seeded perennial grass mix or no seeding. All plots were broadcast seeded with sagebrush. Baseline soil characteristics and VAM spore levels were recorded. Sagebrush seedling numbers were counted plants were collected outside the plot quadrats for evaluating mycorrhizal infection. Data were analyzed using analysis of variance (ANOVA).
Location: North Antelope Coal Mine, approximately 100 kilometers (km) south of Gillette, Wyoming, USA
Findings: VAM differed, though less than expected, between stockpiled and fresh topsoil. A significant interaction (topsoil management × mulch type × grass competition) best explained sagebrush seedling densities, which differed temporally. Mulch type was important for sagebrush seedling densities early in the study while grass seeding competition negatively impacted densities throughout the study. However, over time, sagebrush seedling densities were less responsive to treatments.
Implications: Wyoming big sagebrush reestablishment is affected by topsoil management, mulching, and herbaceous competition. Mine site reclamation should use fresh stripped topsoil, apply mulch, and sow sagebrush seed in islands or strips with no herbaceous competition to ensure the greatest chance of sagebrush reestablishment.
Topics: Mining, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Cooke, J.A., and Johnson, M.S., 2002, Ecological restoration of land with particular reference to the mining of metals and industrial minerals—A review of theory and practice: Environmental Reviews, v. 10, no. 1, p. 41–71.

DOI: https://doi.org/10.1139/a01-014
Background: Restoration planning models are necessary to ensure methods are appropriate and objectives are met. Ecological knowledge of ecosystem levels and organization can enhance restoration planning and overall outcomes. Post-reclamation monitoring is a key step for improving restoration theory and practice. Adopting the concept of adaptive management and conceiving restoration sites as long-term experiments can also improve restoration planning.
Objectives: The authors present a model of restoration planning for ecological restoration in mining and use examples and case studies to explore the problems and solutions of restoring metal and mineral mines.
Methods: The authors outlined the history and direct impacts of mining on a global scale. They discussed the concept of ecological restoration compared to reclamation and the assumptions of each for the post-mining ecosystem. They reviewed restoration planning and discussed global examples where topsoil had been either retained or lost. Finally, they discussed future prospects of integrating theory and practice to improve restoration planning and outcomes.
Location: This is a review paper and does not involve a specific field site location, though examples discussed include mining in Tasmania, Kenya, western Europe, South Africa, and Australia
Findings: Ecological restoration requires an orderly set of considerations for developing successful procedures and practices that incorporate site-specific needs. Mining substrates and wastes are highly toxic with poor nutrients, creating harsh conditions for vegetation establishment without restoration intervention. Relying on natural succession entirely will likely result in landscapes quite different from those pre-mining. Successful restoration can be achieved, especially through adaptive management. Although a post-mining landscape may not be identical to the pre-mining landscape, well planned ecological restoration can still result in a functioning and self-sustaining ecosystem. Future restoration planning must carefully consider the increasing scale of mining and sustainable development.
Implications: This review is helpful for land and reclamation managers interested in employing ecological restoration methods on previously mined lands, especially metal or mineral mines.
Topics: Mining, Reclamation Theory, Reclamation Practices, Reclamation Monitoring, Decision Support Tools

Creasey, R., and Fischer, L., 2004, Reduction of footprint and restoring of function—An approach to cumulative effects management, *in* Society of Petroleum Engineers (SPE) International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Calgary, Alberta, March 29–31, 2004: Society of Petroleum Engineers, no. SPE-86686-MS.

DOI: https://doi.org/10.2118/86686-MS
Background: Oil and gas development disturb the environment in various ways such as the construction of access roads, pipeline rights of way, power lines, and seismic lines. These linear disturbances lead to a cumulative disturbance on the ecosystem, which is difficult to manage due to lacking regulations. Shell Canada attempts to reduce its cumulative disturbance at oil and gas operations and, when possible, adopt a "no net increase" in development of new linear disturbances.
Objectives: The authors reviewed examples of Shell Canada's implementation of best practices that reduce the company's cumulative disturbance effects on developed and surrounding lands.
Methods: The authors review how Shell Canada is reducing the cumulative effects of its seismic operations, well site and facility construction, access road management, and integrated planning. They discussed examples of "low impact" techniques and methods for reducing the environmental impact of energy operations.
Location: This is a review of practices and does not involve a specific field site location
Findings: Oil and gas development has led to negative environmental impacts that persist years into the future. Companies can reduce their cumulative effect by reducing the construction of wide, linear pathways through the natural environment and adopting "low impact" techniques (for example, helicoptering in seismic materials and people to reduce road construction through remote and environmentally sensitive areas or reducing the footprint and edge effect of well sites by constructing well pads that mirror natural disturbances). Managing public access along existing linear features, such as access roads, is important

for reducing further environmental damage. Integrating environmental awareness into the planning of future operations and working with stakeholders who also use the land (for example, the forest service), can reduce cumulative effects and lead to more environmentally sustainable development.
Implications: Oil and gas companies have a responsibility to reduce their cumulative effects on the environment by developing as little infrastructure as necessary. Engaging multiple stakeholders and conservation organizations can lead to best practices for more sustainable energy development.
Topics: Road, Well Pad, Pipeline, Reclamation Theory, GrayLit

Cude, S.M., Ankeny, M.D., Norton, J.B., Kelleners, T.J., and Strom, C.F., 2018, Capillary barriers improve reclamation in drastically disturbed semiarid shrubland: Arid Land Research and Management, v. 32, no. 3, p. 259–276.

DOI: https://doi.org/10.1080/15324982.2018.1448903
Background: Surface soil salinity, sodicity, and crusting (due to salinization) can inhibit plant establishment in reclamation revegetation efforts. Semiarid ecosystems typically have thin surface horizons with more plant nutrients, greater water infiltration rates, and lower salinity. However, mixing subsoils with surface horizons, as occurs in mining operations, increases soil salinity, sodicity, and crusting and negatively impacts plants.
Objectives: This study evaluates three methods to retain water and reduce salt concentrations in the soil: (1) basin and pits (2) sand mulch above seeded soil basins, and (3) capillary barriers beneath seeded soil basins.
Methods: Two study sites were established on natural gas well pads representative of a ridge site and a depression site. At the sites, pits were dug, and one of five treatments was applied: capillary barrier, mulch, dual barrier, dual barrier with wicks, or a control. A salt tolerant grass and forb mix was broadcast across each experiment. Twenty-one Decagon soil sensors were installed to measure soil moisture, temperature, and soil electrical conductivity (EC). Plant data were recorded four times during the first year of the study, including the number of grass plants (density) and maximum leaf length in each of the nine pits per plot and across the control plot. The soils in the seeded area and below the capillary barriers were sampled at one of nine pits at each replicate to determine salinity and water retention.
Location: Two natural gas well pads (ridge site: 41°37′32.45″ N., 108°1′19.50″ W.; depression site: 41°38′14.70″ N., 107°59′48.87″ W.) on private land near Wamsutter, Wyoming, USA
Findings: Soil texture, salinity, landscape position, and local variability in rain and snowfall may explain variability in success of treatments at the two sites. Sand mulch treatments significantly increased the density of new grass growth at both study sites compared to control plots. The mulch treatment resulted in the highest grass density at the ridge site. At the depression site, dual barrier and mulch treatments performed better than the control and treatments without mulch or capillary barriers. Capillary barriers reduced or limited salinization of the soil above the barrier. Mulched and dual barrier treatments become wet faster and dry out faster. At the depression site, mulching increased water availability and improved vegetation establishment.
Implications: This study showed that increased snow capture and capillary barriers, and not sand mulches, were the primary drivers in changing EC. While mulch increased EC, with adequate water plants were still able to germinate effectively. The authors predict that mulch and dual barrier treatments would enhance Wyoming big sagebrush, a key species of the sagebrush-steppe ecosystem. Sand mulch and dual barriers should be incorporated into reclamation practice.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices

Curran, M.F., Cox, S.E., Robinson, T.J., Robertson, B.L., Rogers, K.J., Sherman, Z.A., Adams, T.A., Strom, C.F., and Stahl, P.D., 2019, Spatially balanced sampling and ground-level imagery for vegetation monitoring on reclaimed well pads: Restoration Ecology, v. 27, no. 5, p. 974–980.

DOI: https://doi.org/10.1111/rec.12956
Background: Natural gas development reclamation efforts in Wyoming involve multiple agency and inter-agency stakeholders with varying criteria defining successful reclamation. Typically, multiple field technicians, with differing degrees of skill, collect field data that are used to compare reclaimed well pads with reference sites using Daubenmire frames, ocular estimates, and line point intercept methods. However, there are few procedures in place to ensure data are collected correctly. Using a standardized image-based sampling design such as balanced acceptance sampling can reduce observer bias and increase data accuracy.

Objectives: The authors tested data collection with SamplePoint and a balanced acceptance sampling design to assess natural gas development reclamation efforts focusing on the methods' statistical accuracy, ability to meet various criteria, evaluate species presence compared to the seed mix, increase time efficiency, and decrease observer bias.
Methods: Existing reclamation policies for study sites were identified and it was determined whether sites met erosion criteria, vegetation percent cover and presence criteria, and Sage-grouse Executive Order criteria. ArcMap was used to draw polygons for aerial image analyses and generate quasi-random sampling locations at reclamation and reference sites. In-field ground-level images were taken at 1.3 meter (m) high at each predetermined sampling location. SamplePoint 1.59 was used to estimate vegetation cover at sites using a two-stage sampling design (images as primary sampling units and within-image pixels as secondary sampling units). The amount of time taken to analyze images was recorded. Differences between reclamation and reference sites were determined using chi-square analyses.
Location: Gas field oil pads in the Stud Horse Butte area of the Jonah Infill natural gas field in Sublette County, Wyoming, and on private land near Douglas, Wyoming, USA
Findings: Vegetation communities differed significantly between reclamation and reference sites with the differences in ground cover categories varying among reference sites. All sites met existing criteria. At least 50 percent of the seeded species and one species not seeded were present at all sites. Image analysis time averaged 51.2 minutes (min) for Jonah Infill sites and 38.4 min for Douglas sites. Field collection time average was 16.2 min/well pad and 17.7 min/reference location in Jonah and 24 and 25.1 min per well pad and reference in Douglas. By contrast, typical line point intercept methods have been documented to take a 2-person team 99 minutes or more, thus the method proposed here saves a significant amount of field time with 1 person gathering more data in a fraction of the time that a 2-person team typically does with line point intercept.
Implications: The SamplePoint method can increase the number of secondary sampling units of habitat analyzed by tenfold compared to in-field observer data collection, making the method more time efficient and cost effective. SamplePoint can be used to assess multiple criteria at once, but does not capture vegetation height or canopy gap, the importance of which should be considered on a site-by-site basis. The two-stage sampling design increases statistical power, decreases observer bias, and provides geospatial meta-data for ground-truthing questionable data. SamplePoint using handheld imagery is best used when vegetation height is shorter than the observer (who needs to get the camera above the vegetation to take an accurate photo).
Topics: Well Pad, Vegetation Recovery Data, Reclamation Monitoring

Curran, M.F., Cox, S.E., Robinson, T.J., Robertson, B.L., Strom, C.F., and Stahl, P.D., 2020, Combining spatially balanced sampling, route optimization and remote sensing to assess biodiversity response to reclamation practices on semi-arid well pads: Biodiversity, v. 22, no. 4, p. 171–181.

DOI: https://doi.org/10.1080/14888386.2020.1733085
Background: Oil and gas development threatens biodiversity across the western United States. Reclamation efforts need to be as cost effective as possible in order to ensure compliance and reclamation success. Traditional methods for data collection such as line point intercepts are time consuming and do not yield permanent records that can be re-evaluated. Alternative methods, such as balanced acceptance sampling, are known to increase statistical power and streamline data collection while creating geospatially referenced permanent records. The use of an unmanned aerial system (UAS) may further reduce sampling time and observer bias and increase efficiency and reclamation assessment accuracy.
Objectives: The authors evaluated if a UAS could reduce sampling time associated with oil and gas development reclamation assessment data collection without reducing data quality.
Methods: Polygons of reclaimed areas were acquired from Anadarko Petroleum Corporation. Sampling points were balanced within the polygons using the same methods as Curran and others 2019 (https://doi.org/10.1111/rec.12956), and an optimized travel path among points was generated using R. Images at each point were taken by a field technician using a handheld camera at a height of 1.3 meters (m). Aerial images were also collected at a height of approximately 7.6 m via a remote-controlled UAS. The files were transferred from image devices and examined in SamplePoint using 36 pixels to classify vegetation and ground cover (identifying to species when possible). The handheld camera and UAS image results were compared using linear regression, paired t-statistics, and Pearson's correlation coefficient. The amount of time saved via path optimization was also calculated.
Location: Oil and gas well pads on private land near Douglas, Wyoming, USA
Findings: Ground cover comparison across all categories (bare ground, desired grass, forbs, and invasive species) between handheld and UAS imagery never differed >3.5 percent and neither method produced systematically higher or lower percentages. Pearson correlations of ground cover percentages between methods were high (>0.5) except at one site, likely due to low

prevalence of ground cover types. Image analysis time was similar between methods, but the UAS method saved 2 hours of data acquisition time over 5 sites (22 minutes per site). The UAS was more efficient in traveling among sampling points compared to the field technician gathering handheld images.
Implications: Analyzing handheld images collected in-field increases data collection efficiency, accuracy, and statistical power while decreasing observer bias compared to traditional methods. UAS image acquisition further increases data collection efficiency without decreasing data quality. However, species-specific identification is not always possible with UAS and should be considered on a site-by-site basis.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Reclamation Monitoring

Curran, M. and Gasch, C., 2012, Actosol organic humic product—Impacts on plant establishment and soil development: Report prepared for ARCTech, Inc., and University of Wyoming.

DOI: https://doi.org/10.13140/RG.2.2.19551.87208
Background: Revegetating land after mining or energy production is challenging due to changes in soil structure and chemistry, presence of toxins in the soil, and the introduction of invasive species. Plant establishment on reclamation projects with high sodium levels can be improved with soil amendments and increased soil organic matter. Actosol is a commercial soil amendment with organic matter that has the potential to aid revegetation and restore soil properties for reclamation projects.
Objectives: The authors determined (1) if Actosol increased emergence rates and biomass for five grasses, (2) what concentration of Actosol to water is appropriate for optimal growth, and (3) how Actosol affects microbial activity in soils with varying disturbance histories.
Methods: In a greenhouse study the authors sowed four native grass species and a fifth hybrid species in 4-year-old native rangeland stockpiled soil. Each species was subjected to three soil treatments: a control, a 1:20 Actosol to water dilution, and a 1:40 Actosol to water dilution. The authors recorded the date of emergence and total biomass of each plant. To determine how Actosol affected soil microbial activity, phospholipid fatty acid analysis was conducted on three different soils. These soils included the rangeland soil from the greenhouse study, soil from a recent wildfire, and soil from a reclaimed gas pad. Each soil received the same treatments as the plants in the greenhouse study.
Location: Wyoming, USA
Findings: Soil with Actosol 1:20 and 1:40 dilutions increased germination rates and biomass compared to the control. This was true for all species, except slender wheatgrass, which performed the same as the control in the 1:40 dilution, and worse than the control in the 1:20 dilution. Impacts of Actosol on soil microbial activity from the phospholipid-derived fatty acid (PLFA) analysis were inconclusive due to the short timeframe of the experiment.
Implications: Actosol and other soil amendments can support germination and growth of plants on reclamation projects. While soil microbial communities did not differ between treatments, soils treated with Actosol experienced noticeable changes to porosity and color. Future research should quantify the changes to soil structure and associated effects on plant growth.
Topics: Well Pad, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Curran, M.F., Sorenson, J., and Stahl, P., 2019, Rocky Mountain beeplant aids revegetation in an arid natural gas field: Environmental Connection, v. 14, no. 2, p. 27–29.

Link (non-DOI): https://www.researchgate.net/publication/332725803_Rocky_Mountain_Beeplant_Aids_Revegetation_in_an_Arid_Natural_Gas_Field
Background: In Wyoming, successful reclamation of land disturbed by oil and gas development is complicated by an arid cold environment, poor soil quality, invasive weed establishment, and reduced soil organic matter. Seed mixes used for reclamation are often comprised of perennial forbs, grasses, and shrubs. However, the native annual Rocky Mountain beeplant (*Cleome serrulata*) has potential as a beneficial species to include in seed mixes used on reclamation sites.
Objectives: The authors discussed the benefits of Rocky Mountain beeplant as a component of seed mixes used to revegetation of arid lands disturbed by oil and gas development.
Methods: As part of a case study, vegetation monitoring was conducted in 2016 on three well pads previously seeded in 2013 with a species mix comprised of 21 native species, including the annual Rocky Mountain beeplant. These data were compared to monitoring data in adjacent undisturbed reference areas.

Location: Jonah Infill natural gas field, south of Pinedale, Wyoming, USA
Findings: Overall plant cover and native plant diversity was greater, and bare ground less, on reclaimed areas when compared with adjacent reference areas. Specifically, reclaimed areas had greater forb richness and perennial grass richness and density. Thirteen out of 21 species in the seed mix were present on the reclaimed area, including three of the four shrub species.
Implications: When used in reclamation seed mixes, Rocky Mountain beeplant can stabilize soil, increase organic matter inputs, compete with invasive/undesirable species, and establish conditions for other species to take root. Its height and density can also aid in increasing soil moisture retention by capturing snow cover. In addition to benefiting other plant species, the Rocky Mountain beeplant is beneficial for pollinators, which are necessary for success of long-term revegetation efforts on reclaimed gas fields in arid environments.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Curran, M.F., and Stahl, P.D, 2016, Database management for large scale reclamation projects in Wyoming—Developing better data acquisition, monitoring, and models for application to future projects: Journal of Environmental Solutions for Oil, Gas, and Mining, v. 1, no. 2, p. 31–43.

Link (non-DOI): https://www.sciencegate.app/document/10.3992/2377-3545-1.2.31
Background: This paper justifies and provides context for an oil and gas reclamation database curated by the Wyoming Reclamation and Restoration Center. The project is a collaborative effort between the scientific community, industry, environmental consultants, and regulatory agencies.
Objectives: The authors intend for the database to lead to identifying best management practices for reclamation.
Methods: Data collection began from British Petroleum (BP) American Production Company reclamation efforts on Bureau of Land Management (BLM) land in Wyoming. It was expanded to 20 oil and gas companies on over 50,000 acres. The database contains information on oil and gas pads: soil survey, geographic data, historical data on life of well, and elevation. Reclamation information includes seeding information, soil amendments, and herbicide applications.
Location: Jonah Infill and Moxa Arch natural gas fields in Greater Green River Basin of Wyoming, USA
Findings: The database found inconsistencies in monitoring techniques, monitoring timing, and regulatory success criteria across companies, well pads, and years.
Implications: The authors intend for the database to increase understanding of best reclamation practices in different environments and hope to streamline reclamation for industry who often work in multiple jurisdictions with conflicting or non-uniform reclamation standards and guidance. The database has already catalyzed collaborative efforts for standardizing monitoring efforts.
Topics: Well Pad, Reclamation Monitoring, Decision Support Tools

Curran, M.F., Wolff, B.J., and Stahl, P.D., 2013, Demonstration study—Approaching oil and gas pad reclamation with data management—A framework for the future, *in* Barnhisel, R.I., ed., Reclamation across industries, Joint conference, 2nd Wyoming Reclamation and Restoration Symposium and 2013 National Meeting of the American Society of Mining and Reclamation, Laramie, Wyo., June 1–7, 2013, Proceedings: Journal of the American Society of Mining and Reclamation, v. 2, no. 2, p. 195–204.

DOI: https://doi.org/10.21000/JASMR13020195
Background: The increased extraction of natural gas in Wyoming has made it essential to understand the scope and effect of reclamation practices as they can vary from site to site. To address this, the authors created a database to house oil and natural gas pad reclamation data from public and private sources. This database provides a framework that could be adopted over a much greater (for example, nationwide) scale. The intent of the work was to build a tool which allows users to identify and analyze factors influencing reclamation success and failure, as well as provide data to aid decision making for future reclamation projects.
Objectives: The authors outlined the construction and design of the database framework and provided examples of how the database can be implemented.

Methods: A relational database was built to associate multiple datasets pertaining to well pad reclamation practices and reclamation success using Microsoft Access and ArcGIS. Reclamation data spanning eight years (2005–2012) were gleaned from public and private databases associated with two Wyoming production fields, the Jonah Infill and Moxa Arch in the Greater Green River Basin. Well inspection information was attained from Bureau of Land Management (BLM) data management systems, climate data were obtained from Oak Ridge National Laboratory's DAYMET database, and soil survey data were obtained from the Natural Resource Conservation Service's Soil DataMart and Soil Survey Geographic Database. Data were checked for eight standard metrics of quality and accuracy prior to running test queries to assess database's ability to detect patterns in practices deployed and reclamation success across geographic regions.
Location: Jonah Infill and Moxa Arch natural gas fields in the Greater Green River Basin of Wyoming, USA
Findings: Production fields are inconsistent with the timing and methods for monitoring. At one site Daubenmire squares were used in two consecutive years, but a line-transect was used the following two years. The database allowed researchers to quantify reclamation efforts, including disturbance type and extent as well as the seed mixes used. The database also revealed inconsistent regulatory practices. According to the Jonah Interagency Office's reclamation criteria none of the 116 sites in Jonah passed, however 67 of those sites passed the Wyoming Department of Environmental Quality (WDEQ) Storm Water Pollution Prevention Plan.
Implication: Additional data collection is needed to improve management practices. The framework provided has the potential to improve reclamation efforts and adequately track practices and outcomes. For maximum utility, a database framework must be flexible and sharable to enable new data inputs.
Topics: Well Pad, Reclamation Monitoring, Decision Support Tools

Dangi, S.R., Stahl, P.D., Wick, A.F., Ingram, L.J., and Buyer, J.S., 2012, Soil microbial community recovery in reclaimed soils on a surface coal mine site: Soil Science Society of America Journal, v. 76, no. 3, p. 915–924.

DOI: https://doi.org/10.2136/sssaj2011.0288
Background: Mine land reclamation success is often assessed by aboveground biomass and plant community characteristics. However, restoring belowground soil characteristics and processes is essential for successful reclamation. Topsoil removal during mine operations disturbs soil communities, and the respreading of topsoil during reclamation can have adverse effects on soil health. Examining soil microbial communities on reclaimed mine land is necessary to fully assess reclamation success and ensure long-term ecosystem function.
Objectives: The authors observed recovery of soil microbial communities on reclaimed surface coal mines over time and compared reclaimed communities to those in undisturbed soil.
Methods: Two chronosequences were established within two plant communities: sagebrush and cool-season grass, to assess mine reclamation outcomes through time. Within the sagebrush community, sites included mines that were 1.5, 14, and 26 years since reclamation, and one undisturbed site. In the cool-season grass community, sites included mines that were <1, 5, 10, and 16 years since reclamation, plus one undisturbed site. Soils were sampled at each site, by collecting the top five centimeters (cm) from four points along randomly placed 45 meter (m) transects. Phospholipid-derived fatty acids (PLFA) were extracted from the soils using a modified Bligh-Dyer method and assessed by gas chromatography. PLFA signatures were used to quantify microbial groups and data were analyzed using two-way analysis of variance (ANOVA), Tukey's Honestly Significant Difference test, canonical discriminant analysis, and multivariate analysis of variance (MANOVA).
Location: Dave Johnston and Belle Ayr Mines in the Powder River Basin, Wyoming, USA
Findings: Microbial biomass differed between reclaimed and undisturbed sites. For both chronosequences, total PLFA was lowest at the most recently reclaimed site and increased over time. In the grass chronosequences, bacterial and fungal communities had recovered by 14 years post-reclamation and, in the sagebrush, by 10 years post-reclamation. Microbial community structure in grass sites differed more from undisturbed sites than did the structure in sagebrush sites. Similarity across microbial communities in sagebrush sites was also higher than that across grass sites.
Implications: PLFA seemed to have recovered by 10–14 years post-reclamation, indicating that microbial community recovery responded positively to reclamation efforts. However, the resulting plant community structures differed between sagebrush and grass sites, and between reclaimed and undisturbed sites, indicating reclamation did not result in pre-mine conditions.
Topics: Mining, Soil Data, Reclamation Practices

Day, A.D, and Ludeke, K.L., 1986, Reclamation and fertilization of coal mine soils in the southwestern desert: Desert Plants, v. 8, no. 1, p. 20–22.

Link (non-DOI): https://repository.arizona.edu/handle/10150/609071
Background: The Black Mesa Coal Mine in Kayenta, Arizona, is an example of a degraded environment due to surface mining operations. Revegetating the area is desirable but the semiarid environment and low quality mine spoils make revegetation difficult. Fertilizer amendment, both nitrogen (N)- and phosphorous (P)-based, has been shown to improve soil quality and revegetation and may assist revegetation in the mine's semi-arid conditions.
Objectives: The authors evaluated the effects of two soil materials and two fertilizer treatments on seed germination, establishment, growth, yield, and ground cover of five plant species on a reclaimed coal mine in a semiarid environment.
Methods: In 1978, mined and undisturbed sites were selected for a 5-year experiment on factors affecting plant growth. Sites were disked and 50 soil samples were collected at each. A split-split plot design was established, where soil type was a site level factor, fertilizer treatment was the subplot factor, and plant species were sub-subplot factors. For fertilizer treatment, each research site was divided into two areas, one fertilized and one unfertilized. There were five target species in the study: crested wheatgrass (*Agropyron cristatum*), western wheatgrass (*Agropyron smithii*), Indian ricegrass (*Oryzopsis hymenoides*), vernal alfalfa (*Medicago sativa*), and fourwing saltbush (*Atriplex canescens*); each were broadcast seeded in the sub-subplots with a cyclone seeder at a rate of 500 viable seeds per square meter (seeds/m^2). Plants were irrigated the first two years, and plant growth was measured in October for the five years of the study. Data were analyzed using analysis of variance (ANOVA).
Location: Black Mesa Coal Mine near Kayenta in northeastern Arizona, USA
Findings: Unmined soils had more neutral pH, lower electrical conductivity (EC), fewer soluble salts, less N and sodium (Na), more P and potassium, and a lower percentage of organic matter compared to mined soil. Overall, plant growth and forage yield were higher on undisturbed soils. Fertilization improved all plant measurements. Growth, forage yield, and percent ground cover varied widely by species within soil materials and fertilizer treatments.
Implications: Revegetation of disturbed surface mine land in the semiarid southwest can be improved with the addition of fertilizer though results will vary by species. Land managers should assess soil conditions to determine appropriate seed mixes and fertilizer amendment amounts.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Day, A.D, Ludeke, K.L., and Thames, J.L., 1986, Revegetation of coal mine soil with forest litter: Journal of Arid Environments, v. 11, no. 3, p. 249–253.

DOI: https://doi.org/10.1016/S0140-1963(18)31211-4
Background: The Black Mesa Coal Mine in Kayenta, Arizona, is an example of a degraded environment due to surface mining operations. Revegetating the area is desirable but the semiarid environment and low quality mine spoils make revegetation difficult. Forest litter amendment supplies seeds of locally adapted species as well as organic matter that may result in more suitable habitat for successful revegetation efforts.
Objectives: The authors evaluated seed germination, seedling establishment, plant height, and percent ground cover resulting from forest litter applied to coal mine spoils and undisturbed soil in a semiarid environment.
Methods: Forest litter (including surface soils, dead plant and animal material, and local plant species seeds) was collected from Coconino National Forest near Flagstaff, Arizona. Mined and undisturbed sites were selected for a split-split-plot design with soil material (undisturbed or mine spoil) as the main plots, seeding treatment (no forest litter or forest litter) as the subplots, and moisture treatment (natural rainfall or additional irrigation) as the sub-subplots with four replicates. The sub-subplots were disked, fertilized with 560 kilograms per hectare (kg/ha) of 16–20-0 commercial fertilizer, broadcast with forest litter which was hand raked into the top five cm of soil on all plots, and irrigated throughout the growing season. Measurements of seed germination, seedling establishment, plant height, and percent ground cover was measured at the end of each growing season (1977 and 1978). Data were analyzed by analysis of variance (ANOVA).
Location: Black Mesa Coal Mine near Kayenta in northeastern Arizona, USA
Findings: Site variables (temperature, moisture, elevation, and soil) impacted seed germination and growth. Species established at research sites included *Helianthus petiolaris*, *Salsola kali*, *Sporobolus contractus*, *Senecio douglasii*, *Bouteloua gracilis*, and *Chenopodium watsoni* (all of which were present in soil litter except *Helianthus petiolaris*). All measurements were higher in undisturbed soils, plots with forest litter, and irrigated plots. Coal mine spoil with forest litter and irrigation had comparable seed germination, plant height, and percent ground cover to undisturbed soils with forest litter (though seedling establishment was higher in the latter).

Implications: Revegetation of disturbed surface mine land in the semiarid southwest can be improved with the addition of forest litter and irrigation. Land managers should assess soil conditions to determine appropriate soil amendment and irrigation regimes.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Day, A.D., Tucker, T.C., and Thames, J.L., 1979, Russian thistle for soil mulch in coal mine reclamation: Reclamation Review, v. 2, p. 39–42.

Link (non-DOI): https://www.osti.gov/biblio/5365480
Background: Stabilizing soil after mining activities in semiarid regions of the western United States is difficult due to the water-stressed climate. Several studies have shown that mulching soils can help preserve soil-moisture by reducing evaporative loss. Retaining soil-moisture in arid ecosystems could help in the establishment of vegetation and decrease soil erosion potential on disturbed mine sites.
Objective: The authors compared the effectiveness of Russian thistle mulch and barley straw mulch in reducing soil-moisture loss from different soil materials.
Methods: Three different soil materials (coal mine soil, unmined soil, and Red Mesa loam soil) were mulched with coarsely ground Russian thistle mulch, barley straw, or nothing in a 2:1 ratio by volume. The nine treatment combinations were arranged in a randomized complete block design with four replications in 7 centimeters (cm) diameter waxed cups. The experiment was repeated three times in two different environments; Environment I had a temperature of 27 °C and 54 percent relative humidity, and Environment II had a temperature of 21 °C and 75 percent relative humidity. All soil materials stood in a greenhouse for 7 days to attain a uniform moisture content in equilibrium to the greenhouse before the study started. After 7 days, 50 milliliters (ml) of tap water was added to every sample. Total sample weight was recorded immediately after the addition of tap water and for the following six days to monitor the moisture loss for each soil/mulch material.
Location: Tucson, Arizona, USA
Findings: Both barley straw and Russian thistle mulches significantly reduced soil-moisture loss from all three soil types. There were no significant differences between the two mulches in their effect on soil moisture. Approximately 80 percent of soil moisture was lost in the soil materials without mulch in Environment I, compared to 75 percent moisture loss with mulch. In Environment II, although Red Mesa loam soil saw a significantly lower loss in soil moisture without mulch compared to the unmined and coal mine soils, soil moisture loss was significantly reduced by approximately the same degree when mulched.
Implications: Russian thistle and barley straw mulch were equally effective at reducing the loss of soil-moisture in all three tested soils. In the short term, both mulches can help conserve soil-moisture and prevent erosion, and in the long term added organic matter could help improve soil characteristics and vegetation establishment. Russian thistle may be more available and cost effective than barley straw in areas of western United States disturbed by mining activity.
Topics: Mining, Soil Data, Reclamation Practices

Day, S.J., Norton, J.B., Kelleners, T.J., and Strom C.F., 2015, Drastic disturbance of salt-affected soils in a semi-arid cool desert shrubland: Arid Land Research and Management, v. 29, no. 3, p. 306–320.

DOI: https://doi.org/10.1080/15324982.2014.962666
Background: Salvaging topsoil is a common practice in reclamation, but there is little information about how this practice impacts soil properties important for vegetation reestablishment.
Objectives: This study looked at how topsoil salvage impacts soil properties at recently reclaimed well pads.
Methods: Soil texture and chemical properties were compared on eight recently reclaimed well pads compared to paired nearby sites with undisturbed soils. Properties tested included soil organic matter, structure (dry aggregates by weight), electrical conductivity, sodium absorption ratio, and total nitrogen (N).
Location: Great Divide Basin of Wyoming, USA
Findings: Disturbed and reclaimed soils exhibited lower organic matter, higher salt content, and altered soil structure (more large aggregates). Additionally, disturbed soils had less N and soil organic carbon.
Implications: These results suggest that heavily disturbed soils have a low potential for the successful reestablishment of native plant communities. Successful reclamation requires consideration of soil properties and improvements in soil reclamation techniques.
Topics: Well Pad, Soil Data, Reclamation Practices

Day, S.J., Norton, J.B., Strom, C.F., Kelleners, T.J., and Aboukila, E.F., 2019, Gypsum, langbeinite, sulfur, and compost for reclamation of drastically disturbed calcareous saline-sodic soils: International Journal of Environmental Science and Technology, v. 16, p. 295–304.

DOI: https://doi.org/10.1007/s13762-018-1671-5
Background: Saline-sodic soils have salinity and sodicity (relative abundance of sodium) levels that exceed the tolerances of most plants. Soil disturbance during energy development can redistribute and alter these chemicals in the soil profile, for example moving sodium to the surface, which can inhibit germination of native plants required for successful reclamation.
Objectives: The authors evaluated the application of chemical amendments (gypsum, elemental sulfur, and langbeinite) and compost to remediate calcareous saline-sodic soils after reclamation on a natural gas well pad.
Methods: Topsoil was collected from the top 15 centimeters (cm) of a natural gas well pad near Wamsutter, Wyoming, and transported to Laramie, Wyoming in September 2012 for experimental treatments. The topsoil had been thoroughly mixed due to salvage, stockpiling, respreading, and tillage. The soil was distributed into 15-cm-deep wooden frames for eight amendment treatments with three replications each. The treatments were: compost alone, gypsum, gypsum+compost, elemental sulfur, elemental sulfur+compost, langbeinite, langbeinite+compost, and an untreated control. Amendments were added in October 2012 into the top 10 cm to mimic incorporation by mechanical disking. Soil cores were collected every three months from the treatments for a year and analyzed.
Location: Soil was collected on a natural gas well pad in Sweetwater County near Wamsutter, Wyoming (41°33′50.28″ N., 108°01′24.31″ W.; elevation 2,058 meters [m]) then transported to an uncovered, dryland area at the University of Wyoming Laramie Research and Extension Center
Findings: Sodium leached (sodicity reduced) from the soil surface in all treatments and the control. The langbeinite treatment was the most effective at moving sodium but caused short term increases in salinity. Gypsum moved sodium less than the other treatments, whereas the elemental sulfur and compost treatments were the same as the control. Compost did not affect the activity of the other amendments.
Implications: There was no clear advantage to adding compost with other chemical amendments in this experiment. Regardless of treatment, sodium was leached from the soil surface, however langbeinite was most successful. The high solubility and ease of application of this chemical makes it advantageous in low rainfall reclamation sites. The langbeinite did increase salinity within the first three months after application, which could inhibit plant germination. The authors suggest that managers delay planting until salinity in soils is low.
Topics: Well Pad, Soil Data, Reclamation Practices

DePuit, E.J., 1984, Potential topsoiling strategies for enhancement of vegetation diversity on mined lands: Minerals and Environment, v. 6, p. 115–120.

DOI: https://doi.org/10.1007/BF02043991
Background: Coal surface mine reclamation in the Northern Great Plains of the United States is complicated by a number of interacting factors and harsh climatic conditions. The overall goal is to reestablish natural self-sustaining vegetation conditions, which requires nutrient-rich soil; however, reclamation often uses stockpiled topsoil with or without amendment that may or may not create appropriate growing conditions. Understanding and assessing multiple topsoiling methods is helpful in determining the most successful at reestablishing plant community diversity.
Objectives: The author discussed actual and potential topsoiling strategies for promoting diverse plant communities on reclaimed coal surface mines in the Northern Great Plains.
Methods: The author reviewed topsoiling strategies for diversity *within* plant communities, including direct place topsoiling, supplemental top-dressing, multi-lift topsoiling, topsoil depth, and topsoil treatment and management. They also reviewed potential topsoiling strategies for diversity *among* plant communities, including topsoil depth variation, selective handling of soil types. They summarized the strategies and their implications.
Location: This is a review article and does not involve a specific field site location
Findings: Reapplying topsoil as quickly as possible is generally accepted as the best way to encourage revegetation. Supplementing stockpiled topsoil with fresh topsoil or amendment can aid in nutrient availability. Often a thin layer of topsoil is sufficient (20–60 centimeters [cm]) based on site-specific conditions. Potential practices such as varying topsoil depth and selective handling of topsoil need further field research to determine their effectiveness at increasing plant community diversity.

Implications: Increasing plant community diversity with various topsoiling strategies does not necessarily increase plant productivity. Land managers should choose their topsoil strategy based on their reclamation goals, requirements, and post-mine land use.
Topics: Mining, Reclamation Practices

DePuit, E.J., and Coenenberg, J.G., 1979, Methods for establishment of native plant communities on topsoiled coal stripmine spoils in the Northern Great Plains: Reclamation Review, v. 2, p. 75–83.

Link (non-DOI): https://www.osti.gov/biblio/5267305
Background: Using native species in coal stripmine reclamation in the Northern Great Plains is important for successful revegetation as native species are well adapted to the region's semiarid conditions. However, initial establishment of native species can be difficult and nonnative species tend to dominate reclaimed areas. Certain varieties of native species may be more adept at establishing on reclaimed coal lands, and (or) seeding method (drill versus broadcast) may affect native species revegetation success and plant community diversity.
Objectives: The authors evaluated the effects of seeding method (drill versus broadcast) with different seeding mixtures and rates on productivity, species response, and plant community diversity.
Methods: To assess revegetation of native species on coal stripmine spoils, a complete randomized block design was initiated in 1977 to assess three seeding mixtures, two seeding methods, and three seeding rates for a total of 18 specific treatment combinations, each replicated three times. In the 1977 and 1978 growing seasons, measurements were collected, including species density, standing crop biomass, canopy cover, frequency; plant community diversity was calculated using the Shannon-Weaver Function. Vegetation measurements were compared across treatments.
Location: Rosebud Mine near the town of Colstrip in southeastern Montana, USA
Findings: In general, several native species (that is, perennial grasses and fourwing saltbush) were well established by the second growing season; however, a notable number of nonnative species were also present, including yellow sweetclover, Russian thistle, and annual bromegrasses. Overall species diversity was in the lower range of surrounding native plant communities. Vegetation measurements were higher when the broadcast seeding rate was twice that of the drill seeding rate; however, at equal seeding rates, drill seeding was more productive (except regarding community composition [based on cover], which was higher overall with broadcast seeding). Perennial grass and shrub productivity were similar across seed mixtures, though diversity was highest in mixture 3, which contained more species. Plant community diversity declined as seeding rate increased.
Implications: Land managers should first establish desired species diversity outcomes to determine the most effect seeding methods and rates. In general, a more diverse seed mix will result in a more diverse plant community, though post-reclamation land use and management should inform the chosen seed mixture. Heavier seeding rates could negatively impact plant community diversity but may be necessary to insure speedy revegetation in semiarid conditions.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

DePuit, E.J., and Redente, E.F., 1988, Manipulation of ecosystem dynamics on reconstructed semiarid lands, chap. 8 *of* Allen, E.B., ed., The reconstruction of disturbed arid lands—An ecological approach: Westview Press, p. 162–204.

DOI: https://doi.org/10.4324/9780429314216-8
Background: Recovery of disturbed arid lands in the western United States is often slow, unpredictable, and affected by a number of factors and processes. Anthropogenic manipulation can increase the rate of recovery, though any restoration practices must be rooted in ecological principals to ensure the restored ecosystem is self-sustaining. Both theoretical and applied ecology are necessary for long-term success of restoration efforts.
Objectives: The authors reviewed ecosystem recovery, its associated factors, and manipulation of those factors on drastically disturbed shrub and grasslands in the semiarid western United States impacted by mining disturbances.
Methods: The authors outlined the process of ecosystem recovery on disturbed shrub and grasslands in arid environments. They discussed factors that influence ecosystem recovery in these environments, specifically site factors (for example, climate, soil conditions, and disturbance size and type) and biotic factors related to plants, animals, and microorganisms. They reviewed research on ecosystem reconstruction involving human alteration of site and biotic factors (that is, site modification, topsoiling, fertilization, implications of substrate improvement, biotic propagule supply, and land management).

Location: This is a review paper that discusses research on various mine, oil, and gas operations in Colorado (and specifically the Piceance Basin), Montana, Wyoming, and Northern Great Plains region, USA
Findings: Site and biotic factors can be manipulated during restoration to alter initial succession following mining, oil, and gas disturbance. However, the majority of referenced research was carried out over the short-term, had a limited scope, was empirical rather than functional, and was non-ecologically oriented. As a result, theoretical understanding of ecosystem restoration lags.
Implications: For the field of ecosystem restoration and reclamation to grow, long-term studies with ecologically minded questions focused on functional relationships and interactions are necessary. This will in turn improve technological methods of manipulation and restoration, and thereby restoration outcomes.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Soil Data, Reclamation Theory, Reclamation Practices, Reclamation Standards

Desserud, P., Gates, C.C., Adams, B., and Revel, R.D., 2010, Restoration of foothills rough fescue grassland following pipeline disturbance in southwestern Alberta: Journal of Environmental Management, v. 91, no. 12, p. 2763–2770.

DOI: https://doi.org/10.1016/j.jenvman.2010.08.006
Background: Fescue grasslands are important for maintaining ecological integrity and watershed protection but are threatened by agricultural, residential, and oil and gas development. *Festuca campestris* is a dominant species in these grasslands and vulnerable to human disturbance and is important for maintaining ecological integrity and watershed protection. After 1970, seeding and restoration practices have improved, but the effect of these practices on *F. campestris* has not been assessed. In many cases restoration is inhibited by poor restoration practices.
Objectives: The authors evaluated long-term impacts of pipeline construction and assessed the efficacy of different reclamation techniques for restoring rough fescue communities.
Location: Foothills of the Rocky Mountains (between latitudes 49.32°–55.55° N., and longitudes 114.01°–114.28° W.) in southwestern Alberta, Canada
Methods: A pipeline right-of-way (ROW), sections of which were disturbed and reclaimed between 7 and 40 years ago, was assessed in comparison to adjacent undisturbed sites. Three topographic and hydrologic function location types were monitored: south facing (sub-mesic), crests (sub-xeric), and bottomland north-facing (mesic). Slope, drainage, topsoil depth, and soil texture were characterized at each site. Vegetation data were also collected at each site, including species cover, total canopy cover, and ground cover along line transects, as well as species cover, rangeland health, and shrub cover within subplots. Reclamation reports and historical records were compared to data collected in the field to assess reclamation technique outcomes.
Findings: ROW sites had variable recovery with none to moderate. ROW sites had a higher proportion introduced grasses and forbs, less topsoil, and poorer health than undisturbed. Larger diameter pipelines were associated with decreased topsoil. Even when seeding was used introduced grasses were prevalent even after 40 years. *Poa pratensis* was abundant on ROW sites.
Implications: Competition with nonnative *Festuca ovina* may limit native *F. campestris* establishment. Construction and disturbances should occur during the winter or at the end of the growing season using trench-only stripping to reduce the negative impacts to vegetation. Seeding with exotics should be limited because they remain on the landscape for a long time. Reducing the width of pipeline construction disturbance and avoiding soil admixing can improve reclamation efforts.
Topics: Pipeline, Target Plant Recovery Data, Reclamation Practices

Desserud, P.A., and Hugenholtz, C.H., 2017, Restoring industrial disturbances with native hay in mixedgrass prairie in Alberta: Ecological Restoration, v. 35, no. 3, p. 228–236.

DOI: https://doi.org/10.3368/er.35.3.228
Background: Native grassland restoration can be unsuccessful due to mismatched cultivars from unreliable seed sources as well as competition with non-target species. In Alberta, Canada, less than half of the native dry mixed-grass prairie remains intact and is highly fragmented.
Objectives: The authors tested if wild harvested hay could successfully restore native mixedgrass prairie disturbed on oil and gas well sites and assessed the recovery of the sites used for harvest.

Methods: Native hay was collected via mowing within 0.5 kilometer (km) of five natural gas well sites that were being reclaimed within the context of this study. The hay was coarsely chopped and sprayed on disturbed well sites to a depth of 2–5 centimeters (cm). Vegetation was sampled using quadrats and 100-meter (m) transects, both within the areas where hay was collected and at the well sites; hay collection areas were sampled before mowing and two and three years after mowing. Reclaimed well pads were sampled two and three years after treatments. Data collected included species composition, plant species, litter cover, and bare ground cover. To assess longer term effects of the native hay treatment, three sites that were seeded with native hay seven years earlier were also monitored.
Location: Dry mixedgrass and mixedgrass natural sub-regions (Brooks, Gem, the Eastern Irrigation District, and Pinhorn) of the Grassland natural region in southeastern Alberta, Canada
Findings: Within the native grassland, there was no effect of hay harvesting on percent cover of dominant mixedgrass species, litter, mosses and lichens, total native grasses, forbs, or shrubs. Second-year restored sites had more bare ground, more nonnative species, and lower abundance of native grasses compared to controls (native mixedgrass prairie). However, after two years 71 percent of the native grasses and forbs found at control sites germinated at the restored sites. After three years hay treatment sites had similar overall species cover as controls. Bare soil at restored sites significantly decreased from the second to the third year. The 7-year-old native hay sites were similar in cover to adjacent control sites for forbs and several native grasses.
Implications: Native hay promoted successful germination of grassland species on well sites and is a viable seed source for reclaiming oil and gas well pads. While weedy species dominated in the second year, they were replaced by native species in year three. Mowing did not negatively affect native grasslands where hay was collected, even with subsequent cattle grazing. At the 7-year-old native hay sites reclamation requirements for Alberta, Canada were met.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Desserud, P.A., and Naeth, M.A., 2012, An unexpected response of a bunch grass (rough fescue) to arbuscular mycorrhizae fungi: Ecological Restoration, v. 30, no. 3, p. 165–168.

Link (non-DOI): https://www.jstor.org/stable/44743650
Background: Rough fescue, a late successional species, is difficult to reestablish after reclamation on oil and gas development possibly because disturbance leads to loss of soil nutrients, soil organic matter (SOM) and arbuscular mycorrhizae fungi (AMF). The loss of AMF and associated benefits to late successional species may be a major factor limiting rough fescue’s recovery.
Objectives: The researchers evaluated rough fescue seeded in soil with or without AMF inoculum to see if its recovery benefitted from the presence of AMF.
Methods: Wild-harvested rough fescue was grown in field soil for six months in a greenhouse, after which soil and roots were harvested to be used as AMF inoculum. Pots were filled with sterilized potting soil, inoculated, seeded with five viable rough fescue seeds, placed in a controlled growth chamber set at 16-hours (hr) of light at 20 °C and 8-hrs of darkness at 15 °C, and watered with de-ionized water. Half of the seeded pots were treated with a fungicide treatment (Fenaminosulf and Rovral) to disable the mycorrhizal treatment; each fungicide was applied once a week for 3 weeks prior to seeding, at seeding time, and then at weeks 2, 3, 7, and 15 after seeding. After 22 weeks, plants in all pots were harvested plants and measured for leaf and root length, tiller number, and above- and below-ground biomass. Total biomass was measured, and AMF presence was determined using a glucosamine assay. In addition, field samples of soil around collected around approximately 3-year-old fescue plants and assayed to assess AMF presence.
Location: Alberta, Canada
Findings: Leaf length, number of stems, above ground biomass, root biomass, and root to leaf length ratio were significantly greater in Fenaminosulf treatments than non-fungicide treatments. Root length and root to leaf length ratio were significantly greater in Rovral treatments than non-fungicide treatments. AMF colonization did not differ between treatments. However, root mass was higher with lower glucosamine levels in the Fenaminosulf treatment, and more tillers were correlated with lower glucosamine levels in the Rovral treatment. Adult field plants also had 1.7 times more glucosamine than the greenhouse grown plants.
Implication: Rough fescue is colonized by AMF in the field, however, contrary to their expectations, AMF does not increase growth. Other researchers have also found that AMF can limit growth in young grasses, despite AMF facilitation of nutrient uptake. More research is needed to confirm the effect of AMF on rough fescue and should be extended to different life stages. Factors other than reduced AMF in stored topsoil might be responsible for the poor recovery of rough fescue on oil and gas well pads.
Topics: Well Pad, Target Plant Recovery Data, Soil Data, Reclamation Practices

Desserud, P., and Naeth, M.A., 2013, Establishment of a native bunch grass and an invasive perennial on disturbed land using straw-amended soil: Journal of Environmental Management, v. 114, no. 15, p. 540–547.

DOI: https://doi.org/10.1016/j.jenvman.2012.11.001
Background: *Festuca hallii* dominates healthy and intact fescue prairies in North America. However, these prairies are threatened by disturbance from well development and associated increases in nonnative species. One introduced species of concern is *Poa pratensis* that grows well in highly disturbed soils that are rich in nitrogen (N) and have high pH and electrical conductivity (EC). One method of recovery may be the addition of straw as a soil carbon (C) amendment. Straw may alter soil properties via its decomposition by adding C, potassium, and ammonium.
Objectives: The authors tested if (1) addition of straw amendment would positively affect *Festuca hallii* by altering soil chemistry, and (2) *F. hallii* is negatively affected by disturbed soils with altered soil chemistry, and if *P. pratensis* tolerates it.
Methods: Three sites were treated with a high, low, or no straw treatment and monitored for three years. The three sites consisted of an abandoned natural gas well after the topsoil was removed, an agricultural field sprayed with Roundup, and an uncultivated site that was prepped for gas drilling. Strips of *F. hallii* and *P. pratensis* were seeded perpendicular to and across the straw treatments. Leaf length, number of inflorescences, and dry biomass were measured on a number of individuals from each species. Soil samples were collected next to the measured plants and for total C, total soil N, available ammonium, available nitrate, soil EC, pH, and available phosphate and potassium, as well as texture.
Location: Three field sites in central Alberta, Canada: two in the Central Parkland natural region at Ellerslie (53°25′ N., 113°29′ W.) and Byemoor (51°59′ N., 112°19′ W.) and one in the Northern Fescue subregion of the Grassland natural region at Drumheller (51°26′ N., 112°21′ W.)
Findings: *F. hallii* had higher biomass (total and root), leaf length, and cover in the high straw treatment. The straw treatment had little effect on *P, pratensis.* High pH and EC were associated with increased growth for *P. pratensis* and lower growth for *F. hallii. F. hallii* grew best on the driest site and responded best to the previous year soil water.
Implications: While adding straw does not reduce the growth of nonnative species it does increase soil nutrients and benefits native grasses. Straw amendments, preferably in large quantities, should be considered as a low-cost soil amendment in reclamation of disturbed sites in fescue prairies.
Topics: Well Pad, Target Plant Recovery Data, Soil Data, Reclamation Practices

Desserud, P.A., Naeth, M.A., 2013, Natural recovery of rough fescue (*Festuca hallii* (Vasey) Piper) grassland after disturbance by pipeline construction in Central Alberta, Canada: Natural Areas Journal, v. 33, no. 1, p. 91–98.

DOI: https://doi.org/10.3375/043.033.0111
Background: It can be difficult to revegetate grassland after a large-scale pipeline disturbance. This study looked at how pipeline construction methods affect natural recovery of the grassland vegetation.
Objectives: The authors looked at vegetation recovery as a gradient of disturbance caused by construction of the pipeline, from clearing a wide swath of land to creating a minimal disturbance.
Methods: Thirteen pipelines were constructed in the area since the 1950s, using three construction methods: plow-in (pipeline laid in a small cut with no sod removed), ditch-witch (sod removed, chopped and mixed with topsoil; and spread across pipeline scar), and topsoil-strip (sod removed, set aside, and replaced a week after construction). From 2006–2010, random segments of each pipeline construction method were selected, and paired quadrats were used to compare the pipeline with the nearby undisturbed vegetation.
Location: Rumsey Natural Area (between latitudes 51.796°–51.883° N., and longitudes 112.417°–112.701° W.; elevation 900 meters [m]) in the Central Parkland natural region of Alberta, Canada
Findings: The authors found that the vegetation community on the ditch-witch and topsoil-strip pipelines had converted to a wheatgrass community, and the plow-in method retained the fescue-bluegrass community similar to the undisturbed landscape. Litter was reduced on all pipelines compared to the undisturbed community, with more litter on the plow-in plots compared to the other construction methods.
Implications: The results show how methods such as plow-in pipeline construction can increase the chance for diverse grassland communities, because this method reduces disturbance to existing sod, retains viable perennial grass roots, and reduces bare ground. Large disturbances create more bare ground and give more competitive grasses, such as wheatgrass, the advantage over other native vegetation that may be slower to establish.
Topics: Pipeline, Target Plant Recovery Data, Reclamation Practices

Di Stéfano, S., Karl, J.W., Bailey, D.W., and Hale, S., 2020, Evaluation of the automated reference toolset as a method to select reference plots for oil and gas reclamation on Colorado Plateau rangelands: Journal of Environmental Management, v. 265, article 110578.

DOI: https://doi.org/10.1016/j.jenvman.2020.110578
Background: Weather and soil conditions on rangelands make successful reclamation of oil and gas disturbance difficult. Often, an expert is required to select a reference plot (an undisturbed comparable area) to assess reclamation efforts, which is time consuming and not always replicable on a larger scale. The Automated Reference Toolset (ART; described here by Nauman and Duniway, 2016, at https://doi.org/10.2136/sssaj2016.05.0151) is a potential tool for increasing the efficiency and replicability of selecting reference plots for rangeland reclamation assessments. However, this method does not always accurately measure important reclamation characteristics, such as distinguishing between native and invasive species.
Objectives: The authors proposed and evaluated an improved methodology for using the ART model, focusing on local topography, soil water content, vegetation composition, and ground cover, by comparing ART-selected reference plots against expert reference plots and reclamation sites.
Methods: Fourteen reclamation sites with 11 corresponding expert reference plots were selected. Datasets which incorporated new characteristics important to reclamation assessment were input into ART to select two reference plots per reclamation site (28 total ART plots). These 28 reference sites were compared to reference sites identified from the previous versions of ART that did not include the additional input characteristics. Specifically, continuous variables were not categorized but instead a similarity index was used to create a gradient of similarity between reclamation sites, expert reference plots, and the ART-selected reference plots. Line point-intercept cover, species, richness, and soil characteristics were collected at all sites following the BLM's Assessment, Inventory, and Monitoring program protocols. Data were compared using linear regression and correlation.
Location: Bureau of Land Management (BLM) White River Field Office in northwestern Colorado, USA
Findings: The ART was able to select plots with similar landform position and soil gravimetric moisture as expert plots but was not able to consistently select areas with conditions on a scale finer than dominant vegetation cover. Slope, in general, was steeper at the ART selected plots compared to expert plots. As expected, most expert plots had a high ART value (>0.9) compared to corresponding reclamation sites.
Implications: While the ART model is a useful and efficient tool for selecting rangeland reclamation reference plots, it is best used in combination with expert input, especially on fine scale vegetation characteristics. The ART model provides a standardized method for selecting reference plots that increases transparency among the various organizations involved with rangeland reclamation assessments.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Monitoring, Reclamation Standards, Decision Support Tools

Dollhopf, D.J., and Goering, J.D., 1982, Mined land erosion control with surface manipulation, *in* Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Proceedings: Lexington, Ky., University of Kentucky, p. 325–328.

Link (non-DOI): https://www.osti.gov/biblio/5439657
Background: In the western United States, soil moisture is the leading factor limiting successful revegetation of reclaimed mine lands. Excessive runoff renders much of the annual precipitation unusable for plants, and leads to erosion, which further degrades the landscape. Methods for reducing runoff and erosion and increasing soil moisture could improve revegetation on western mine lands.
Objectives: The authors tested the efficacy of select techniques (that is, gouging, dozer basins, and chiseling) to reduce runoff and erosion on disturbed mine land in the Northern Great Plains of the western United States.
Methods: Five micro-watersheds (37 × 60 meters [m]) were constructed on regraded spoil slopes at each of five surface coal mine sites. Within each watershed boundary, the following treatments were applied: (1) non-topsoiled chiseled, (2) topsoiled-chiseled, (3) non-topsoiled gouged, (4) topsoiled-gouged, and (5) topsoiled dozer basins. Chiseling was achieved via steel shanks and represented the control treatment. Erosion was measured directly and via rill and gully formations. Surface

depression longevity was determined using plastic liners molded to the ground surface at select sample points in each watershed. Water was poured into depressions until they filled to measure sedimentation rate in depressions. Sites were monitored immediately after installation and over the next two years (1975–1976).
Location: Five surface mine coal sites in the Northern Great Plains in Savage and Colstrip, Montana; Beulah, North Dakota; and Glenrock and Hanna, Wyoming, USA
Findings: Surface water runoff was reduced by 75 percent on dozer basin slopes and 18 percent on gouged slopes compared to the control (chiseling). Topsoil application of 15–30 centimeters (cm) on gouged slopes reduced runoff by 55 percent compared to non-topsoil gouged slopes. Precipitation lost as runoff varied wildly across sites (2.2–20.4 percent) due to environmental conditions. Topsoil application reduced erosion by 92 percent on dozer basin slopes compared to controls; gouged slopes (regardless of topsoil) had 50 percent less erosion compared to controls. Though surface depression longevity was difficult to ascertain, dozer basins may control runoff and erosion for 10–20 years.
Implications: Topsoil was important for reducing runoff and erosion, especially when combined with gouging or dozer basins. Both treatments performed better than the control (chiseling) and land managers should consider which treatment would best suit their site-specific conditions. For slopes >20 percent, dozer basins are an effective way to reduce runoff and erosion for decades. Gouging is more effective for 1- to 2-year erosion control.
Topics: Mining, Erosion Data, Hydrology Data, Reclamation Practices, GrayLit

Dreesen, D.R., Harrington, J.T., Wagner, A.M., Murray, L., and Sun, P., 2001, Testing native grasses for survival and growth in low pH mine overburden, *in* Barnhisel, R.I., Buchanan, B.A., Peterson, D., and Pfeil, J.J., coordinators, Land reclamation, a different approach—18th Annual National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mex., June 3–7, 2001, Proceedings: American Society for Surface Mining and Reclamation, p. 2–17.

DOI: https://doi.org/10.21000/JASMR01010002
Background: Revegetation of the Molycorp molybdenum mine in New Mexico is complicated by its mixed volcanic overburden piles with low pH and high salinity. Identifying grass species most likely to survive could increase reclamation and revegetation success. In addition, altering the pH and salinity of the overburden piles with amendment could improve revegetation efforts.
Objectives: The authors assessed and identified grass species most likely to survive the low pH and high salinity overburden conditions, and therefore be most suited for revegetation efforts.
Methods: A randomized complete block design was used to test three substrate treatments on growth and survival of 54 different native cool-season grass species: (1) unmixed acid rock (low pH, high soluble salts), (2) an acid neutral overburden mixture ratio of 3:1 (low soluble salts, high pH), and (3) an acid neutral overburden mixture ratio of 9:1 (high soluble salts, intermediate pH). Grass seedlings were germinated in 1996 and transplanted in 1997 into treatment blocks. In 1998, survival of transplants was measured, then grasses were harvested for biomass calculations. Data were analyzed using analysis of variance (ANOVA) and categorical ANOVA.
Location: This study was conducted at the New Mexico State University Mora Research Center in Mora, New Mexico using overburden from the Molycorp molybdenum mine near the towns of Questa and Red River in northcentral New Mexico, USA
Findings: Biomass across all species was highest (1.17 grams [g]) in the acid neutral 3:1 treatment with the effect of substrate varying by species. Overall, salinity had a greater negative correlation with survival than acidity level. Seven Molycrop seed sources, nine commonly available grass varieties, and five additional species were most successful across all substrate types and were recommended for use on low pH, high salinity soils.
Implications: Successful revegetation of mine overburden with low pH and high salinity is dependent on species. A number of grass species are suitable for such soil conditions, with separate suites of species recommended for varying combinations of pH and salinity levels. Land managers with similar soil conditions to this study could reference these suites of species for possible reclamation use.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Driessen, C.A., 2011, Characteristics of reclaimed and undisturbed soil profiles in southwest Wyoming, chap. 2 *of* Properties of reclaimed soils and their response to a controlled livestock treatment: Laramie, Wyo., University of Wyoming, Department of Ecosystem Science and Management, master's thesis, p. 8–27.

Link (non-DOI): https://www.uwyo.edu/wrrc/_files/docs/theses_dissertations/driessen_cally.pdf
Background: Soils in arid environments are difficult to restore following energy development. This is often exacerbated by deep excavation of soil to build a level platform for drilling on well pads in Wyoming. Soil properties and soil structure are damaged by these processes. Understanding soil properties before and after disturbance may improve soil reclamation efforts by identifying changes in the soil structure that may limit revegetation.
Objectives: The author characterized and compared soil properties at reclaimed sites and undisturbed sites.
Methods: Soils up to eight inches (in.) deep were salvaged, stockpiled, and reapplied. Before vegetation emerged, soil pits were constructed at reclaimed well pads and adjacent undisturbed sites. Soil morphological properties were assessed in the field, but the chemical, physical, and biological properties of soil were analyzed in the lab. Soil was collected from each soil horizon. Researchers used the soil samples to quantify soil organic matter (SOM) fractionation, mineral- associated carbon (C) and nitrogen (N), total organic C and N, soil texture, electrical conductance (EC), pH, and bulk density.
Location: Three well pads near Jonah natural gas field in Sublette County, Wyoming (42°27′ N., 109°44′ W.) and three at the Wamsutter natural gas field in Sweetwater County, Wyoming (41°40′ N., 107°51′ W.)
Findings: Undisturbed soils were characterized as Aridisols, typically, and reclaimed soils were Entisols lacking eluviation or illuviation. Soil properties differed by depth at both disturbed and undisturbed sites. Undisturbed soils had thicker and more coarse surface horizons and lower EC, whereas disturbed soils retained little structure. pH, EC, sand content, occluded-fraction C and N, and mineral-associated fraction N significantly differed between reclaimed and undisturbed sites. Specifically, reclaimed sites had a higher pH, contained less sand, lower occluded-fraction C and N, lower mineral-associated N, and had lower calcium carbonate ($CaCO_3$) content than undisturbed sites.
Implications: Reclaimed soils differ from undisturbed soils in morphology, chemistry, biology, and physical properties. Disturbed soils have higher EC which may reduce the quality of the soil and limit plant regeneration. However, calcium-rich salts and fine soil particles may promote soil aggregation and subsequent plant growth in reclaimed soils. Salts from deeper soils may mix with upper soil layers during excavation and increase pH and EC. Soil formation may be challenging in Wyoming as undisturbed soils were formed under different climate conditions in the past. Organic amendments and irrigation may improve reclamation success by promoting soil formation.
Topics: Well Pad, Soil Data, Reclamation Practices, GrayLit

Driessen, C., Mason, A.J., Norton, J., and Strom, C., 2011, Immediate effects of controlled livestock treatment on reclaimed natural gas well pads: Natural Resources and Environmental Issues, v. 17, no. 1, article 6, p. 1–7.

Link (non-DOI): https://digitalcommons.usu.edu/nrei/vol17/iss1/6/
Background: Oil and gas reclamation in the shrublands of Wyoming occur on public lands designated as multiple use. Decision making for the reclamation process often doesn't include the ranching community also using the lands. Cattle have the capacity to improve reclamation efforts directly and indirectly. For instance, their hooves alter soil structure, and their feces contribute organic matter and nutrients to the soil. Soil organic matter (SOM) aids in plant establishment by providing nutrients to plants, improving water holding capacity of soils, and reducing erosion.
Objectives: The authors quantified the effects of controlled livestock impact on SOM to characterize the potential for livestock to contribute to plant establishment and persistence on reclaimed oil and gas pads.
Methods: Ten well pads received two treatment plots: (1) controlled livestock impact treatment with added hay and reclamation, and (2) reclamation only. The pads were reclaimed and seeded in the fall of 2009, according to Bureau of Land Management (BLM) field office and reclamation company standards. Stocked cattle at a rate of 240 cattle per hectare per day (cattle/ha/d). Analyzed soil samples for percent light fraction organic matter and labile carbon (C) and nitrogen (N).
Location: Pinedale Anticline, Jonah, and Wamsutter natural gas fields in Wyoming, USA

Findings: After the cattle treatment, labile organic C concentrations were significantly higher at all sites, labile organic N was greater at the Jonah site, and there was no difference in free or occluded organic matter. At the Jonah site, occluded organic matter was significantly higher with cattle presence.
Implications: Adding livestock with hay forage to reclamation practices could affect soil properties. This study showed how labile organic C increased with controlled livestock impact, while other measured properties of SOM were not affected. It remains to be tested if these impacts lead to achieving reclamation goals.
Topics: Well Pad, Soil Data, Reclamation Practices

Duniway, M.C., Herrick, J.E., Pyke, D.A., and Toledo, D.P., 2010, Assessing transportation infrastructure impacts on rangelands—Test of a standard rangeland assessment protocol: Rangeland Ecology and Management, v. 63, no. 5, p. 524–536.

DOI: https://doi.org/10.2111/REM-D-09-00176.1
Background: Road and vehicle related disturbances have increased on rangelands due to infrastructure development, all-terrain vehicle access, and recreation. The direct effects of these disturbances are well studied, but the indirect effects on the health and resilience of rangelands, such as altered hydrology and sediment transport, are unclear. Establishing protocol for quickly and accurately assessing the impacts of roads, trails, and pipelines in arid and semiarid rangelands is critical to developing appropriate travel management plans. The Interpreting Indicators of Rangeland Health (IIRH) assessment is an internationally recognized qualitative protocol that could be used to quickly assess the impacts of roads.
Objectives: The authors investigated the effects of transportation-related disturbance (roads, trails, and pipelines) on rangeland soil and vegetation using the IIRH assessment. The specific objectives of this study were to: (1) assess if the IIRH was sensitive to the impacts of roads on rangelands, (2) test if different observers affected the accuracy of the IIRH assessment, and (3) determine if the IIRH qualitative results were correlated with quantitative indicators of rangeland health.
Methods: At three different locations (Wyoming, New Mexico, and Utah), four sites for each of the four road types were monitored, for a total of 48 sites. Within each site, 2–6 plots were assessed, along with paired control plots. Field plots were established within 5 meters (m), between 5 and 10 m, and more than 40 m from each road type. To determine the relative health of a plot researchers used IIRH version 4 to compare 17 indicators of rangeland health at a plot to a “healthy” reference range. These 17 indicators were used to determine the relative health of a rangeland’s soil and site stability, hydrologic function, and biotic integrity. To test observer bias, each member of a three-person team completed an IIRH assessment followed by a consensus evaluation. Quantitative measures such as vegetation structure, soil stability, and rill and gully formation were completed along transects 1–14 days after the IIRH assessment.
Location: Three semiarid regions of the Northern High Plains (Wyoming, major land resource area [MLRA] 58.2), the Colorado Plateau (Utah, MLRA 35), and the Chihuahuan Desert (New Mexico, MLRA 42.2)
Findings: Rangeland health, per the IIRH, differed significantly based on distance from the road. The impact of a road was greatest within 5 m and decreased at further distances. Within 5 m of the road soil stability and hydrologic function were more impacted than biotic integrity. At one location, with a two track and a pipeline, hydrologic function was impacted farther than 5 m. Bare ground cover, soil surface loss, and compaction layer properties were the only three IIRH indicators that differed with distance from the road at all three locations. There was little variability in observer ratings using IIRH. The quantitative measurements and the IIRH qualitative measurements were highly correlated, but these correlations varied by region and indicator. Notably, at all three study locations the amount of bare ground and connectivity of bare ground were correlated with soil stability and hydrologic function.
Implications: The IIRH assessment can detect impacts of transportation-related disturbances to rangeland health across a variety of ecosystems. The IIRH can be used to quickly detect areas impacted by roads, however, should not replace long-term quantitative monitoring. Hydrologic function and soil and site stability were most negatively impacted by roads and should be closely monitored with additional quantitative methods.
Topics: Pipeline, Vegetation Recovery Data, Decision Support Tools

Eldridge, J.D., Redente, E.F., and Paschke, M., 2012, The use of seedbed modifications and wood chips to accelerate restoration of well pad sites in western Colorado, U.S.A.: Restoration Ecology, v. 20, no. 4, p. 524–531.

DOI: https://doi.org/10.1111/j.1526-100X.2011.00783.x
Background: Increased oil and gas activities in the arid and semi-arid western United States negatively impact surrounding ecosystems. These disturbances, and a naturally slow recovery rate in this region, complicate reclamation efforts.
Objectives: The authors identified successful restoration strategies following natural gas development for semi-arid ecosystems by examining the effects and interactions of seedbed modifications, soil amendments, seed mixtures, and seeding methods.
Methods A split-split experimental design was established on five well pads in pinyon-juniper and semidesert shrub plant communities. Well pads were considered blocks, with six 25 × 27 meter (m) whole plots established on each well pad. Whole plots were assigned one of two seedbed modifications: rough soil surface with micro-catchments or smooth soil surface. Whole plots were then subdivided into two split plots, which received one of two amendment treatments: wood chips or no wood chips. Within split plots, two additional split-split plot factors were fully crossed within 6 m × 12 m sections: seeding technique (broadcast or island broadcast) and seed mix type (annual+perennial or perennial only). The possible 16 different treatment combinations were each replicated three times for a total of 48 sub-plots at each well pad. Prior to treatment application, all plots were ripped, fertilized, and mulched with weed free straw. The treatments were applied late fall 2006, monitored across two growing seasons using the point intercept method for plant cover data, and in summer 2007, soil samples were collected soil samples to compare pH, electrical conductivity (EC), soil absorption ratio (SAR), texture, and percent organic matter.
Location: Parachute (39°27′07″ N., 108°03′08″ W.), on the Western Slope of Colorado, USA
Findings: Soil patches with high soil salinity had an unexpectedly strong impact on plant cover; on 55 (of a total 240) plots with high salinity, cover was below 20 percent. These 55 plots were removed from analysis for interpretation of treatments. Across all treatments the average pH, EC, organic matter, and sodium adsorption ratio (SAR) was 7.6, 5.4 deciSiemens per meter (dS/m), 1.6 percent, and 7.1 respectively. Woodchips increased organic matter from 1.3 to 1.8 percent. Results for native species cover varied depending on the year. In 2007, average cover between all plots was 4.5 percent and with an average of six species present. By 2008 native seedling cover increased to 13 percent across all plots and was composed of nine species on average. Roughened seedbeds had the greatest impact on native species establishment. The seed mix of annuals and perennials had significantly higher cover than the mix with perennial species only in 2007 but showed no statistical difference in 2008. In 2007, nonnative cover was 29.5 percent across all treatments and 34 percent in 2008. In 2007, woodchips reduced nonnative cover by 18 percent and 27 percent in 2008. Noxious species increased from 0.2 percent in 2007 to 4.5 percent in 2008 averaged across all treatments. Total plant cover increased from 36 percent (13 species) to 54 percent (19 species) from 2007 to 2008. Woodchips reduced overall plant cover but suppressed nonnative species.
Implications: The combination of woodchip amendments and roughened seedbeds could have long-lasting effects on the success of restoring native plant communities. Roughened seedbeds can improve native plant cover. Woodchips can reduce nonnative species, possibly by reducing plant available nitrogen (N), and increase organic matter in the soil. Extensive soil sampling is recommended to identify patches of high salinity to treat before restoration planting.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Elkins, N.Z., and Whitford, W.G., 1984, The effects of high salt concentration on desert soil microarthropod density and diversity: The Southwestern Naturalist, v. 29, no. 2, p. 239–241.

Link (non-DOI): https://www.jstor.org/stable/3671035
Background: Deep-strata salt formations have been proposed as a possible depository for nuclear wastes in southeastern New Mexico. Construction of such a facility would involve surface dumping of thousands of cubic yards of salt-bearing rock produced by shaft sinking and driving operations. Adjacent to the proposed construction site is a potash mine with a shafting pile of near equivalent composition as the piles that would be created from the proposed facility construction. This shafting pile can be used to better understand the effects of constructing a nuclear waste facility on the soil microarthropod community.
Objectives: The authors evaluated the effects of soil salting on soil microarthropod density and diversity.
Methods: In 1980 and 1981, soil microarthropod fauna were sampled at the base of a pile of salt-bearing rock, as well as from three radial distances upslope and downslope of the salt pile, adjacent to the salt pile, and from nearby unaffected natural soils. All samples were 10 cubic centimeters (cm^2) soil cores. Soil fauna was characterized and compared across sample locations.

Location: Shafting pile (>65 percent salt content) on a potash mine ~60 kilometers (km) east-southeast of Carlsbad, New Mexico, USA
Findings: The natural soil microarthropod community contained 17 families and three genera of various mites, collembolans, and psocopterans. Soil microarthropod density and diversity decreased drastically downslope from the shafting pile and did not increase even 100 meters (m) out from the pile base. Microarthropod number and diversity increased upslope of the shafting pile base with no major differences from control soil (other than the suppression of oribatid mites and psocopterans) at 100 m from the base. Mites in the families *Nanorchestidae*, *Pachygnathidae*, and *Paratydeidae* appeared to have adapted to the high-salt soils. However, overall results suggest a significant reduction and alteration of soil ecosystem function due to salt loading.
Implications: Microarthropods are important for nutrient cycling, decomposition, and mineralization. Soils with decreased microarthropod density and diversity may be less productive. Land and reclamation managers with high-salt soil or shafting piles should carefully consider placement and long-term management of these soils to reduce negative impacts on microarthropod communities and revegetation efforts.
Topics: Mining, Soil Data, Reclamation Practices

Elsinger, M.E., 2009, Reclamation status of plains rough fescue grasslands at Rumsey Block in Central Alberta, Canada after oil and gas well site and pipeline disturbances: Edmonton, Alberta, University of Alberta, master’s thesis, 232 p.

Link (non-DOI): https://central.bac-lac.gc.ca/.item?id=MR54677&op=pdf&app=Library&is_thesis=1&oclc_number=738400154
Background: The 183 square kilometers (km^2) (71 square miles [mi^2]) Rumsey Block has one of the largest plains rough fescue (*Festuca hallii*) plant communities in western Canada. Construction and revegetation practices for energy development have evolved over time at this location. Construction techniques started with no topsoil salvage before the mid-1960s, followed by topsoil salvage from the 1970s to the 1990s, and settling on minimal soil disturbance techniques in the late 1990s. Revegetation involved nonnative species for many decades and more recently with native seeds; however, efforts have since shifted toward a more natural recovery where disturbance sizes are small, or the sod layer has been left intact.
Objectives: The author wanted to compare plant community and soil quality characteristics on oil and gas well sites with adjacent undisturbed plains rough fescue prairie sites; determine the effects of construction technique, revegetation technique, age, and grazing pressure on plant community and soil characteristics on pipelines and well sites; and develop recommendations for future reclamation efforts.
Methods: Fifty-three pipeline segments and well sites, reclaimed between 1967 and 2004, were selected for the study. In 2006 and 2007, data were collected on vegetation metrics (canopy cover, herbaceous species composition, and species richness) and soil variables (texture, bulk density, penetration resistance, sodium absorption ratio, electrical conductivity, pH, carbon (C), nitrogen (N), and various mineral contents). The datasets for each pipeline, well site, and undisturbed location were analyzed using Bray-Curtis dissimilarity, multi-response permutation procedures, Spearman rank correlation, and non-metric multidimensional scaling.
Location: Rumsey Block located about 80 km southeast of Red Deer, Alberta, Canada
Findings: Almost all study sites had yet to reach revegetation and soil reclamation goals. Soil characteristics were significantly different between most well site and pipeline disturbances and undisturbed prairie; some sites differed widely from undisturbed sites. Compared to undisturbed sites, disturbed sites had more bare ground and stone cover, broader levels of herbaceous cover, significantly different plant species composition, and lower species richness. The differences were smaller in more recent years as construction and revegetation techniques improved. Any form of topsoil handling significantly impacted soil and vegetation characteristics on pipelines as opposed to the technique of leaving the sod layer intact; and revegetation with a seed mix, regardless of prescribed mix content, was linked to significant alteration of plant community and soil. Grazing pressure was confounded by other factors and too variable to analyze.
Implications: This case study suggests that leaving the sod and root layers intact will lead to better outcomes than topsoil salvage and replacement, and that revegetation via natural recovery will also result in better outcomes than planting a seed mixture, regardless of prescribed mixture content. This may be especially true for pipelines and locations where disturbance footprint is small.
Topics: Well Pad, Target Plant Recovery Data, Reclamation Practices, GrayLit

Emam, T., 2016, Local soil, but not commercial AMF inoculum, increases native and non-native grass growth at a mine restoration site: Restoration Ecology, v. 24, no. 1, p. 35–44.

DOI: https://doi.org/10.1111/rec.12287
Background: Arbuscular-mycorrhiza fungi (AMF) is a type of endomycorrhizal fungi found in grasslands that forms a relationship with grassland plant species. Inoculating disturbed soil with AMF has been proposed as a method to increase success of mine reclamation. There are many factors such as site characteristics, soil condition, AMF type, plant community composition, and application method that could affect AMF inoculation success. Understanding the conditions needed for successful AMF inoculation could improve restoration efforts on reclaimed mine sites.
Objectives: The author evaluated the impacts of AMF inoculum type and application on native and non-native plants on a reclaimed mine site.
Methods: Two experiments were conducted. In the first, initiated in 2011, eight experimental blocks with a range of soil depths were divided into three plots each. One plot was inoculated with local AMF, one plot with was inoculated with commercially produced AMF, and one plot was left one as an untreated control. All plots were broadcast seeded with a mix of five native grass species. Non-native plants were allowed to disperse in from the surrounding area. The plots were monitored plant community data were collected over three years. Data were analyzed using multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA). In the second experiment, *Stipa pulchra* (purple needlegrass) was germinated in soil that was either (1) inoculated with local AMF, (2) inoculated with commercial AMF, or (3) sterilized. After six weeks of growth, in December 2011, the seedlings were transplanted into subplots in accordance with their soil treatment. After 18 months, the plants were harvested. The shoots were dried to obtain biomass, and roots were analyzed for mycorrhizal colonization. Data were analyzed using ANOVA and MANOVA.
Location: Knoxville mercury mine (38.824632° N., 122.326788° W.) in Napa County, California, USA
Findings: For the first experiment, the local AMF significantly increased non-native grass biomass and native grass biomass (although not significantly) compared to the control in 2011. By 2013, the effect of soil inoculation was no longer significant. For the second experiment, seedlings inoculated with local AMF were shorter after 6 weeks than those grown in sterilized or commercial AMF inoculated soil. After transplanting, seedlings inoculated with local AMF had higher nutrient content.
Implications: Using soil inoculated with local AMF can promote both native as well as non-native species growth on reclaimed mines. If seedlings are being transplanted as part of reclamation, germinating them first in soil inoculated with local AMF can also facilitate growth and nutrient processing post-transplant.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Espeland, E.K., Hendrickson, J., Toledo, D., West, N.M., and Rand, T.A., 2017, Soils determine early revegetation establishment with and without cover crops in northern mixed grass prairie after energy development: Ecological Restoration, v. 35, no. 4, p. 311–319.

DOI: https://doi.org/10.3368/er.35.4.311
Background: Cover crops are commonly used in agricultural systems to improve soil health. Techniques for applying cover crops to agricultural systems might also improve reclamation success.
Objectives: This study aimed to assess if cover crops compete or facilitate native grass establishment and rangeland health in oil field reclamation by testing two cover crop methods: (1) perennial grass with an oat cover crop, and (2) a single grass species with a cover crop cocktail of native grasses and forbs.
Methods: The experiments were part of interim reclamation on oil fields in 2014 and 2015. In the 2014 study, sites were seeded with two perennial grass mixes with or without an oat cover crop. In the 2015 study, sites were seeded with a single grass species with an oat cover crop or a cover crop cocktail using the broadcast seeding method. For both studies, the authors measured presence and frequency of species and assessed soil nutrients along transects. Rangeland health was determined using the Interpreting Indicators of Rangeland Health (IIRH) method.
Location: Fort Berthold Indian Reservation (New Town and Mandaree), North Dakota, USA
Findings: Soil nutrients affected plant establishment. Sites with poor overall establishment had depleted levels of phosphorus, and higher levels of calcium, iron, and manganese. There was no significant difference in native grass establishment between the cover crop and native grass only treatments. Cover crop presence increased rangeland health according to the IIRH.

Implications: The findings suggest that cover cropping has little effect on early establishment of native plants, but long-term studies on the benefits of cover crops are needed. Additionally, remediating or burying salt-contaminated soils might lead to greater plant establishment.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Etter, H.M., 1973, Mined-land reclamation studies on bighorn sheep range in Alberta, Canada: Biological Conservation, v. 5, no. 3, p. 191–195.

DOI: https://doi.org/10.1016/0006-3207(73)90009-8
Background: Winter range is important for sustaining populations of bighorn sheep (*Ovis canadensis*) in Alberta, Canada. Roughly 20 percent of bighorn sheep winter range in Alberta overlaps with coal leases, and the potential for expanding surface mining operations may threaten bighorn sheep survival. Reclaiming important winter range habitat is necessary for protecting this species.
Objectives: The author discussed the impacts of surface mining on bighorn sheep and necessary considerations for successful reclamation of sensitive winter range habitat.
Methods: The author reviewed bighorn sheep winter range ecology and protection. They discussed the potential threats from coal surface mining. They offered potential methods and necessary actions for successful reclamation of disturbed big horn sheep winter range habitat.
Location: Mined lands near Luscar, Alberta, Canada
Findings: Revegetation trials revealed several candidate species for use in reclaiming winter range habitat: *Agropyron cristatum*, *Agropyron trichophorum*, *Elymus junceus*, *Festuca rubra*, *Phleum pratense*, and *Medicago sativa*. However, appropriate aspect and soil characteristics are necessary for successful germination and long-term survival of these plants. In addition, feeding trials will be required to determine the nutritional value of these species for big horn sheep consumption.
Implications: Revegetating disturbed bighorn sheep winter range is possible, and potential candidate plant species have been identified. However, cooperation between mining companies and environmental agencies and long-term monitoring will be necessary for successful reclamation.
Topics: Mining, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Practices

Falk, A.D., Pawelek, K.A., Smith, F.S., Cash, V., and Schnupp, M., 2017, Evaluation of locally-adapted native seed sources and impacts of livestock grazing for restoration of historic oil pad sites in south Texas: Ecological Restoration, v. 35, no. 2, p. 120–126.

DOI: https://doi.org/10.3368/er.35.2.120
Background: Historical oil and gas pad sites can be difficult to restore, in part due to seed stocks that are not adapted to the planting site. These challenges, combined with grazing pressure in south Texas, make the success of restoration of old gas sites highly variable.
Objectives: The authors (1) tested the efficacy of using a locally adapted native seed mix to restore former oil and gas pad sites, and (2) determined the effect of cattle grazing on restoration success.
Methods: Well pads used for the experiment were prepared in 2011 by removing an artificial caliche base layer that had been added during well construction and ripping and disking the original native soil beneath. In September, each pad was sprayed with a mixture of glyphosate and 2,4-D amine herbicides and then immediately seeded. The seed mix was composed of 15 native perennial grass and 5 perennial forb and legume species. Seeding was done via a combination of drill seeding and hand broadcasting seeds that did not flow through the drill seeder. Three cattle grazing exclosures were installed on each pad site. Vegetation sampling occurred in the spring and fall for three consecutive years following seeding, and included evaluation of basal cover of each species, species density, and species richness.
Location: Two pads in Kleberg County, and two pads in the adjacent Jim Wells County within 2,000 meters (m) of each other on King Ranch (27°34′00.00″ N., 98°3′56.48″ W.) in south Texas, USA
Findings: Seven months after applying the native seed mix, the density of restored species was ≥0.9 plants per square meter (plants/m^2) consisting of, on average, eight different species. Continual moderate grazing had little impact on species density and richness, however, grazing marginally altered species composition.
Implications: Using high quality locally adapted seed mixes can improve the success of restoration on oil and gas well pads despite drought, soil limitations, and grazing.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Wildlife/Habitat Data, Reclamation Practices

Farrell, H.L., Barberán, A., Danielson, R.E., Fehmi, J.S., and Gornish, E.S., 2020, Disturbance is more important than seeding or grazing in determining soil microbial communities in a semiarid grassland: Restoration Ecology, v. 28, no. S4, p. S335–S343.

DOI: https://doi.org/10.1111/rec.13156

Background: Soil condition is immensely important for functioning and healthy ecosystems. Oil and gas development disturbs various chemical, structural, and functional properties of soil, which can take decades to restore. In some cases, as with arid dryland soils, severe disturbance may prevent full recovery despite reclamation efforts. Reclamation methods, such as seeding and grazing, also impact post-mine soil health. Vegetation outcomes and the response of soil conditions and soil microorganism communities to reclamation methods are useful metrics for assessing and altering reclamation protocols.

Objectives: The authors examined the influence of seeding and grazing on soil fertility and bacterial, fungal, and plant communities in a natural gas pipeline disturbance corridor three years after restoration.

Methods: Study plots were established immediately following pipeline construction. Six sections were randomly selected to be seeded, six sections to be left unseeded, and six sections adjacent to unseeded pipeline sections were marked as undisturbed controls; all sections measured 150 × 30 meters (m). A 1 × 1.5 m grazing exclosure was constructed within all sections at a minimum of 10 m away from treatment edges to avoid edge effects. In 2017, aerial vegetation cover data by species were recorded and soil samples were collected for all treatment combinations (*n*=4 seeded/not grazed; *n*=4 seeded/grazed; *n*=6 not seeded/not grazed; *n*=6 not seeded/grazed; *n*=6 undisturbed control/not grazed; *n*=4 undisturbed control/grazed). Soil samples were sent to a commercial laboratory for physicochemical analysis. The QIAGEN DNeasy Power-Lyzer PowerSoil kit was used to extract and analyze prokaryote and fungi genomic deoxyribonucleic acid (DNA). Data were analyzed using nested analysis of variance (ANOVA) with a false discovery rate correction in R.

Location: A 2 kilometer (km) stretch of the 30 m wide, 97 km long pipeline construction zone in the Sonoran Desert (32°15′12.4560″ N., 110°54′42.4404″ W.) southwest of Tucson in southern Arizona, USA

Findings: Plant cover was similar between the seeded and unseeded restoration treatments, though plant species richness was highest in the seeded restoration treatment. Grazing did not significantly affect plant species richness. Electric conductivity, pH, calcium, manganese, organic matter, and total herbaceous cover were lower in the undisturbed controls compared to restoration treatments. Maintaining the topsoil (whether it was seeded or unseeded) was the most influential factor determining plant, prokaryote, and fungal community composition; grazing did not influence community composition.

Implications: Grazing did not significantly impact soil or community characteristics and the unseeded treatment recovered similar vegetation cover, plant community composition, and microbial community composition compared to the seeded treatment. Topsoil redistribution and fertility played an important role in reclamation outcomes. Storing topsoil for less than two months before redistribution during reclamation is important for maintaining microbial function.

Topics: Pipeline, Vegetation Recovery Data, Soil Data, Reclamation Practices

Farrell, H.L., and Fehmi, J.S., 2018, Seeding alters plant community trajectory—Impacts of seeding, grazing and trampling on semi-arid re-vegetation: Applied Vegetation Science, v. 21, no. 2, p. 240–249.

DOI: https://doi.org/10.1111/avsc.12340

Background: Natural resource reclamation on semi-arid and arid lands is especially difficult due to climate and soil conditions that impact revegetation. Direct seeding is the most common seeding method due to low cost and large-scale application and seeding time can have long-term “priority effects” on resulting plant communities (some species suppress others). Additionally, livestock and vehicular traffic can impact species establishment and presence (like introducing nonnative species) and, ultimately, plant community composition. Understanding the interactions among seeding and soil disturbance could improve revegetation in disturbed semi-arid and arid environments.

Objectives: The authors evaluated the effects of seeding, cattle grazing, and vehicular use on vegetation establishment, community trajectories, and soil movement in newly reclaimed pipeline right-of-way (ROW).

Methods: Within a pipeline ROW, researchers randomly selected 18 plots; nine were seeded with an 18-species mix and nine were left unseeded. Adjacent to the ROW, nine plots were selected as undisturbed unseeded controls. All 27 plots were 30 × 45 meters (m). Within each plot, grazed-trampled, grazed-untrampled, and ungrazed-untrampled 2 × 1.5 m subplots were established. One year after reclamation, undesirable plant cover, herbaceous biomass, species richness, and soil movement

were measured in 0.16 square meter (m^2) quadrats. Plant community trajectories were compared between treatment plots to undisturbed plots. Data were analyzed with linear mixed-effects nested analysis of variance (ANOVA) and non-metric multidimensional scaling.
Location: A 2.5-kilometer (km) section of a 30-m-wide pipeline construction zone/ROW (32°15′12.4560″ N., 110°54′42.4404″ W.) roughly 48 km south of Tucson, Arizona, USA
Findings: Seeded sites had significantly greater native plant cover compared to undisturbed control plots, and higher species richness than both unseeded and undisturbed plots. Reclaimed but unseeded plots had significantly higher cover of undesirable species compared to undisturbed plots, and higher cover than reclaimed and seeded plots, but this was a not significant difference. Nonmetric multidimensional scaling (NMDS) analysis found that plant species assemblages were similar between undisturbed sites and reclaimed and unseeded sites, dominated by annual species; reclaimed and seeded sites had a different assemblage dominated by perennial species which were components of the seed mix. Grazed-trampled plots had significantly reduced native plant cover, species richness, and herbaceous biomass, and increased soil erosion compared to ungrazed and untrampled subplots; undesirable species were not significantly reduced.
Implications: Natural revegetation of reclaimed semi-arid and arid lands is possible if the seed bank is intact and local recruitment is possible. If seeding is necessary, using a seed mix with additional species may alter plant community trajectories. Land and reclamation managers should limit grazing and trampling in reclaimed areas to reduce negative impacts to native species.
Topics: Pipeline, Vegetation Recovery Data, Erosion Data, Reclamation Practices

Fehmi, J.S., 2018, Research note—A rock mulch layer supported little vegetation in an arid reclamation setting: Arid Land Research and Management, v. 32, no. 2, p. 253–256.

DOI: https://doi.org/10.1080/15324982.2017.1391356
Background: Constructed slopes like mine tailings are expected to last for long time spans, for example, “50 to 200” years, 1,000 years or “in perpetuity.” A surface rock layer (rock amor or rock mulch) is often used to reduce erosion and maintain slope stability over time. However, revegetation can also maintain slope stability and is more visually pleasing and similar to undisturbed sites. In arid and semiarid environments, vegetation of main tailings is a difficult and fragile process, so combinations of rock and vegetation layers are often used. Investigating the appropriate amount of rock material could increase mine tailing revegetation success.
Objectives: The author evaluated the ability of rock layers to support vegetation in a semiarid reclamation setting.
Methods: In June 2013, a reclamation scenario was simulated by removing all vegetation, excavating soil to 46-centimeters (cm) deep, then replacing the soil. Within the simulated disturbance, 91 × 91 cm study plots were established; these were separated by 2 meters (m) and there was a 3 m disturbance buffer around plots. Local rocks were collected, including from granitic and metamorphic sources (at 31°50′34.30″ N., 110°45′05.96″ W.; 1,615 m) and several fan-alluvium sources (near 31°49′20.48″ N., 110°44′03.62″ W.; 1,501 m). Rocks were with 5–20 cm diameter were placed in layers that were either 10 cm, 15 cm, or 20 cm thick in the plots; control plots did not receive rocks. The four treatments were replicated four times in a randomized study design. In July and August 2013, and June and August 2014, plots were hand seeded with a commercial 10-species seed mix at 550 seeds per square meter (seeds/m^2) as recommended for the region. In 2016, cover of all rooted vegetation in the center 50 × 50 cm section of each plot was assessed. Data were analyzed by analysis of variance (ANOVA).
Location: University of Arizona Agricultural Center (32°16′51.77″ N., 110°56′13.14″ W.; 716 m) within the Sonoran Desert in Tucson, Arizona, USA
Findings: Control plots had significantly more vegetation compared to plots with rocks. Seeded species made up only 5 percent of vegetation; the majority of vegetation were locally recruited volunteer species. Vegetation cover decreased significantly as rock layer thickness increased. Exposed soil at plot edges had the most vegetation, suggesting conditions under the rock layers were inhospitable for growth.
Implications: For the study site, rock layers <10 cm thick may result in vegetation growth within 3 years; for thicker rock layers, vegetation growth would likely take >3 years to occur. This study suggests that a mosaic of rocks and local soil or growth medium may be a more productive technique to encourage plant growth and slope stabilization.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Fehmi, J.S., and Kong, T.M., 2012, Effects of soil type, rainfall, straw mulch, and fertilizer on semi-arid vegetation establishment, growth and diversity: Ecological Engineering, v. 44, p. 70–77.

DOI: https://doi.org/10.1016/j.ecoleng.2012.04.014
Background: In semiarid and arid environments disturbed by mining, reclamation is complicated by unpredictable rainfall and variable soil moisture capacity. In addition, reclamation practices applied on less disturbed soils may be inappropriate for heavily disturbed soils (for example, mine tailings, dams, and waste rock) that were brought to the surface from several meters deep and have different texture than surface soils. Soil amendments like straw mulches and fertilizer can help increase soil moisture, prevent runoff, and increase revegetation on disturbed soils. Understanding the interactions among these amendments, rainfall, and soil texture is important for successful reclamation planning.
Objectives: The authors evaluated the effects of straw mulch and fertilizer on biomass, species richness, and diversity in various soil textures in both wet and dry years in a semiarid environment.
Methods: A greenhouse experiment was set up to replicate a proposed mine "target site" using a randomized complete block design with three simulated rainfall scenarios (to mimic the target site's bimodal annual precipitation pattern in wet and dry years), three amendment levels (bare soil, tackified straw, and tackified straw+fertilizer), and three soil types (very gravelly sand, very gravelly loamy sand, and very gravelly sandy loam). Each unique treatment combination was replicated four times for total of 432, 15-liter (L) pots. Four seed mixes (with 28 native species) were hand sown into pots and used as a blocking factor to broaden research application. Soils were analyzed for physical and chemical characteristics. The number of established plants were tallied every 2–4 or 3–4 weeks and tissue samples were collected for biomass calculations. Data were analyzed using multivariate analysis of variance (MANOVA) and univariate analysis of variance (ANOVA).
Location: Greenhouses at the University of Arizona Agricultural Center with environmental conditions mimicking a proposed mine reclamation site (target site; 31°53.447′ N., 110°46.046′ W.; 1,500 meters [m] elevation) 80 kilometers (km) southeast of Tucson, Arizona, USA
Findings: Interactions among all treatments and soil type were significant. Straw alone or with fertilizer significantly increased aboveground biomass compared to bare soil (72–177 percent) on the gravelly sandy loam and very gravelly loamy sand soils, but decreased biomass on the very gravelly sand, although only significantly so in fertilized plots (54 percent). Straw with fertilizer resulted in >50 percent decline in establishment (density) for all soil types; straw without fertilizer only significantly reduced establishment on the very gravelly sand. Straw (with or without fertilizer) significantly increased aboveground biomass in the low (205–217 percent) and average rainfall scenarios (40–52 percent) but on increased biomass in the high scenario when applied with fertilizer (48 percent). Overall, plant establishment was reduced in the low rainfall scenario and very gravelly sand soil.
Implications: Both straw and fertilizer increased biomass in at least some plots but had negative effects in others. Ultimately, site-specific characteristics will likely drive choice or techniques to improve plant establishment. Soil texture plays a major role in revegetation and is a factor that land managers should heavily consider when developing reclamation plans.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Ferguson, R.B., and Frischknecht, N.C., 1985, Reclamation on Utah's Emery and Alton coal fields—Techniques and plant materials: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-335, 78 p.

Link (non-DOI): https://www.osti.gov/biblio/5907600
Background: Utah's potential coal surface mining lands are in semiarid and arid environments, which complicate successful revegetation following mining disturbance. While Utah has not yet undergone large-scale surface mining, the Emery and Alton coal fields present opportunities to experimentally determine the most successful site preparation and revegetation methods. Identifying best management practices and reclamation methods before large-scale mining occurs can help increase reclamation success as the industry grows.
Objectives: The authors determined effective site preparation and revegetation methods for use in future coal surface mining reclamation in Utah using the Emery and Alton coal fields as sites for multiple experiments each.
Methods: At the Emery coal field, an experimental site was prepared in 1977 by removing the first 12 to 15 inches (in) of topsoil and ripping 30 in deep. Soil amendment treatments were then applied, including grass hay, alfalfa hay, or composted conifer bark. Plots were broadcast seeded. In 1978, measurements on plant establishment were taken within 10 square feet (ft^2) randomly placed frames in each treatment area, including frequency, density, and the average blade height of grass species, and frequency,

density, and average height of shrub species. In additional plots, the effects of hay and composted bark amendments were tested on select grass species. Container-grown shrubs, globemallow, and alkali sacaton were planted and 12 pinyon and 19 juniper trees were transplanted to determine ease of reestablishment after disturbance. Microclimate data were collected using an automatic logger and the experimental sites were monitored for five years. At the Aldon coal field, several treatments were applied to determine erosion risks, including topsoil removal, subsoil ripping, topsoil replacement, area gouging, and seeding treatments. Ideal revegetation species were determined using several field experiments and a greenhouse bioassay study. Microclimate data were collected in the same way as at the Emery coal field, and the experimental sites were monitored for six years.
Location: Emery coal field in central Utah and Alton coal field in southwestern, Utah, USA
Findings: At the Emery coal field, general shrub and grass frequency declined over the 5-year study. Pinyon and juniper mortality varied by height. Results were impacted by precipitation that varied across years from drought to above-average conditions. At the Alton coal field, broadcast seeding of grasses and legumes was successful even without raking in the seed. Returning quality topsoil post-disturbance greatly benefited revegetation and a variety of plant species successfully established.
Implications: This report provides useful information regarding revegetation of semiarid and arid environments in Utah and can guide reclamation planning following mining disturbance. Land managers should consider reviewing these results when selecting revegetation species and site preparation methods.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Fifield, C., Booth, T., Cox, S. and Cagney, J., 2008, Monitoring a level 5 watershed with very-large scale aerial imagery, *in* 61st Annual Meeting Society for Range Management, Louisville, Ky., 2008, Poster: Society for Range Management, 2 sheets.

Link (non-DOI): https://www.researchgate.net/publication/284157036_Monitoring_a_Level_5_Watershed_with_Very-Large_Scale_Aerial_Imagery
Background: Monitoring reclamation success and evaluating landscape-level conditions (like that of a watershed) are resource- and time-limited, with on-the-ground data collection taking up to two months with a limited scope. For this type of monitoring, very-large scale aerial (VLSA) imagery is a potential method for streamlining and increasing data collection and reducing resource needs. Testing VLSA methods for watershed and rangeland reclamation assessments could lead to more efficient and informative data collection in the future.
Objectives: The authors evaluated the use of VLSA imagery to assess reclamation success in a watershed-level monitoring effort.
Methods: A four-phase project to collect and analyze data was conducted. In phase I, a two-camera system was mounted on a Moyes-Bailey Dragonfly light airplane to collect 3,600 geocoded aerial images (samples) representing 244,000 acres of a 450,660-acre watershed. The image analysis software VegMeasurement was used to measure percent bare ground as a primary indicator of rangeland and watershed health. In phase II, the image analysis software SamplePoint was used to measure sage-grouse lek habitat within the study site. In phase III, aerial imagery of major drainages was collected to evaluate channel condition, riparian habitat, and salt cedar invasion. In phase IV, aerial imagery was collected on the oil and gas pipeline right-of-way to assess reclamation success. Data were analyzed separately by phase; some data were not fully analyzed at the time of presentation.
Location: Salt Creek Watershed 14 miles (mi) north of Casper, Wyoming, USA
Findings: Bare ground measurements correlated with expected values and field data. Percentage of bare ground was higher on locations within oilfields compared with those outside of oilfields. Phase II analysis was incomplete when presented, but in 29 percent of the images containing ant hills (important for sage-grouse chick diets), the ant hills were located within 0.5 mi of highly concentrated sage-grouse scat locations. Plant species were difficult to identify in aerial images. Phase III data were not assessed at the time of presentation. Pipeline vegetation cover (74 delete) was just below the reclamation success measurement (75 delete). Data acquisition costs were $0.07/acre ($0.22/sampled location).
Implications: Analysis was time-intensive, comparable to field evaluation, but VLSA methods saved field travel time and costs. Images must be evaluated by highly experienced individuals. Currently, there is no alternative method for acquiring these data. No civilian unmanned aerial systems can capture 1 millimeter (mm) ground sample distance imagery or cover 244,000 acres in a reasonable timeframe. Contractors using standard fixed-wing aircraft cannot capture better than 30 mm ground sample distance over so large an area. The described equipment set was unique and designed to meet Bureau of Land Management (BLM) watershed-monitoring needs. Without further agency support and development, it is unlikely that contractors will invest in the types of equipment needed to do similar aerial survey.
Topics: Pipeline, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Monitoring, GrayLit

Fisher, J.T., Fancher, G.A., and Aldon, E.F., 1990, Factors affecting establishment of one-seed juniper (*Juniperus monosperma*) on surface-mined lands in New Mexico: Canadian Journal of Forest Research, v. 20, no. 7, p. 880–886.

DOI: https://doi.org/10.1139/x90-118
Background: Pinyon-juniper woodlands are at risk of disturbance from surface mine operations. Restoring these woodlands in the arid southwestern United States is complicated by climate variables, seed predation, and competition. In 1981, the United States Forest Service began experimenting with propagating one-seed juniper for transplanting during revegetation efforts on reclaimed surface mines. Research into survival and growth on transplants is necessary for future efforts.
Objectives: The authors evaluated survival and growth of one-seed juniper transplants five years after planting, and assessed the effects of planting date, mulch, predation prevention, fertilization, and site conditions on transplant establishment.
Methods: Three experiments were conducted at two sites (experiments 1 and 2 at the Zia Mine and experiment 3 at the McKinley Mine) to test various treatment effects on one-seed juniper seedling survival. Experiment 1 used a complete randomized block design with four replicates to test the effects of three fertilizer treatments, two seedling protections (with or without), and two wood chip mulch levels (with or without). Experiment 2 fully crossed two mulch levels (with or without) with four fertilizer treatments and included additional seedling protection; four replicates were again used. Experiments 1 and 2 were conducted on a 0.25-hectare (ha) area with all standing vegetation mechanically removed prior to installation. Experiment 3 used a complete randomized block design with six replicates to test the effect of three planting dates (August, September, and November), two fertilizers, and two rodent protection treatments. Survival and growth of plant species was monitored for all experiments and data were analyzed using general linear models.
Location: Zia and McKinley mines near Grants and Gallup, New Mexico, USA
Findings: In experiment 1, protection increased seedling survival and growth but there was no effect of fertilizer or mulch unless restricted to protected seedlings only, in which mulch increased growth but not survival. In experiment 2, overall survival decreased over time, however, seedlings in mulched plots had higher survival; there was no effect of fertilizer. Growth was higher with seedling protection. In experiment 3, while overall survival decreased, planting date affected seedling survival and growth (negatively correlated over time); there was no effect of fertilizer, but protection was beneficial to survival.
Implications: For one-seed juniper, predator protection is one of the most important considerations for successful growth and survival after transplantation to reclaimed surface mines. Fertilizer and mulch are less affective, though may prove useful for specific site conditions. Planting earlier in the fall (August) may lead to more successful transplantation.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Fisher, J.T., Fancher, G.A., and Neumann, R.W., 1986, Survival and growth of containerized native juniper (*Juniperus monosperma*) on surface-mined lands in New Mexico: Forest Ecology and Management, v. 16, no. 1–4, p. 291–299.

DOI: https://doi.org/10.1016/0378-1127(86)90029-0
Background: In the southwestern United States, harsh climate variables, predation, and competition complicate revegetation of disturbed lands. The pinyon-juniper woodland habitat is extensive across the southwest and is often the dominant vegetation type on surface mine lands. While revegetation with native pinyon-juniper woodland species is preferred, they are not often used during reclamation because of complications with establishment. Understanding factors that affect propagation could improve successful transplantations and revegetation.
Objectives: The authors assessed the effects of planting date, mulch, rodent protection, and fertilization on the survival and growth of containerized juniper seedlings two years after transplanting on disturbed surface mine spoil banks.
Methods: Three experiments were conducted (experiment 1 at York Canyon Mine, experiment 2 at McKinley Mine, and experiment 3 at Zia Mine) to test various treatment effects on juniper seedling survival. For experiment 1, a split-plot randomized block design with six replicates was used to test the main plot effects of drip irrigation and straw mulch; six subplots were randomly assigned in each main plot, which included three planting dates (July and August 1981 and May 1982) crossed with one of two fertilizer treatments. Experiment 2 used a randomized complete block design with six replicates to test the effect of three planting dates, two fertilizers, and two rodent protection treatments. Experiment 3 crossed two mulch levels (with or without) with four fertilizer treatments, and included a seedling protection treatment, each with four replicates.
Location: York Canyon, Zia, and McKinley mines in New Mexico, USA

Findings: In experiment 1, the earliest planting date had the highest survival. The drip irrigation/no fertilizer subtreatment had higher survival across time except August. Fertilizer decreased seedling survival across time. In experiment 2, the earliest planting date had higher survival. The protection/no fertilizer subtreatment had the highest survival across time except for September. In experiment 3, mulched plots had higher survival. Although unprotected seedlings in the control treatment survived, nearly all had rodent damage.
Implications: For containerized native juniper, predator protection is one of the most important considerations for successful growth and survival after transplantation to reclaimed surface mines. Planting after June drought was critical to trees, although timing varied by elevation with July the most successful month for the higher elevation more mesic sites and August more successful for the lower elevation more xeric site. Fertilizer and mulch are less affective, though may prove useful if combined with irrigation.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Fleisher, K.R., and Hufford, K.M., 2020, Assessing habitat heterogeneity and vegetation outcomes of geomorphic and traditional linear-slope methods in post-mine reclamation: Journal of Environmental Management, v. 255, p. 1–9.

DOI: https://doi.org/10.1016/j.jenvman.2019.109854
Background: Traditional surface mining reclamation methods often result in homogenous and simplified topography that does not reestablish natural landscape features. Geomorphic reclamation is a new and novel approach that incorporates surrounding landscape elements by mimicking stable landforms to reduce erosion. Geomorphic reclamation increases landscape heterogeneity and leads to more natural looking reclaimed mines. However, the success of geomorphic reclamation methods compared to traditional methods is not well known.
Objectives: The authors compared revegetation success in semiarid rangelands between sites with traditional and geomorphic reclamation methods to determine (1) differences in vegetation characteristics between the two methods, (2) if standard indicators of reclamation success are achieved with geomorphic methods, and (3) if sites reclaimed with geomorphic methods are more similar to undisturbed rangeland relative to sites reclaimed with traditional methods.
Methods: Two separate reclaimed surface mines were selected (Gas Hills and Lionkol), each with sections of traditional and geomorphic treatments areas. Each study site was divided into three treatments (geomorphic reclamation, traditional reclamation, and undisturbed rangeland) and remote sensing was used to assess landscape features. In May and July of 2017 and 2018, vegetation data were collected along sixty 15-meter (m) line-point intercept transects per study area (20 in each treatment). Data were analyzed with linear mixed effect models and metric multidimensional scaling.
Location: Central Spoils Reclamation Project at the former Gas Hills uranium mine in Fremont County (42.785728° N., 107.667358° W.) and the Lionkol Drainage Reclamation Project at a former coal mine in Sweetwater County (41.650486° N., 109.163387° W.) in Wyoming, USA
Findings: At Gas Hills, more species were identified on the undisturbed site (31) compared with geomorphic (22) and traditional (23) treatments. Total and native species diversity were also higher in undisturbed rangeland compared to reclamation areas; between treatments, diversity was higher on the geomorphic treatment (significant for Simpson’s index and borderline significant for Shannon-Weaver), and more similar to the undisturbed site. Wyoming big sagebrush and rabbitbrush had higher abundance on the geomorphic treatment compared to traditional treatment. At Lionkol, geomorphic and traditional treatments had the same number of species (17), which was lower than the undisturbed site (30). Reclaimed treatments were more similar to each other than the undisturbed site. At both sites, “Pryor” slender wheatgrass (*Elymus trachycaulus* ssp. *trachycaulus*) was the most common species on reclaimed sites.
Implications: Geomorphic reclamation methods can increase species diversity and richness and may be more successful than traditional methods at reestablishing foundation species like sagebrush. However, both reclamation methods were still more similar to each other than undisturbed sites. Longer term studies are needed to better assess the success and value of geomorphic reclamation methods.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Fowers, B., Mealor, B.A., and Kniss, A.R., 2014, Developing weed management strategies to improve reclamation of drastically disturbed lands, *in* University of Wyoming Agricultural Experiment Station Field Days Bulletin 2014: Laramie, Wyo., University of Wyoming, p. 109–110.

Link (non-DOI): https://www.uwyo.edu/uwexpstn/publications/field-days-bulletin/2014-field-days-bulletin.pdf
Background: Successful reclamation of disturbed areas is crucial in establishing desirable plant communities for wildlife conservation. In arid and semiarid environments, this can be difficult because invasive species establish readily and lead to high levels of noncompliance for reclaimed coal-bed methane sites. Determining the effects of herbicides and season of application on weed control could improve reclamation of arid and semiarid environments.
Objectives: The authors investigated how various herbicide treatments (chemical, rate, and application timing) affect reclamation and which species may establish best in these settings.
Methods: Field trials were established at three research centers in Wyoming. In fall 2011 and spring 2012, ten different seeding treatments were applied; seed mixes were composed of plant species commonly used in reclamation. Six pre-emergent herbicide treatments were applied in fall 2011 around the time of seeding. Eight post-emergent treatments were applied in spring 2012. Vegetation measurements included species establishment and growth, percent vegetation cover, and weed control.
Location: Sheridan Research and Extension Center, Laramie Research and Extension Center, and near Ucross in northeast Wyoming, USA
Findings: Most herbicide treatments were not significantly effective on annual grasses, but imazapic and rimsulfuron (two grass-specific herbicides) were the most effective. Herbicide effectiveness varied by seeding season. Herbicides, such as aminopyralid and those with aminocyclopyrachlor, had the best control on annual forbs. Season of application had little effect on weed control.
Implications: Herbicides that target grasses, such as imazapic and rimsulfuron, may reduce the establishment of invasive species on reclaimed sites.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Fowers, B., Mealor, B.A., and Kniss, A.R., 2014, Developing strategies to improve reclamation seeding of drastically disturbed lands, *in* University of Wyoming Agricultural Experiment Station Field Days Bulletin 2014: Laramie, Wyo., University of Wyoming, p. 111–112.

Link (non-DOI): https://www.uwyo.edu/uwexpstn/publications/field-days-bulletin/2014-field-days-bulletin.pdf
Background: Successful reclamation of disturbed areas is crucial in establishing desirable plant communities for wildlife conservation. In arid and semiarid environments, this can be difficult because invasive species establish readily and lead to high levels of noncompliance for reclaimed coal-bed methane sites. Determining the effects of herbicides and season of application on weed control could improve reclamation of arid and semiarid environments.
Objectives: The authors evaluated desirable species' ability to establish following reclamation and the effect of herbicide application on species establishment.
Methods: Field trials were established at three dryland locations in Wyoming. In fall 2011 and spring 2012, ten different seeding treatments composed of plant species commonly used in reclamation were planted, including single-species grasses and forb/shrub mixes. Single species plantings included: "Arriba" western wheatgrass at 12 pounds of pure live seed per acre (lb PLS/ac), "Sherman" big bluegrass at 4 lb PLS/ac, "Trailhead" basin wildrye at 12 lb PLS/ac, "Anatone" bluebunch wheatgrass at 14 lb PLS/ac, "Sodar" streambank wheatgrass at 12 lb PLS/ac, alkali sacaton at 2 lb PLS/ac, "Hycrest" crested wheatgrass at 9 lb PLS/ac and "Bozoisky" Russian wildrye at 12 lb PLS/ac. Six pre-emergent herbicide treatments were applied in fall 2011 around the time of seeding and eight post-emergent treatments were applied in spring 2012. Researchers measured species establishment and growth, percent vegetation cover, and weed control.
Location: Sheridan Research and Extension Center, Laramie Research and Extension Center, and near Ucross in northeast Wyoming, USA
Findings: At the Laramie and Ucross sites, low precipitation resulted in minimal seedling emergence. At the Sheridan site, light disking was performed to reduce grass density, which resulted in increased seedling establishment in spring plots. Crested wheatgrass, Russian wildrye, and native wheatgrasses had the greatest emergence.

Implications: For reclamation goals requiring establishment of perennial plant cover (not necessarily native plants), crested wheatgrass, Russian wildrye, and native wheatgrasses may be candidate species for reclamation following natural resources extraction in Wyoming.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Fowers, B., Mealor, B.A., and Kniss, A.R., 2015, Evaluating direct herbicide impacts on desirable species used in reclamation, *in* University of Wyoming Agricultural Experiment Station Field Days Bulletin 2015: Laramie, Wyo., University of Wyoming, p. 21–22.

Link (non-DOI): https://www.uwyo.edu/uwexpstn/publications/field-days-bulletin/2015-field-days-bulletin.pdf
Background: Natural resources extraction directly impacts native plant communities. Herbicides can be used during reclamation efforts to control weeds and cultivate the desired plant community following reseeding. However, the direct effects of herbicides (excluding environmental variables) are poorly studied, and herbicide application could have unintended consequences that slow successful reclamation efforts.
Objectives: The authors evaluated impacts of different herbicides at various timings on the growth of desirable and weed species for reclamation use following natural resource extraction.
Methods: Researchers planted 14 different desirable and weedy species in 1 × 6.3-inch (in.) containers with a 3:1 mixture of potting medium and sand. Ten different herbicide x rate combinations were applied in a spray chamber delivering 20.13 gallons per acre (gal/ac) at 40 pounds per square inch (PSI) at three different growth stages: preemergence, postemergence 30 days after planting, and postemergence 53 days after planting. Non-treated plants served as controls. Plant injury was assessed weekly. All plants were harvested 83 days after planting, dried for biomass measurements at 140 °F for 48 hours, and weighed to the nearest milligram.
Location: A greenhouse experiment at the University of Wyoming
Findings: Herbicide application timing was significant for all species and herbicides. Herbicide damage was greatest when applied preemergence and decreased as days after planting increased. When comparing non-treated and treated plants, streambank wheatgrass, blue grama, and crested wheatgrass were less affected by herbicide while other plant species such as basin wildrye and big bluegrass, and especially all forbs, were more sensitive.
Implications: Herbicide application, especially preemergence, can be effective in decreasing the growth of unwanted species in reclamation efforts. However, application should be weighed carefully if forbs are a desired species as they show increased sensitivity to herbicide treatment. When using herbicide, land managers should weigh the consequences of negatively impacting desired species through application or reducing efficiency on unwanted weed species if application is delayed.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Fowers, B., Mealor, B.A., and Kniss, A.R., 2015, Developing strategies to improve reclamation success of drastically disturbed lands, *in* University of Wyoming Agricultural Experiment Station Field Days Bulletin 2015: Laramie Wyo., University of Wyoming, p. 125–126.

Link (non-DOI): https://www.uwyo.edu/uwexpstn/publications/field-days-bulletin/2015-field-days-bulletin.pdf
Background: Successfully establishing native plant communities following disturbance, such as coal-bed methane activity, is often hindered by the establishment of undesirable vegetation. Weeds and non-native species readily take root in exposed soil, preventing native plant species colonization. Methods such as herbicides may be effective for reducing weeds and lead to more successful reclamation efforts.
Objectives: The authors assessed how various herbicide treatments affected weed control in a reclamation setting, the effect of seeding season on desired species establishment, and which desirable species successfully establish following reclamation.
Methods: Field trials were established at three dryland locations in Wyoming. In fall 2011 and spring 2012, ten different seeding treatments composed of plant species commonly used in reclamation were planted, including single-species grasses and forb/shrub mixes. Single species plantings included: “Arriba” western wheatgrass at 12 pounds of pure live seed per acre (lb PLS/ac), “Sherman” big bluegrass at 4 lb PLS/ac, “Trailhead” basin wildrye at 12 lb PLS/ac, “Anatone” bluebunch wheatgrass at 14 lb PLS/ac, “Sodar” streambank wheatgrass at 12 lb PLS/ac, alkali sacaton at 2 lb PLS/ac, “Hycrest” crested

wheatgrass at 9 lb PLS/ac, and "Bozoisky" Russian wildrye at 12 lb PLS/ac. Six pre-emergent herbicide treatments were applied in fall 2011 around the time of seeding. Eight post-emergent treatments were applied in spring 2012. Researchers measured canopy cover of all species and biomass of seeded species in 2014.
Location: Sheridan Research and Extension Center, Laramie Research and Extension Center, and near Ucross, Wyoming
Findings: Annual forbs occurred in higher numbers at most sites and herbicides including aminocyclopyrachlor most effectively reduced weed pressure. Most herbicides used were broadleaf specific, however, at one site where annual grasses were dominant, two grass herbicides were substituted. Season of seeding had the most impact on reducing weed cover. Seeded species' response depended on site, species, and herbicide application, but the most successful species included crested wheatgrass, Russian wildrye, basin wildrye, and western and streambank wheatgrasses. Herbicide applications resulting in higher desirable cover included aminocyclopyrachlor and aminopyralid products.
Implications: Herbicide impacts were beneficial at weed dominated sites and aminocyclopyrachlor and aminopyralid combinations showed greatest weed management and desirable species responses. Use of wheatgrass and wildrye species was most successful in establishment across the sites.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Fresquez, P.R., and Lindemann, W.C., 1982, Soil and rhizosphere microorganisms in amended coal mine spoils: Soil Science Society of America Journal, v. 46, no. 4, p. 751–755.

DOI: https://doi.org/10.2136/sssaj1982.03615995004600040017x
Background: Surface mining destroys the landscape and alters vegetation and soil communities. In strip mining operations, the surface soil is removed and stored in stockpiles for several years before being respread over the area during reclamation. Storage alters the physical and chemical properties as well as the organic matter and biological communities of the soil. In the southwestern United States, topsoil for respreading is sparse so mine spoil is often used; however, spoil is generally of poor quality for revegetation purposes. Amending spoil could improve revegetation success in cases where topsoil is unavailable.
Objectives: The authors compared the microbial characteristics of mine spoil and soil and assessed the effect of spoil amendment on these characteristics.
Methods: Samples were collected from four sites at the San Juan coal mine to determine baseline microbial numbers: (1) a 1-year-old non-vegetated spoil bank, (2) a topsoil stockpile that was at least 1 year old, (3) a reclaimed area, and (4) an undisturbed surface soil. For the greenhouse study, soil from a non-vegetated spoil bank and a topsoil stockpile were collected to use as growing media; chemical and physical properties of the soils were reported. A randomized block design was established with four replicates for each of six treatments was established in the greenhouse: (1) spoil alone, (2) spoil+topsoil inoculant (224 metric tons per hectare [t/ha]), 3) spoil+alfalfa hay (22.4 t/ha) +fertilizer (336 kilograms [kg] urea and 336 kg phosphorus pentoxide/ha), 4) spoil+alfalfa hay+fertilizer+topsoil, 5) spoil+sewage sludge (89.6 t/ha), and 6) spoil+sewage sludge+topsoil. Fourwing saltbush was planted in each pot in September 1979 and later thinned to two plants per pot. In April 1980, rhizosphere samples were collected from each pot for microbial analyses, including rhizobial microbe numbers, dehydrogenase activity, and isolation of fungal colonies by genera.
Location: Greenhouse experiment using soil and spoil samples collected from the San Juan coal mine near Farmington, New Mexico, USA
Findings: Undisturbed soil and reclaimed soil had higher microbial numbers, dehydrogenase activity, and number of fungal genera than the stockpile topsoil or spoil; the spoil had the lowest values across all metrics. Stockpiled topsoil microbial characteristics were most similar to that of spoil. Topsoil inoculation only increased fungal genera. Sludge-amened soils had high occurrence of *Rhizopus*. Organic amendment affected fourwing saltbush rhizosphere populations.
Implications: Organic amendment is more useful than topsoil inoculation for improving microbial communities. However, this was a greenhouse experiment and environmental variables may alter results in the field. Regardless, either method is recommended when using mine spoil in place of topsoil for reclamation.
Topics: Mining, Target Plant Recovery Data, Soil Data, Reclamation Practice

Fresquez, P.R., and Wolters, G.L., 1990, The composition of soil fungi occurring on reclaimed areas of the McKinley coal mine: International Journal of Surface Mining and Reclamation, v. 4, no. 2, p. 43–45.

DOI: https://doi.org/10.1080/09208119008944166
Background: Coal mining alters fungal communities, though research shows that fungal communities can reestablish in mine spoil with time since disturbance. Comparing mine spoil fungal community characteristics at undisturbed and variously aged, reclaimed sites can provide a better understanding of fungal community regeneration.
Objectives: The authors characterized and compared the soil fungal communities among an undisturbed site and three reclaimed sites of varying age (1-, 6-, and 11-years post reclamation).
Methods: Reclaimed mining sites that had been recontoured, topsoiled, fertilized, mulched, and seeded in 1977, 1982, and 1987, as well as an undisturbed control site, were identified for the study. Three 12.2 × 18.3-meter (m) study plots were installed at all four sites for a total of 12 plots. Five subsamples were collected and combined into a composite sample for each study plot for analysis of chemical and physical properties, as well as for estimation of fungal spore number using dilution and plating techniques.
Location: McKinley Coal Mine in west-central New Mexico, USA
Findings: The most recently reclaimed site had more fungal spores compared to older reclaimed sites and the undisturbed site, likely due to the addition of fertilizer. Older reclaimed sites had fungal spore counts closer to the undisturbed site. Fungal populations appeared stable by six years post-reclamation. Fungal species differed between reclaimed and undisturbed soils, likely due to difference in plant species between reclaimed and undisturbed soils. The older reclaimed sites had similar fungal diversity as the undisturbed site.
Implications: Stockpiled topsoil has low fungal density and transferring live topsoil may provide more fungal diversity and abundance when used for reclamation. Increased fungal diversity may also contribute to competition among an increased diversity of plant species post-reclamation.
Topics: Mining, Soil Data, Reclamation Practices

Gasch, C.K., 2013, Recovery of soil properties, sagebrush steppe community structure, and environmental heterogeneity following drastic disturbance and reclamation: Laramie, Wyo., University of Wyoming, Ph.D. dissertation, 143 p.

Link (non-DOI): https://www.uwyo.edu/wrrc/_files/docs/theses_dissertations/gasch_caley.pdf
Background: Sagebrush steppe rangelands are home to several wildlife species of conservation concern. Additionally, these ecosystems are important for energy development, livestock grazing, and recreation. Disturbances from pipeline development affect soil and plant communities. Reclamation efforts after disturbance vary and it is important to understand how disturbance affects soil properties and heterogeneity across time.
Objectives: The author (1) examined variability in soil properties across different age disturbances following restoration; (2) determined how sampling design, analysis, and inference from spatial and non-spatial soil data differs; and (3) assessed reclamation along a chronosequence of restored pipelines.
Methods: Vegetation data, soil organic carbon (SOC), total nitrogen (N), microbial community structure, moisture, salinity, and alkalinity were measured on reclaimed pipelines. Reclaimed areas were compared to reference sites using Bayesian modeling. Soil samples were collected in a non-spatial, randomized, and a spatially explicit manner in disturbed and undisturbed reference areas. Additionally, a spatially explicit sampling design was used to sample vegetation and soil samples along a chronosequence of buried and restored pipelines from 1 to 54 years.
Location: Near Wamsutter (41°41′17.11″ N., 107°58′24.41″ W.; elevation 2,052 meters [m]), Wyoming, USA
Findings: Disturbance affects variance in soil properties, especially those associated with above ground vegetation. Soil properties became more similar to reference sites over time. Soil mixing, common in reclamation, reduces heterogeneity in the soil. More recent disturbances are characterized by weedy plant species followed by grass cover. Even after 55 years diversity and shrub establishment were low. Soil properties in the chronosequence study were variable across sites. While microbial abundance is correlated with above-ground vegetation, other soil properties were not. Disturbance increases soil homogenization.
Implications: Disturbance to sagebrush steppe landscapes has long lasting impacts to soil and vegetation characteristics. Restoration of soil properties is likely coupled with vegetation recovery. Therefore, shrub establishment during reclamation may help restore soil properties and should be emphasized. Spatial assessment of soil properties (as opposed to non-spatial random sampling) can improve our understanding of soil properties and soil heterogeneity.
Topics: Pipeline, Vegetation Recovery Data, Soil Data, Reclamation Monitoring, GrayLit

Gasch, C.K., Huzurbazar, S.V., and Stahl, P.D., 2016, Description of vegetation and soil properties in sagebrush steppe following pipeline burial, reclamation, and recovery time: Geoderma, v. 265, p. 19–26.

DOI: https://doi.org/10.1016/j.geoderma.2015.11.013
Background: Sagebrush steppe ecosystems are unique semiarid rangelands dominated by big sagebrush (*Artemisia tridentata* Nutt.) with spatially associated soil physical, chemical, and biological characteristics and processes. In Wyoming, the sagebrush steppe ecosystem is threatened by oil and gas development that reduces vegetation and soil health, which are difficult to reestablish over time. Understanding how the sagebrush steppe plant community and soil properties respond temporally and spatially to reclamation is necessary for designing successful reclamation plans.
Objectives: The authors assessed sagebrush steppe temporal and spatial response to reclamation and compared across reclaimed pipelines of various ages.
Methods: Four adjacent reclaimed pipelines (1-, 5-, 36-, and 55-years post-reclamation) and two undisturbed reference sites on either side of the pipeline corridor were selected for the study. A cyclic sampling design was used to establish three 10 square meters (m^2) sampling grids on each pipeline and in the undisturbed reference site for a total of 108 total sample points. A 1 m^2 frame was placed 2 meters (m) above and centered on each sampling point then photographed. SamplePoint software was used to quantify and classify vegetation by species and ground cover within each photograph. At each sample point, the top 5 centimeters (cm) of soil was collected for chemical, nutrient, and phospholipid-derived fatty acid (PLFA) analyses. Twelve stratified locations across each sampling grid were also sampled for soil particle size analysis; three of them were randomly selected to assess bulk density. Descriptive statistics for each treatment were analyzed using Bayesian geostatistical modeling.
Location: Reclaimed pipeline corridor in Wyoming's Red Desert Basin near Wamsutter (41°41′17.11″ N., 107°58′24.41″ W.) in southcentral Wyoming, USA
Findings: Total vegetation cover and type varied among plots; the 1-year pipeline was the least vegetated and was dominated by weeds and the 55-year pipeline most resembled undisturbed sites in vegetation composition (dominated by shrubs and, secondarily, by grasses). Despite these differences, spatial correlation of vegetation and bare ground cover was not distinctly different across plots. Soil properties varied widely; electric conductivity and microbial abundance varying the most within and across plots. Overall, the 1- and 5-year pipelines were the least similar, and the 55-year pipeline most similar, to undisturbed references sites. Differences between the two undisturbed sites emphasize the high variability of sagebrush steppe characteristics.
Implications: Revegetation after oil and gas disturbance on sagebrush steppe takes decades but tends to follow a predictable pattern. Soil properties in particular have less predictable long-term patterns than vegetation and require more rigorous monitoring and reclamation planning. Implementing a long-term monitoring program can provide managers a means to access revegetation progress and success.
Topics: Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Gasch, C.K., Huzurbazar, S.V., Wick, A.F., and Stahl, P.D., 2016, Assessing impacts of crested wheatgrass and native species establishment on soil characteristics in reclaimed land using Bayesian posterior predictive distributions: Land Degradation and Development, v. 27, no. 3, p. 521–531.

DOI: https://doi.org/10.1002/ldr.2453
Background: Crested wheatgrass (*Agropyron cristatum*) has been used extensively to re-vegetate disturbed land throughout intermountain and midwestern North America but can lower species diversity through competitive exclusion and alter soil properties compared to native perennial grasslands.
Objectives: The authors examined soil and vegetation properties common for reclamation monitoring under two post-reclamation plant communities, crested wheatgrass dominated and native cool-season grass mix, at different ages since reclamation.
Methods: Soil characteristics were compared across five reclaimed coal surface mine sites varying in age since reclamation and an undisturbed reference site. Three reclaimed sites (ages 11, 16, and 29 years) were seeded with just crested wheatgrass, and two (ages 14 and 26 years) were seeded with a native cool-season grass mix. Soil was sampled in late spring 2005 at two depths and soil properties and soil microbial abundance were measured. Aboveground plant biomass, surface cover, and species richness were also sampled in mid-summer 2005.

Location: Belle Ayr and Cordero mines in the Powder River Basin (44°17′28″ N., 105°30′08″ W.; elevation 1,390 meters [m]) in Campbell County near Gillette, Wyoming, USA
Findings: Reclaimed soils had similar total aggregate weights, but larger macroaggregates than the reference. Additionally, soil in the native cool-season grass mix treatment had lower carbon (C) to nitrogen (N) ratios, while the crested wheatgrass and reference soils did not differ. Soils that were seeded with crested wheatgrass had significantly lower microbial abundance than the reference and native seed soils. The reference site had more vegetative cover and native species richness, however, reclaimed sites had higher litter cover, aboveground biomass, and introduced species richness. Crested wheatgrass accounted for <90 percent of the biomass at sites where it was seeded. Bare ground cover increased with age since reclamation and surpassed the reference site. Species richness increased with site age in the grass mix sites, but not the crested wheatgrass sites.
Implications: Disturbances can have long term effects even after reclamation. Re-seeding solely with crested wheatgrass can produce a distinctly different plant community compared to reclamation using a native seed mix. The authors recommend restoring with native species mixes to attain a community similar to the reference site and to avoid nonnative plant establishment.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Gharaibeh, M.A., Rusan, M.J., Eltaif, N.I., and Shunnar, O.F., 2014, Reclamation of highly calcareous saline-sodic soil using low quality water and phosphogypsum: Applied Water Science, v. 4, p. 223–230.

DOI: https://doi.org/10.1007/s13201-014-0189-3
Background: Reclamation of saline-sodic soils requires specific approaches to reestablish and maintain soil productivity. Highly soluble calcium and gypsum are often used to reclaim salt-affected soils, although phosphogypsum, a by-product of the Jordanian phosphate industry, may be more productive and cost-effect than mined gypsum for reclamation purposes. Phosphogypsum has higher levels of natural uranium that question its use on agricultural fields; however, average levels (22 becquerel per kilogram [Bq/kg]) are still well below global guidelines (2,880 Bq/kg). Additionally, water sources in Jordan are highly salt affected. Determining the effectiveness of phosphogypsum in reclamation, in combination with salt affected leaching water, could increase productivity of saline-sodic soils in the region.
Objectives: The authors identified (1) the reclamation efficiency of phosphogypsum and calcium chloride on saline-sodic soil leached with moderate saline-sodic canal water, and (2) the optimum gypsum quantities required to reduce soil sodicity and salinity to levels for crop production.
Methods: Surface (0–20 centimeter [cm]) soil samples of saline-sodic sandy loam were collected, passed through a 2-millimeter (mm) sieve, and assessed for physical and chemical properties. Forty-five plexiglass columns were packed with soil subsamples. Each sample received either (1) phosphogypsum applied at 5, 10, 15, 20, 25, 35, or 40 milligrams per hectare (mg/ha), (2) calcium chloride dissolved in irrigation water, applied at 4.25, 8.5, 12.75, 17.0, 21.25, 29.75, or 34 mg/ha, or (3) no amendment; each treatment was replicated three times. Subsamples were leached with irrigation water which had moderate salinity and a moderate sodium absorption ratio. Leachates were collected, and leaching stopped when effluent electrical conductivity matched canal water. Soil chemical properties were assessed, and data were analyzed using a two-way analysis of variance (ANOVA).
Location: Soil was collected from agricultural fields in the southern parts of the Jordan Valley, 20 kilometers (km) north of the Dead Sea in Jordan. Irrigation water for soil leaching was collected from King Abdullah Canal. Experiments were conducted in laboratories.
Findings: Both phosphogypsum and calcium chloride reduced soil salinity and sodicity. Phosphogypsum removed 79 percent of the total sodium and 60 percent soluble salts; calcium chloride removed 90 percent of both. Both amendments reduced exchangeable sodium by 90 percent.
Implications: Phosphogypsum application of 30 mg/ha and leaching with 4 pore volume is a cost-effective method for reclaiming saline-sodic soils in the study region. Land managers with similar soil conditions may consider testing the effectiveness of this reclamation recommendation.
Topics: Mining, Soil Data, Reclamation Practices

Glenn, E.P., Waugh, W.J., Moore, D., McKeon, C., and Nelson, S.G., 2001, Revegetation of an abandoned uranium millsite on the Colorado Plateau, Arizona: Journal of Environmental Quality, v. 30, no. 4, p. 1154–1162.

DOI: https://doi.org/10.2134/jeq2001.3041154x
Background: Arid landscapes are especially difficult to reclaim due to harsh climate and environmental conditions. For many sites, which species will be most successful at establishing using what methods is unknown and land managers must consult research from similar sites or refer to anecdotal evidence. Experimenting on-site to determine appropriate seeding species and protocol can make reclamation more successful.
Objectives: The authors experimented with a variety of native species, soil types, and standard revegetation methods to determine the most successful techniques for the arid study site.
Methods: Two experiments were established on a mill site remediated in 1986 and 1988 which had livestock exclusion fencing. For experiment 1, four-wing saltbush fruits (var. *occidentalis* and var. *angustifolia*) were collected on-site, grown out in a nursery, and in 1996, 750 of the seedlings were transplanted into nine adjacent blocks at each of two locations. The soil at location 1 was unaltered and soil at location 2 was ripped 1–3 meters (m) deep. In 1997, plants were randomly sampled to estimate growth and survival. In 1999, all plants were sampled for survival and canopy measurements. In experiment 2, planting method was tested using a mix of six perennial shrubs, four grasses, and one forb. A randomized split plot design was used, with planting method compared in whole plots (transplants only, direct seeding of shrubs only, and shrub transplants and direct seeding combined) and soil preparation (ripped versus unripped) and irrigation (applied once, four times, or 18 times) assessed within split-plots. Treatments were replicated three times. Plant success was evaluated in 1998 (20 months after planting) and 1999 (33 months after planting).
Location: Former uranium mill site on the Navajo Nation (36°08¢ N., 111°10¢ W.; elevation 1.554 m), 8 kilometers (km) east of Tuba City, Arizona, USA
Findings: In experiment 1, both four-wing saltbush varieties had greater survival (75 percent) at location 2 (sandy loam cemented by caliche) and var. *angustifolia* had twice the canopy volume across sites compared to var. *occidentalis*. In experiment 2, none of the treatments effectively produced satisfactory plant cover. In seeded plots, four-wing saltbush was the only species with significantly greater cover in seeded compared to unseeded plots. Transplanted species survival and growth in experiment 2 were lower than observed in experiment 1.
Implications: For this site, four-wing saltbush varietals can be successfully transplanted on dune or caliche soil if irrigated; however, direct seeding a native grasses, forbs, and shrubs mixture is unlikely to be successful, especially with limited irrigation accesses at the site. Other arid landscapes with more water access may be more successful with direct seeding efforts.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Gould, A.B., and Liberta, A.E., 1981, Effects of topsoil storage during surface mining on the viability of vesicular-arbuscular mycorrhiza: Mycologia, v. 73, no. 5, p. 914–922.

DOI: https://doi.org/10.1080/00275514.1981.12021421
Background: Topsoil disturbance caused by oil and gas mining alters vesicular-arbuscular mycorrhiza (VAM) communities. Mycorrhizal relationships are important for revegetation, therefore understanding how mycorrhizae respond to stockpiling could better inform the use of stockpiled topsoil for reclamation purposes. Previous research suggests that mycorrhizal communities are lower in stored topsoil, but that mycorrhizal root fragments may initiate new mycorrhizal infections. Reassessing stored topsoil 15 months after initial mycorrhizal analysis will provide data regarding changes in fungal communities over time.
Objectives: The authors assessed the mycorrhizal inoculum potential of a topsoil stockpile and compared with previous (15 month prior) results to explore the role of indigenous mycorrhizae in new mycorrhizal infection initiation.
Methods: In 1979, soil samples were collected below the root zone at both a 4-year-old topsoil stockpile and at an undisturbed control site. Samples were sifted to isolate indigenous root fragments and spores, which were counted and identified. Soil subsamples were analyzed for chemical and physical characteristics. Two greenhouse experiments were conducted to (1) assay soil samples either undiluted or diluted with potting medium, and (2) compare inoculum potential of indigenous mycorrhizal root fragments from the undisturbed and stored topsoil. In the first experiment, mycorrhizal inoculum potential for each soil treatment was determined and in the second experiment, percentage of mycorrhizal pieces in various root segments was calculated. Data were analyzed using contingency chi-square tests.
Location: Indian Mine in North Dakota, USA

Findings: The number of spores was similar in the stockpiled topsoil compared to the undisturbed control. In the greenhouse experiments, both inoculum potential and the extent of mycorrhizal infection in root segments of bioassay plants was significantly lower in the stockpiled topsoil compared to the undisturbed soil; in both soil samples, inoculum potential and infection decreased with dilution.
Implications: This study suggests that mycorrhizal spore count decreases over time and that mycorrhizal inoculum potential and fragments are higher in undisturbed soil compared to stockpiled topsoil. Land managers should assess stockpiled topsoil for mycorrhizal content to determine if amendment or inoculation is needed for reclamation purposes.
Topics: Mining, Soil Data, Reclamation Practices

Grant, A.S., Nelson, C.R., Switalski, T.A., and Rinehart, S.M., 2011, Restoration of native plant communities after road decommissioning in the Rocky Mountains—Effect of seed-mix composition on vegetative establishment: Restoration Ecology, v. 19, no. 201, p. 160–169.

DOI: https://doi.org/10.1111/j.1526-100X.2010.00736.x
Background: Roads fragment habitats, alter hydrological processes and water quality, and impact wildlife movement. Decommissioning roads is important for ecological restoration and the primary goal is to reestablish vegetation as quickly as possible. Seed mixes often include non-native species even though they can have negative environmental impacts when planted, and seed mixes are often low in species and functional richness. In addition, land managers often use coarse woody debris to control erosion, but this can reduce seedling germination and establishment.
Objectives: The authors compared the efficacy of native and non-native seed mixes for revegetation of decommission roads in the Rocky Mountains to assess (1) the short-term effects of road decommissioning on plant community composition, (2) how seed mix origin, diversity, and density affect plant establishment, and (3) the effects of coarse woody debris and overstory canopy cover on establishment.
Methods: Thirteen road segments were selected in Montana forests, ten in Kootenai National Forest, and three in Clearwater National Forest. Prior to road decommission, a 63 × 7-meter (m) belt transect was established within each segment, with seven 7 × 9 m experimental plots within each. Percent cover of understory vegetation was estimated within 1 square meter (m^2) subplots at the center of each experimental plot and overstory canopy cover at each subplot edge. Vegetation cover was estimated in six 1 m^2 quadrats in a section of forest without roads adjacent to the roadbed. Roads were decommissioned in 2007 with full recontour and scarification in Kootenai and recontour in Clearwater. After decommissioning, six experimental plots were hand-seeded, and one plot was left unseeded as a control plot. Seed mixes varied by origin (native versus non-native), seed mix diversity (three versus six species), and seeding density (low: 16.8 kilogram per hectare [kg/ha] versus high: 33.6 kg/ha). Vegetation cover, coarse woody debris, and overstory canopy were measured one year after seeding. Data were analyzed using paired *t*-tests and multifactor and univariate analysis of variance (ANOVA).
Location: Road segments on the Kootenai National Forest Three Rivers Ranger District in northwestern Montana and Clearwater National Forest Powell Ranger District in northeastern Idaho, USA
Findings: Road removal disturbance significantly impacted total vegetation cover, native vegetation, and non-native vegetation. Compared to plots seeded with the non-native seed mix, plots with the native seed mix had significantly higher native cover and lower non-native cover, though there was no difference compared to unseeded controls. Plots seeded with the native seed mix also had higher cover (43 percent) of seeded species. Coarse woody debris, overstory canopy cover, seeding diversity, and seeding density had no significant effects on vegetation establishment.
Implications: In the short term (1-year) after road decommissioning, seeding native species was more successful than seeding non-native species in facilitating vegetation establishment, although the results suggest that seeding may not be necessary in this region, as there were no differences between native-seeded and unseeded control plots. Furthermore, current seeding densities may be higher than needed and could be reduced to cut costs. Longer-term studies are necessary for tracking this trend over time. Land and reclamation managers should consider seeding a wide variety of native species to see which are most successful at their site.
Topics: Road, Vegetation Recovery Data, Reclamation Practices

Graves, W.L., Kay, B.L., and Williams, W.A., 1978, Revegetation of disturbed sites in the Mojave Desert with native shrubs: California Agriculture, v. 32, no. 3, p. 4–5.

Link (non-DOI): https://calag.ucanr.edu/archive/?type=pdf&article=ca.v032n03p4
Background: Construction of rights-of-way (ROWs) for roads or pipelines disturbs the landscape and native vegetation. In the Mojave Desert, a number of factors lead to poor revegetation success (for example, poorly adapted seeds, phenological mismatch in planting date, browsing, and competition). Identifying successful species for revegetation is important for reclamation of disturbed arid landscapes.
Objectives: The authors evaluated five plant species for their revegetation potential in disturbed areas of the Mojave Desert.
Methods: Seeds were collected from the west site of the Mojave Desert and placed in cold storage for six months prior to greenhouse germination in 1972. Five species (*Ambrosia dumosa*, *Atriplex canescens*, *Atriplex polycarpa*, *Larrea tridentata*, and *Lepidospartum squamatum*) were direct seeded and transplanted to assess the impact of seeding method on establishment. One-time irrigation was applied on selected plants and an "SSO Anti-Stress Agent" (sarasaponin) was applied to assist with growth on half of the irrigated plants. Treatments were completely randomized and replicated four to six times at both sites. Data were collected in April 1973 and March 1975, including stand counts, plant height, flowering, and seed production.
Location: Two sites (Mojave and South Freeman) in the ROW for the second Los Angeles Aqueduct in the Mojave Desert in California, USA
Findings: Effects of seeding method varied greatly by species. At both sites, *A. canescens* was the most successfully established species by direct seeding and *A. dumosa* was the most successfully established species by transplanting. The one-time irrigation and sarasaponin application did not improve establishment.
Implications: Revegetating disturbed arid land can be successful, though great care should be taken in selecting seed source and species. Irrigation may not be cost effective as it was not shown to improve establishment.
Topics: Road, Pipeline, Target Plant Recovery Data, Reclamation Practices, GrayLit

Grigg, A.H., Sheridan, G.J., Pearce, A.B., and Mulligan, D.R., 2006, The effect of organic mulch amendments on the physical and chemical properties and revegetation success of a saline-sodic minespoil from central Queensland, Australia: Australian Journal of Soil Research, v. 44, no. 2, p. 97–105.

DOI: https://doi.org/10.1071/SR05047
Background: In Queensland, Australia, open-cut coal mine spoil is highly sodic and forms surface crusts that prevent seedling emergence following reclamation. This saline-sodic topsoil is also nutrient poor and requires amendment for successful vegetation establishment. Previous studies have demonstrated the potential of organic mulches to improve spoil conditions and revegetation success. Testing various organic mulches on saline-sodic mine spoil in Queensland could better inform reclamation planning.
Objectives: The authors evaluated the effectiveness of straw and pine sawdust organic mulches in improving substrate for revegetation success on saline-sodic mine spoil.
Methods: In greenhouse trials, 15 centimeter (cm)-diameter plastic pots were treated with one of the following nine amendments: (1) spoil mixed with straw (up to 13.1 metric tons per hectare [t/ha]), (2) spoil mixed with pine sawdust (up to 44.2 t/ha), (3) spoil with surface-applied straw at 25 percent, (4) 50 percent, or (5) 75 percent cover, (6) spoil with surface-applied pine sawdust at 25 percent, (7) 50 percent, or (6) 75 percent cover, and (9) unamended spoil; there were three replicates of each treatment. All pots were wetted, and surface crust development was measured using a pocket penetrometer. The effects of amendments on infiltration and water retention were investigated using a tilting flume and rainfall simulator. In a field trial, a study site was divided into four blocks with plots containing (1) surface-applied mulches (straw at 0, 2.5, 5, or 10 t/ha and pine sawdust at 0, 5, 10, or 20 t/ha), (2) incorporated mulches (straw at 0, 5, 10, or 20 t/ha and pine sawdust at 0, 20, 40, or 80 t/ha, (3) gypsum (5 or 20 t/ha) plus incorporated mulches, or (4) topsoil replaced with surface-applied mulches. Plots were hand-seeded in 1994 with native grasses and trees or with introduced pasture species. Due to poor germination, vegetation was seeded again with five native grasses and 14 native trees in 1997. Spoil and topsoil samples were collected before plot establishment in 1994, and from select plots in 1998; samples were collected in 0.05-meter (m) intervals to a 0.1 m depth then in 0.1 m intervals to a 0.5 m depth.

Location: Greenhouse and a 2-ha site on an out-of-pit dump at the Goonyella Riverside open-cut coal mine (21°43′ S., 147°58′ E.) in central Queensland, Australia
Findings: In the greenhouse trials, surface crust formation decreased with incorporated mulch rate but leveled off by day 19. Lower rates of straw were needed to reduce equivalent surface crust compared to sawdust. Incorporated straw had the highest rates of infiltration and water retention. Incorporated straw and sawdust treatments had significantly lower surface salinity compared to unamended spoil. Gypsum had no significant effect nor did surface amendment application (except surface-applied straw on topsoil due to a lack of capillary rise). Sawdust application of 20 t/ha and straw of at least 5 t/ha improved vegetation cover; salinity must be removed from both the surface and rootzone for successful revegetation.
Implications: Land managers who revegetate saline-sodic mine spoils should consider straw and sawdust mulch amendments for increased revegetation success. Though, the effect of these amendments is unknown beyond four years post-application.
Topics: Mining, Vegetation Recovery Data, Soil Data, Hydrology Data, Reclamation Practices

Gundlach, S.J., Dollhopf, D.J., Harvey, K.C., 2009, Grass establishment on natural gas drill pads in Wyoming as impacted by reclamation techniques, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, v. 1, p. 518–537.

DOI: https://doi.org/10.21000/JASMR09010518
Background: Establishing perennial grasses as part of oil and gas reclamation can be difficult in areas of low precipitation. There are several treatments that can promote establishment of seeded species. A better understanding of how these treatments work under various conditions is needed to streamline restoration.
Objectives: The authors set up an observational study to explore different combinations of treatments used to promote plant establishment.
Methods: Twenty-five combinations of reclamation techniques were tested on six well pads, including both saline-sodic soils and non-saline soils. Treatments included combinations of soil ripping, fertilizer applications, gypsum or sulfur application, chopped straw or woodchip amendments, imprinting, pitting, mulch, irrigation, fencing, and site-specific seed mixes. Treatments were tailored to individual well pads and treatments covered large portions of a single well pad. Grass density and species composition were measured on five drill pads six weeks after reclamation.
Location: Washakie Basin near Baggs, Wyoming, USA
Findings: Irrigation increased grass density on all pads. Imprinting significantly increased grass cover on all soils. Wood chips, gypsum and fertilizer, chopped straw, sulfur, and fertilizer significantly increased grass cover on saline-sodic soils. Other results were site specific.
Implications: Particular combinations of treatments early in reclamation, including imprinting and irrigation, for example, can return grass densities to similar levels comparable to undisturbed sites quickly.
Topics: Well Pad, Vegetation Recovery Data, Erosion Data, Reclamation Practices, GrayLit

Hall, D.B, and Anderson, D.C., 1999, Reclaiming disturbed land using supplemental irrigation in the Great Basin/Mojave Desert transition region after contaminated soils remediation—The Double Tracks project, *in* Shrubland Ecotones, Proceedings: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, RMRS-P-11, p. 260–265.

Link (non-DOI): https://www.fs.usda.gov/rm/pubs/rmrs_p011/rmrs_p011_260_265.pdf
Background: In May 1963, plutonium and depleted uranium were exploded on the Nellis Air Force Range Double Tracks test site, scattering plutonium waste across approximately 9.3 acres. Remediation occurred in 1996, which included removal and disposal of the top 5–15 centimeters (cm) of soil and reclamation with native vegetation reestablishment.
Objectives: The authors described reclamation procedures, presented revegetation results, and outlined the monitoring program to assess the site's reclamation success.

Methods: The site was disked and recontoured to reestablish natural drainages. It was broadcast seeded using a locally informed seed mixture at 23.5 kilograms of pure live seed per hectare (PLS kg/ha) with gel crystals added to the mix to increase soil moisture. The area was mulched and crimped with wheat straw applied at 4,500 kg/ha. Irrigation was applied with respect to precipitation events in the fall/winter/spring of 1991–1993, and 1994–1995. Four different treatments were compared: (1) fall/spring irrigation with topsoil removed, (2) fall/spring irrigation with some topsoil removed and later replaced, (3) spring irrigation with little or no topsoil removed, and (4) no irrigation with little or no topsoil removed. Seed bags containing seed mixture samples were placed in each treatment to determine germination timing. Several climate variables were measured via an onsite weather station. Electrical resistance using thermistor soil cells was recorded. Seeded and non-seeded plant densities were recorded in five randomly placed quadrats in each treatment plot. Onsite wildlife use was documented. Data were analyzed using analysis of variance (ANOVA).
Location: Double Tracks site on the Nellis Air Force Range in southcentral Nevada, USA
Findings: In the spring season that followed the fall 1996 seeding, the irrigated plots had a higher percent soil moisture by volume, a potential explanation for the higher germination also noted in those plots. However, the difference was not statistically significant, likely due to an exceptionally wet year following seeding. All 15 seeded species emerged and established, as did an additional five non-seeded species. There was a significant difference among treatment plots; seedling densities were highest in the spring irrigation with little or no topsoil removed treatment and lowest in the no irrigation with little or no topsoil removed treatment. In addition, individual species responded differently to treatments. Wildlife use (based on scat presence) included the black-tailed jackrabbit and pronghorn. Future monitoring will occur again 3-, 5-, and 10-years post-reclamation to determine reclamation success.
Implications: Irrigation significantly increased seedling emergence and establishment and is a useful tool for land managers (based on site specific conditions) reclaiming semiarid and arid landscapes.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Haney, R.L., Hossner, L.R., and Haney, E.B., 2008, Soil microbial respiration as a tool to assess post mine reclamation: International Journal of Mining, Reclamation and Environment, v. 22, no. 1, p. 48–59.

DOI: https://doi.org/10.1080/17480930701414584
Background: Coal mining regulations require soil sampling before and after reclamation, and that companies monitor progress during the extended responsibility period following reclamation. An important component of reclamation success is soil quality including physical, chemical, and biological components. Soil microbial respiration is an indicator of microbial activity and nutrient cycling. Testing used by mining companies is extensive, but also expensive and time consuming. Detecting soil microbial activity using 1-day carbon dioxide (CO_2) analysis may provide a fast and reliable method for assessing soil health that integrates biological, chemical, and physical properties into one indicator.
Objectives: The authors assessed the effectiveness of the 1-day CO_2 method and compared results to tests commonly used by regulatory agencies.
Methods: This study was conducted at two mines which were reclaimed after mining operations were discontinued, which was 20 years prior to the samples collected here. During reclamation, stockpiled soil was redistributed, fertilizer was disked, and bufflegrass (*Pennisetum ciliare* - now considered an invasive species in the United States), was planted at 1.8 kilograms of pure live seed per acre (kg PLS/ac). For this study, soil was collected from the two mines in reclaimed areas with “poor” and “good” vegetation establishment, and from soil under undisturbed, native vegetation. Approximately 20 soil samples at each location were collected at a depth of 15 centimeters (cm). For each sample, standard chemical analyses included pH, electrical conductivity (EC), plant-available nutrients (nitrate, ammonium, and phosphorus [P]), soluble nutrients (sodium [Na], calcium [Ca], and magnesium [Mg]), sodium adsorption ratio (SAR), texture, soil organic matter (SOM), soil microbial biomass carbon (SMBC), 30-day nitrogen (N) mineralization, and microbial activity (30-day CO_2 analysis) were quantified in each sample. The 1-day CO_2 method was also used on all samples.
Location: Palafox and Rachal lignite mines in Webb County near the Rio Grande in the South Texas Plains, Texas, USA
Findings: Native soils had higher EC than the two reclaimed sites. Nitrate, P, and ammonium levels were low at all sites indicating that these soil nutrients are not driving vegetation differences. However, all biological tests indicate that areas with “good” quality vegetation had higher levels of biological activity in the soil, and SOM was higher in reclaimed areas with good vegetation compared to either poorly vegetated areas or native soils. However, the 1-day CO_2 analysis was a better test for organic carbon (C) quality than SOM because it indicates whether the organic C in the soil is resistant versus readily mineralizable; it is also highly correlated with N mineralization, revealing similar patterns across sites. The values of SMBC were also significantly higher on reclaimed soils with good vegetation compared to poor or native soils, suggesting

that measures of microbial activity may be more sensitive than other methods tested in detecting differences in soil quality than chemical and physical tests. All five biological soil quality indicators were highly correlated with each other, and each significantly differed among areas of good and poor revegetation areas.
Implications: Twenty years after reclamation the two mines had equal or greater biological soil quality than adjacent native sites. Overall, indicators of microbial activity and cellular respiration may be better indicators of reclamation success and soil quality than physical or chemical analyses. The 1-day CO_2 method is an appropriate and useful tool for assessing soil quality following reclamation because it is highly correlated with the most sensitive methods (SMBC), is easy to perform, and is a rapid test.
Topics: Mining, Soil Data, Reclamation Monitoring

Harrington, J.T., Dreesen, D.R., Wagner, A.M., Murray, L., and Sun, P., 2001, Results of species trials on low pH overburden materials for mine land reclamation, *in* Burger, J.A., ed., Land reclamation, a different approach—18th Annual National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mex., June 3–7, 2001, Proceedings: American Society for Surface Mining and Reclamation, p. 112–120.

DOI: https://doi.org/10.21000/JASMR01010112
Background: Revegetation of the Molycorp molybdenum mine in New Mexico is complicated by its mixed volcanic overburden piles with low pH and high salinity. Identifying a diverse range of plant species most likely to survive could increase reclamation and revegetation success. In addition, increasing the pH and decreasing the salinity of the overburden piles could improve revegetation efforts.
Objectives: The authors assessed and identified plant species among several plant types that were most likely to survive the low pH high salinity overburden conditions.
Methods: A randomized complete block design was used to test four substrate treatments: (1) unmixed acid rock (low pH, high soluble salts), (2) an acid:neutral overburden mixture ratio of 3:1 (low soluble salts, high pH), (3) an acid:neutral overburden mixture ratio of 9:1 (high soluble salts, intermediate pH), and (4) an acid:neutral overburden mixture ratio of 1.25:1 (high pH, low soluble salts) on growth of 10 conifer, 16 legume, 5 forb, and 21 shrub species. Each species × substrate × block was replicated by three seedlings per block. Species survival was analyzed by analysis of variance (ANOVA) and categorial ANOVA.
Location: This study was conducted at the New Mexico State University Mora Research Center in Mora, New Mexico using overburden from the Molycorp molybdenum mine near the towns of Questa and Red River in northcentral New Mexico, USA
Findings: Overall, survival varied among substrates and species. Both native and non-native species survived, and some species experienced within-species variation (for example, *Holodiscus dumosus* and *Rhus trilobata*). All ten conifer species, seven shrub species, and three legume species survived in the unmixed acid rock (low pH, high soluble salts), though none of the five forb species survived the treatment.
Implications: Revegetation of low pH high salinity soils can be improved by adjusting the chemical environment toward neutrality and reduced salinity. In contrast, some species survived without altering the soil environment. Land managers looking to reclaim disturbed mixed volcanic soils should choose their preferred method (altering soil or selecting more suitable species) for revegetation based on their site-specific conditions.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Harrington, J.T., and Loveall, M.W., 2006, Evaluating forest productivity on reclaimed mine land in the western United States, *in* Barnhisel, R.I., ed., 7th International Conference on Acid Rock Drainage and 23rd Annual Meeting of the American Society of Mining and Reclamation, St. Louis, Mo., March 26–30, 2006, Proceedings: American Society of Mining and Reclamation, p. 721–737.

DOI: https://dx.doi.org/10.21000/JASMR06020721
Background: In the western United States, post-mining land use is rarely commercial forestry and most reclamation focuses on herbaceous or shrub community revegetation. For this reason, few regulations or performance standards exist for post-mine forest plant communities. Site index, the most commonly used quality or productivity measure for forests in the United States, is a metric that could be applied to forested reclamation sites in western states to inform reclamation success. However, the site index curve for ponderosa pine (*Pinus ponderosa*) is based on a long time period (100 years) and trees take an average 6–29 years to reach measuring size, which complicate the use of site index for this species.
Objectives: The authors described and contrasted growth of ponderosa pines at a reclamation site in northern New Mexico with trees planted on a typical reforestation site and trees naturally regenerated on undisturbed areas of the mine site.
Methods: Two planting sites and two undisturbed sites were selected on the Questa Mine and nine planting sites were selected in Carson National Forest. All planted trees at the sites were <25 years old at the time of the study and all seedlings (aside from natural regeneration) were hand-planted. One of the mine planting sites was a safety berm with seedlings planted in 1978 and the other was a series of bench plantings in 1992. Carson National Forest seedlings were planted between 1982–1991. One of the two natural regeneration mine sites was on a naturally occurring geologic alteration scar/debris. The researchers measured the height of each branch whorl on planted ponderosa pines and tree rings on natural regenerated ponderosas and compared averages across all sites.
Location: Molycorp Inc.'s Questa molybdenum mine in the Taos Range of the Sangre de Cristo mountains in northern New Mexico, USA
Findings: There was no difference in average height over time between the two mine planting sites. There was no difference in average height of the natural regeneration sites and the Carson National Forest from 0 to 11 years after planting, after which naturally regenerated ponderosas were taller on average. The variable growth rates observed may have been due to the relatively younger age of planted trees. Ponderosas naturally regenerated on the alteration scar were taller than other naturally regenerated trees. The observed height of naturally regenerated and Carson National Forest ponderosas did not fit the site index curve or the species (calculated using Minors formula). Climatic fluctuations may have skewed the index curve from observed trends.
Implications: The ponderosa pine site index was not sufficient for assessing reclaimed forests established as post-mine land use. A more appropriate alternative may be comparison or check plantings; these plants would be of the same stock as those used for reclamation and planted in the same geographic (specifically climatic) region. However, this method needs further testing to determine its efficacy.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Monitoring, GrayLit

Heil, M., Wagner, A., and Buchanan, B.A., 2011, Estimating vegetation cover using various GIS techniques, *in* Barnhisel, R.I. ed., Reclamation—Sciences leading to success, 28th Annual Meeting of the American Society of Mining and Reclamation, Bismarck, N.D., June 11–16, 2011, Proceedings: American Society of Mining and Reclamation, p. 269–281.

DOI: https://dx.doi.org/10.21000/JASMR11010269
Background: Monitoring vegetation cover over time is an important aspect of mine reclamation. While ground surveys are the most commonly used methodology, aerial imagery can be an effective way of gathering larger-scale vegetation cover data over time. There are several geospatial analysis methods that offer alternatives for determining vegetation cover. Understanding which method is best suited for various landscapes can increase data collection accuracy.
Objectives: The authors compared several geospatial analysis methods (simple filter method, kriging, and universal kriging) to determine which was most effective and accurate at generating vegetation cover values on molybdenum mine tailings.

Methods: Vegetation cover data were collected in the field from 2004 to 2009. Along each of 260 randomly placed transects, 100 readings were taken, spaced at 0.5-meter (m) intervals. With this data, percent cover was calculated by species per transect. In 2010, 50 transects were used for ground truthing. From aerial imagery, vegetation cover reflectance values were derived, inverted, and normalized. Aerial imagery was filtered using the simple filter smoothing method and applied the quantile method of classification to account for discrepancies in vegetation cover due to point data type. Transect and aerial imagery data were combined to generate vegetation cover values through the universal kriging process using both raw aerial reflectance values and simple filter data. Mean vegetation cover values were compared between the transect data, simple filter method, and universal kriging processes within two datasets (binary data and continuous data).
Location: Molybdenum tailing facility operated by Chevron Mining Inc. near Questa, New Mexico, USA
Findings: There were no significant differences between the datasets (binary and continuous) among the vegetation estimation methods. The most accurate method compared with ground truth data was the universal kriging with the simple filter method data. However, the highest R^2 value was 0.61, indicating overall low geospatial analysis accuracy compared to ground truthing. Since pixel sizes were so large in the aerial National Agricultural Imagery Program (NAIP) data (compared to drone captured orthomosaics), it may not have captured the true cover variability that exists in the field. The pixels effectively average out data within the area it represents, whereas field data collection averages vegetation cover over a transect line. This difference in data collection between both methods may be the cause for decreased accuracy. Perhaps if field methods were designed to observe the same vegetation within each corresponding aerial photo pixel, results would have been different.
Implications: While geospatial analysis of aerial images can estimate vegetation cover on a large scale, none of the methods used in this study were precise enough to replace field observations and data collection. Annual variation in vegetation cover may complicate geospatial analyses accuracy.
Topics: Mining, Vegetation Recovery Data, Reclamation Monitoring, GrayLit

Herrick, J.E. Schuman, G.E., and Rango, A., 2006, Monitoring ecological processes for restoration projects: Journal for Nature Conservation, v. 14, no. 3–4, p. 161–171.

DOI: https://doi.org/10.1016/j.jnc.2006.05.001
Background: Defining restoration and reclamation success based on vegetation metrics alone fails to include the diverse goals of restoration and ignores reestablishing important ecological processes necessary for a self-sustaining ecosystem. Short-term monitoring alone can lead to false conclusions regarding treatment success, which has long-term consequences for future restoration planning. Monitoring approaches should include ecological process indicators to ensure restoration address full ecosystem function.
Objectives: The authors proposed and illustrated a cost-effective monitoring approach for restoration of semi-arid upland ecosystems.
Methods: A proposed monitoring system was defined, and details were provided for a monitoring design. The importance of both short-term and long-term monitoring protocol was outlined. Data analysis systems and standard indices were discussed, as well as additional indicators that should be considered. The proposed monitoring system was illustrated with a case study of mine-land restoration in northeastern Wyoming. Future considerations for the proposed monitoring approach were suggested.
Location: Two reclaimed mine sites in northeastern Wyoming, USA
Findings: The proposed monitoring system is a 10-step process divided into three modules. The first module, Year 1 (steps 1–6), involves developing the site-specific monitoring program. The second module, Year 2 (steps 7–8), focuses on short-term monitoring. The third module, every 1–5 years (steps 9–10), involves repeated long-term monitoring and may lead back to step 7. There are 17 ecological indicators for qualitative assessments that address soil and site stability, hydrological function, and biotic integrity. Case study results from implementation of the third module in Wyoming indicated that mine site 1 was partially recovered, and mine site 2 near-completely recovered. Process-based indicators were important for assessment accuracy; vegetation cover and composition indicators alone suggested complete recovery at mine site 1 and incomplete recovery at mine site 2.
Implications: Both vegetation-based and process-based indicators are necessary for complete assessment of reclaimed mine sites. This monitoring protocol is an option for land and reclamation managers tasked with reclaiming semi-arid uplands or similar environments. It should be noted, however, that the proposed monitoring system does not include landscape level processes; these processes are important to consider, and new indicators and high-resolution remote sensing tools will be necessary to apply this proposed protocol at the landscape level.
Topics: Mining, Vegetation Recovery Data, Reclamation Monitoring, Reclamation Standards

Hiatt, H.D., Olson, T.E., and Fisher, J.C., Jr., 1995 Reseeding four sensitive plant species in California and Nevada, *in* Roundy, B.A., McArthur, E.D., Hayley, J.S., and Mann, D.K., compilers, Wildland Shrub and Arid Land Restoration Symposium, Las Vegas, Nev., October 19–21, 1993, Proceedings: U.S. Department of Agriculture Forest Service, Intermountain Research Station, General Technical Report INT-GTR-315, p. 94–98.

Link (non-DOI): https://doi.org/10.2737/INT-GTR-315
Background: The construction of natural gas pipelines can disturb vegetation and threaten sensitive species. Prior to construction of the Kern River Gas Transmission pipeline, surveys revealed the presence of nine sensitive plant species in the pipeline's planned alignment. Avoiding these plant populations and reseeding species where necessary can mitigate the negative environmental impact of pipeline construction.
Objectives: The authors reviewed the mitigation methods taken to reduce disturbance of four sensitive species in the alignment of the Kern River Gas Transmission pipeline and resulting reestablishment of these species after post-project seeding.
Methods: The authors surveyed for sensitive plant species within a 200-foot (ft) wide survey corridor in the pipeline's project alignment; locations of occurrences of sensitive plant species were avoided when possible. For those occurrences that could not be avoided, seeds were gathered locally for Rusby's desert mallow (*Sphaeralcea rusbyi* ssp. *Eremicola*), Parish's phacelia (*Phacelia parishii*), rosy twotone beardtongue (*Penstemon bicolor* ssp. *Roseus*), and yellow twotone beardtongue (*Penstemon bicolor* ssp. *Bicolor*) and separated to preserve distinct gene pools. Seeds were dried and stored then tested for viability. Following pipeline construction, species were reseeded in appropriate habitats along pipeline route with an emphasis on proximity to disturbance sites. Plots were inventoried to assess reseeding success.
Location: Various locations along the Kern River Gas Transmission pipeline route in the Mojave Desert located in Clark County, Nevada, and San Bernardino County, California, USA
Findings: Overall, reseeding was successful but varied among species and among reseeded sites within species. Notably, Rusby's desert mallow seemed well adapted to disturbance and had additional seed recruitment from outside reseeded areas. Parish's phacelia had substantially higher numbers of individuals in reseeded plots compared to non-reseeded plots. Pre-seeding preparation of the reseeded site to make the microsite conditions similar to those of natural sites likely assisted the successful re-establishment of Parish's phacelia. Monitoring of the two taxa of beardtongue was confounded by post-project disturbance by off-road vehicles and by agency-required second reseeding with a wild horse habitat enhancement seed mix.
Implications: Avoiding areas with sensitive species is the preferred method for reducing disturbance due to oil and gas development. When this is not possible, reseeding can mitigate disturbance and maintain the presence of sensitive species. When conducting reseeding experiments, the following considerations are especially important: (a) timing of seed collection, which may often need to be done on more than one occasion; (b) consensus by all stakeholders on reseeding objectives to avoid possibly favoring nonnative plants and animals over native species; and (c) the need for long-term and repeated monitoring to quantify species survival and reseeding success.
Topics: Pipeline, Target Plant Recovery Data, Reclamation Practices, GrayLit

Hickman, L.K., Desserud, P.A., Adams, B.W., and Gates, C.C., 2013, Effects of disturbance on silver sagebrush communities in dry mixed-grass prairie: Ecological Restoration. V. 31, no. 3, p. 274–282.

DOI: https://doi.org/10.3368/er.31.3.274
Background: Silver sagebrush (*Artemisia cana*) is important for wildlife species in dry-mixed grass prairies of North America. Understanding the best practices to restore these communities after disturbance from energy development is important for wildlife conservation. Researchers wanted to examine whether restoration efforts on well and pipelines sites within blowout areas (dry zones characterized by hardpan soil layers caused by excess sodium) and overflow areas (low relief inclines in valley or basin that receive rain runoff from upland slopes and have mesic soil) have achieved restoration of silver sagebrush communities.
Objectives: The researchers compared silver sagebrush communities in areas disturbed by energy development with undisturbed areas in similar ecological range sites and assessed the effect of various seeding treatments on emerging plant communities and silver sagebrush regeneration.

Methods: The researchers measured species composition and litter, moss, lichen, forb, shrub, and grass cover along transects at paired disturbed and undisturbed sites at blowout and overflow sites. On a 50-meter (m) transect, shrub density, distribution, and volume (estimated from height and canopy diameter) were recorded. Rangeland health was assessed based on five factors: ecological status, community structure, hydrologic function, site stability, and cover of noxious weeds. Rangeland health site scores were calculated and classified into three categories: unhealthy (0–49 percent), healthy with problems (50–74 percent), healthy (75–100 percent)
Location: Between latitudes 49.002°–49.438° N. and longitudes 110.008°–110.944° W. within the dry mixed-grass natural sub-region in the southeastern corner of Alberta, Canada
Findings: Disturbed blowout sites had more than double the cover of sagebrush than undisturbed sites, but it was not significantly different due to highly variable results in disturbed areas, potentially associated with the influence of untested soil properties. The introduced species, northern wheatgrass (*Elymus lanceolatus*), had double the cover on disturbed sites compared to undisturbed sites. Native grasses had a higher mean percent cover on undisturbed sites. Species richness, moss cover, and lichen cover were higher on undisturbed sites. Disturbed and undisturbed blowout sites were rated “healthy,” but the undisturbed sites had a higher mean score than disturbed sites (99.9 and 76.7 respectively). Sites with natural recovery had the greatest sagebrush cover and density. For overflow sites, sagebrush cover on both disturbed and undisturbed sites was not significantly different. Native grass cover did not differ between undisturbed and disturbed sites except for Sandberg bluegrass in undisturbed sites. Overflow undisturbed and disturbed sites were both rated “healthy,” but undisturbed sites had a higher mean score (89.9 and 71.9 respectively).
Implications: Sagebrush recovery did not differ between overflow and blowout sites. However, vegetation communities on overflow sites returned to their original composition and were more resilient than blowout communities. Generally, reclaimed silver sagebrush communities were similar to reference communities and were rated “healthy.” Natural recovery management practices that reduce erosion and minimize introduction of invasive species should be prioritized.
Topics: Well Pad, Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Hydrology Data, Wildlife/Habitat Data, Reclamation Practices

Hild, A.L., Shaw, N.L., Paige, G.B., and Williams, M.I., 2009, Integrated reclamation—Approaching ecological function?, *in* 26th Annual Meetings of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, p. 578–596.

DOI: https://doi.org/10.21000/JASMR09010578
Background: Reclamation of arid and semiarid lands disturbed by mining activity often focuses on plant species composition and standardized metrics. However, a systems approach is important for reestablishing sustained ecological processes. Integrating abiotic and biotic factors, together with long-term monitoring procedures, can improve reclamation efforts to reestablish ecosystem function. Case studies are useful tools to assess and demonstrate the value of integrated reclamation approaches and to encourage land managers and researchers to practice integrated approaches.
Objectives: The authors outlined an integrated approach that targets functional ecosystem processes to increase the success of reclamation efforts on arid and semiarid lands disturbed by mining activity.
Methods: The authors reviewed components important to an integrated reclamation approach, focusing on composition, structure, and function. They discussed current methods for seed selection, reseeding, establishing species diversity, restoring wildlife habitat, assessing soil and microbial communities, and defining functional species traits. The authors provided suggestions for future considerations. They included proposed methods for an integrated, site-appropriate reclamation plan and simulated such an approach using a case study example.
Location: This is a review article and does not involve a specific field site location
Findings: To address full ecosystem function, reclamation of mine sites would benefit from an integrated systems approach, which includes standardizing measuring units for planning and monitoring; focusing on temporal trends; pairing long-term datasets with standardized monitoring; including biotic and abiotic factors; and using simulated models and decision-making matrices to plan and assess reclamation.
Implications: An integrated approach to reclamation (for example, employment of tools such as state-transition models and Ecological Site Inventory) is critical to ensure ecosystem functions are on a trajectory toward reestablishment. Advances in reclamation technology and computer simulations have made an integrated approach more accessible. Any such approach should include clear communication and collaboration among reclamation managers and researchers.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Theory, Reclamation Practices, Reclamation Standards, GrayLit

Holmstead, G.L., and Anderson, D.C., 1998, Reestablishment of *Eriastrum hooveri* (*Polemoniaceae*) following oil field disturbance activities: Madroño, v. 45, no. 4, p. 295–300.

Link (non-DOI): https://www.jstor.org/stable/41425280
Background: *Eriastrum hooveri* (Hoover's woolly-star) is an endemic herb to San Joaquin Valley, California and was Federally listed as threatened due to increasing land development. Previous research suggests that *E. hooveri* might require dense cryptogamic soil crust for propagation. To protect this species, it is essential to know how it responds to oil development related disturbance and reclamation techniques.
Objectives: The authors evaluated the reestablishment of *E. hooveri* on a well pad and a pipeline as compared to adjacent undisturbed habitat and determined if seeding for reclamation impacts *E. hooveri* reestablishment.
Methods: At both the pipeline and well pad sites, a shrub, forb, and grass seed mix was drill seeded, and straw mulch was added and crimped in. At the well pad site, three plots were not seeded, and three additional sites were monitored in adjacent undisturbed *E. hooveri* habitat. At both sites, transects were used to quantify vegetation ground cover in two consecutive years (1991 and 1992) following reseeding using an ocular projection device. *E. hooveri* density and frequency was determined using belt transects and quadrats; grass and forb density was determined using quadrats. Monthly precipitation was recorded at eight stations.
Location: Two pipelines with a construction corridor 15–20 meters (m) wide, 38 kilometers (km) long (7 hectares [ha] of disturbed habitat) and a well pad (0.4 ha of disturbed habitat) at the Naval Petroleum Reserve No. 1, Kern County, California, USA
Findings: The density and frequency of *E. hooveri* and total plant cover and density of grasses and forbs increased significantly across the two years of the study. *E. hooveri* increased from 38 to 68 percent in undisturbed habitat and from 18 to 26 percent in seeded topsoil plots between 1991 and 1992 in the pipeline site. Cryptogamic soil crust cover decreased from 4.6 percent to 1.3 percent in undisturbed habitat and increased from 0 to 0.5 percent on the seeded topsoil plots in the pipeline site. In the well pad study site, *E. hooveri* density increased significantly between 1991 to 1992, but frequency did not. Total plant cover and density of grasses and forbs increased significantly in all treatments, with the highest increase found in undisturbed habitat. *E. hooveri* density and frequency was higher on unseeded topsoil compared to seeded topsoil plots, but not significantly so. At disturbed sites soil crust was not present in 1991 but was present in 1992.
Implications: *E. hooveri* can quickly colonize disturbed sites and may not be reliant on presence of cryptogamic soil crust. Seeding treatments does not reduce *E. hooveri* reestablishment. Late winter/early spring rainfall may promote high germination and establishment of *E. hooveri*. Long-term studies are needed to investigate the persistence and vigor of *E. hooveri* populations in disturbed areas.
Topics: Well Pad, Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Hooper, M.J., Glomb, S.J., Harper, D.D., Hoelzle, T.B., McIntosh, L.M., and Mulligan, D.R., 2016, Integrated risk and recovery monitoring of ecosystem restorations on contaminated sites: Integrated Environmental Assessment and Management, v. 12, no. 2, p. 284–295.

DOI: https://doi.org/10.1002/ieam.1731
Background: Restoration of contaminated lands should coincide with reduction of the contamination risk; restoration monitoring is an integral tool for achieving this. A well-developed monitoring plan keeps restoration goals on track using site-specific metrics and can result in desired restoration outcomes and contaminant risk reduction.
Objectives: The authors discussed how to design and implement monitoring protocol for restoring lands contaminated by industrial activities.
Methods: The authors introduced restoration approaches and the role of monitoring. They discussed the key components of a restoration monitoring plan. They reviewed the roles of adaptive management and clear communication in responding to monitoring findings. They discussed a few key takeaways and information learned from restoration monitoring.
Location: This is a methods paper and does not involve a specific field site location
Findings: Monitoring provides key inputs into restoration planning to ensure desired outcomes can be met. When designing a restoration monitoring plan, one should carefully consider what actually needs to be monitored, the restoration scale and functional metrics, what metrics will be driven by restoration outcomes, statistical power and data quality, and monitoring

frequency and timeframe. Communication and adaptive management are vital for responding to monitoring results and keeping restoration progress on track through the many years often necessary to reach desired restoration goals and claim restoration success.
Implications: Land and reclamation managers could use this article as a guide for planning and implementing restoration and reclamation monitoring programs.
Topics: Mining, Reclamation Theory, Reclamation Monitoring, Decision Support Tools

Hourihan, E.V., 2011, Climatic influences on sagebrush establishment in arid rangelands—Applications or rangeland rehabilitation: Reno, Nev., University of Nevada, master's thesis, 71 p.

Link (non-DOI): http://hdl.handle.net/11714/3947
Background: Sagebrush (*Artemisia spp.*) is an important plant throughout the Great Basin ecoregion of the United States. Sagebrush plants are fairly long-lived with few large recruitment bursts. This physiological mechanism complicates reestablishment following disturbance, such as oil and gas development. Understanding how factors, such as climate variables, affect establishment is important for ensuring successful revegetation during reclamation or restoration efforts. Collecting stand age data using dendrochronology is one method for exploring factors associated with establishment.
Objectives: The author wanted to assess demographic characteristics of four *Artemisia* species/subspecies, determine the impact of climate variables on *Artemisia* establishment, and development management guidelines for *Artemisia* seeding methods in Nevada.
Methods: Stands of four sagebrush (*Artemisia*) species/subspecies (including Wyoming big sagebrush, *Artemisia tridentata* ssp. *Wyomingensis*, black sagebrush, *Artemisia nova*, low sagebrush, *Artemisia arbuscula* ssp. *arbuscula*, and Lahontan sagebrush, *Artemisia arbuscula* ssp. *longicaulis*) were identified in areas where they naturally occurred in within eight sites across Nevada. Three 100 square meter (m^2) plots were established at each site and 80 stems were sampled from each plot. Data were collected for each species/subspecies from at least two different sites, including stem cross-sections from each sagebrush stand using a stratified random sampling method. Annual growth-rings in the cross-sections were examined and counted using a 10-power stereomicroscope. Climate data were collected. The "Parameter-elevation Relationships on Independent Slopes Model" was used to account for missing data. Data were analyzed using a one-way analysis of variance (ANOVA), linear regression, and multiple stepwise regression.
Location: Eight sites with naturally occurring *Artemisia* species/subspecies dispersed across Nevada, USA
Findings: Stand age differed significantly by site and species; mean stand age ranged from 18- to 27-years-old. The oldest detected individual was a Wyoming big sagebrush. The impact of weather variables differed by species and site and included summer precipitation; total annual precipitation during, 1-year prior, and 1-year following recruitment; average annual dewpoint; and the Pacific Decadal Oscillation index.
Implications: Seeding methods for *Artemisia* species/subspecies in Nevada need to be timed with precipitation and temperature for successful revegetation. This timing may vary by species so land managers should be aware of their select species recruitment needs. Additionally, land managers should factor in the unpredictable and high variable nature of precipitation events across the Great Basin. A State-and-Transition Model can be used to guide reestablishment efforts of sagebrush.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices, Decision Support Tools, GrayLit

Howard, G.S., and Samuel, M.J., 1979, The value of fresh-stripped topsoil as a source of useful plants for surface mine revegetation: Journal of Range Management, v. 32, no. 1, p. 76–77.

Link (non-DOI): https://www.jstor.org/stable/3897392
Background: Reestablishing vegetation after surface mining often involves respreading previously removed topsoil. Studies have suggested that topsoil may contain seeds, rhizomes, and vegetative plant parts from native species that may aid in revegetation of disturbed areas. However, natural revegetation may need to be augmented by seeding or transplantation depending on topsoil quality and environmental conditions.
Objectives: The authors assessed species establishment and plant density on reclaimed coal spoils one year (two growing seasons) after fresh topsoil application.

Methods: In spring 1976, topsoil sourced from nearby previously undisturbed areas was transported and applied to two coal spoil study sites. In Kemmerer, Wyoming, the topsoil was dominated by a big sagebrush community and in Oak Creek, Colorado by a mixed-shrub community. Topsoil was spread as uniformly as possible at a 20 centimeters (cm) depth. In June 1977, all established plant species were identified and assessed on the study spoils. In September 1977, quadrats and transects were established at each study spoil within which species were counted.
Location: Coal surface mine operations near Kemmerer, Wyoming and Oak Creek, Colorado, USA
Findings: Oak Creek received over twice as much precipitation as Kemmerer. Fourteen months after topsoil application, 39 and 41 species had established at the Kemmerer and Oak Creek coal spoils, respectively; however, most of these species were not present in the September count. Russian thistle (*Salsola kali*) densely populated the Oak Creek site. Kemmerer had a greater density of grasses, likely due to the rhizomatous characteristic of western wheatgrass (*Pascopyrum smithii*), and perennial forbs. Woody shrub presence was similar at both sites. Plant density was not high enough at either site to meet State and Federal revegetation requirements.
Implications: While topsoil application did result in some revegetation (more so at Kemmerer than Oak Creek), neither site had high enough densities to meet reclamation requirements. Topsoil alone is not sufficient for reclamation practices and should be combined with seeding or transplantation, along with additional methods (for example, irrigation) based on site-specific conditions.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Howard, G.S., Schuman, G.E., and Rauzi, F., 1977, Growth of selected plants on Wyoming surface-mined soils and flyash: Journal of Range Management, v. 30, no. 4, p. 306–310.

Link (non-DOI): https://www.jstor.org/stable/3897312
Background: Surface mining in arid and semi-arid environments has associated complications with revegetation due to limited precipitation and alkaline soils. Research indicates that on disturbed lands in Wyoming, revegetation is often dominated by less desirable species and is limited by high exchangeable sodium. Organic matter and fertilizer may not impact seedling emergence or growth, but planting distance and windbreaks can improve revegetation success. Greenhouse experiments using soil from mine sites could help develop successful reclamation revegetation methods.
Objectives: The authors tested potential plant growth on surface-mined soils and associated overburden and coal fly ash mixtures in a greenhouse experiment to evaluate reclamation alternatives.
Methods: In 1974 and 1975, samples of topsoil and newly uncovered overburden from three Wyoming mine sites were collected. Soil electric conductivity (EC) and pH were assessed in the samples. A randomized, replicated greenhouse experiment was used to test combinations of overburden, topsoil, sludge, and (or) manure (there were seven treatments total for two sites, and three treatments for the third site). Treatments were prepared in pots then a variety of woody plant species, newly germinated native seedlings, alfalfa, and grass species were planted. Plant growth and forage yields were monitored.
Location: Greenhouse experiment using soil from Wyodak Coal Mine, Seminoe No. 1 Coal Mine, and Utah International Uranium Mine in Wyoming, USA
Findings: pH did not vary significantly among topsoils and overburden across sites. EC was high in overburden from the Wyodak and Seminoe No. 1 mines. Results varied by site, but generally, collected topsoil and overburden from surface mine sites did not impede revegetation. All plants, including woody shrubs (specifically four-wing saltbush and winterfat), benefited from added nitrogen (N) more than phosphorous (P) fertilizer. Sewage sludge increased plant growth markedly.
Implications: Added N and sewage sludge amendment positively impacted seedling growth on surface mine soils in a greenhouse experiment and could be useful treatments in surface mine reclamation. However, further research is needed to test these treatments in the field where weather and precipitation variables are not controllable.
Topics: Mining, Target Plant Recovery Data, Soil Data, Reclamation Practices

Hoy, R.N., Spears, R.G., Dennis, D.S., and Vincent, R.B., 2006, Reclamation of an in situ coal gasification test site in Wyoming, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 260–287.

DOI: https://dx.doi.org/10.21000/JASMR06010260
Background: Coal gasification sites in the early 1980s in the Hanna Basin of south-central Wyoming were the first such experimental tests in the area. Tests and reclamation efforts were conducted by Sterns Catalytic Corporation. Water restoration was completed in 1989 and surface reclamation in 1993. Though the license site is relatively small, a number of issues were encountered that provide insight for future coal and non-coal related reclamation efforts.
Objectives: The authors evaluated reclamation efforts of coal gasification sites at the Hanna No. 1 Coal Seam in Wyoming. Specifically, they highlighted the reclamation issues addressed (that is, drought impacts, reclaimed vegetation selection areas, species planted compared with species expressed) and reviewed lessons learned regarding in situ mining projects (that is, groundwater contamination, measuring successful revegetation at sites with little disturbance, and sampling soil for water impacts).
Methods: Original reclamation efforts were twofold and followed criteria for Bond Release Category 5, the most stringent. Groundwater restoration was completed relatively quickly due to the efficiency of the burn and techniques used to quench it, and included removing oils, dissolved metals, dissolved nitrogen (N), and organic compounds. The surface reclamation that had occurred at these sites included an initial seeding of a mix of wheatgrasses (western, thickspike, and slender), Indian ricegrass, fourwing saltbush, and big sagebrush; minor control of Canada thistle and whitetop; spotty one-time inter-seeding early on; and fence repair. Vegetation cover, production, shrub density, and species diversity assessments were conducted in the early 2000s to evaluate revegetation success.
Location: Hanna No. 1 Coal Seam in the Hanna Basin of southcentral Wyoming, USA
Findings: The majority of reclamation issues are related to evaluation procedures, not success criteria. Water restoration was relatively simple, but surface reclamation faced several issues. Drought conditions negatively impacted vegetation cover in 2002, but cover increased by 2004. Undisturbed comparison areas were selected in 1995 but deemed unsuitable for evaluation, requiring a different comparison area to be selected in 1998. There were no comparable maps of the site before coal gasification facilities were constructed, which complicated the process of evaluating the extent of surface disturbance. Species expression did not match species seeded, and several weeds invaded the area, though not enough to deem revegetation unsuccessful.
Implications: When selecting comparison sites to evaluate vegetation reclamation, care should be taken to ensure the initial sites are appropriate and unimpacted by outside factors (such as grazing). Maps detailing the area should be generated before establishment of on-site facilities to best identify surface disturbances. Groundwater contamination can differ between industrial and gasification sites, so care should be taken that appropriate methods are employed. Persistence in reclamation efforts is important to ensure setbacks do not decrease success.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, GrayLit

Hueso-Gonzáleza, P., Muñoz-Rojas, M., and Martínez-Murillo, J.F., 2018, The role of organic amendments in drylands restoration: Current Opinion in Environmental Science and Health, v. 5, p. 1–6.

DOI: https://doi.org/10.1016/j.coesh.2017.12.002
Background: Restoration of dryland areas (regions with 0.05–0.65 aridity index values) represent 40 percent of global land surface and most are affected by changing global processes. Overtime, these lands will undergo higher temperatures, increases in aridity, altered precipitation events, and reduced soil organic carbon content. Restoration will likely be necessary to reverse or mitigate current and future changes to dryland ecosystems.
Objectives: The authors reviewed research evaluating the role of organic amendments in dryland restoration.
Methods: The authors explained "ecological restoration" according to the Society of Ecological Restoration definition and outlined how restoration applies to dryland areas. They discussed the past and present uses of organic amendment in dryland restoration efforts focusing on amendment types, selection criteria, application methods, and the beneficial systemic effects of amendment.

Location: This is a literature review and does not involve a specific field site location
Findings: Manure application has historically been used in agricultural practices on drylands but there are a number of amendment options including compost, crop residue, mulch, organic waste, and biofertilizers. Amendment selection and application method should be based on site-specific conditions. The benefits of amendment application vary with environmental and soil conditions; some studies suggest amendment application can reduce erosion and increase soil moisture on disturbed drylands.
Implications: Organic soil amendment is a useful tool for dryland restoration. Site-specific conditions and restoration outcomes are principal considerations when selecting amendment and applications methods.
Topics: Well Pad, Reclamation Practices

Hutson, H.J. and Thoman, R.W., 2017, Advancements in geomorphic mine reclamation design approach, Wyoming abandoned mine land, Lionkol coal mining district, Sweetwater County, Wyoming: Journal of the American Society of Mining and Reclamation, v. 6, no. 2, p. 51–83.

DOI: https://doi.org/10.21000/JASMR17020051
Background: The Wyoming Department of Environmental Quality (WDEQ) Abandoned Mine Lands agency has sought to address abandoned and historical coal mines in need of reclamation to mitigate public safety hazards. Returning the landscape to pre-mining conditions is often cost prohibitive given budget constraints and degraded channels can be challenging to reclaim. Geomorphic reclamation strategies were developed and employed by Natural Regrade technology at the Lionkol Project to return the landscape to a more natural appearance and meet budget constraints.
Objectives: The authors summarized detailed analysis of the successes and challenges of reclaiming the Lionkol Project using geomorphic reclamation techniques.
Methods: Carlson Natural Regrade software was used to create stable, diverse, and natural landscapes that encourage vegetation growth and mimic native channels. The software includes a channel stability analysis to calculate shear stress of flowing water in the design channels. From 2008–2013, the Lionkol drainage was reclaimed in four phases in four different areas. This involved reclaiming open pits, restoring hydrological function, realigning channels, and reducing erosion.
Location: Lionkol drainage in the high desert plateau in Sweetwater County near Rock Springs, Wyoming, USA
Findings: Four years after reclamation of Reliance No.11 North and South Pits, revegetation varied and was complicated by the arid area, little to no available cover soil material, and pH and salinity issues in the spoils. Despite relatively poor vegetative cover, the majority of the on-site channels functioned properly. General performance of the geomorphic channels at the Reliance No. 3 site matched expected behaviors of naturally establishing channels and was similar to both Reliance No. 11 sites. Vegetation was limited to small communities in depressions, sheltered areas, and along channel flowlines and banks (areas that focused and gathered runoff and snowmelt). Channel performance in the Lionkol Main Pit area was mixed. Stable channels resulted even at higher gradients due to the small drainage areas (supported by the relatively low modeled shear stresses) but a few channels within the largest basins performed poorly and required repair. Smaller basins performed well and behaved similarly to geomorphic channels in Reliance No.11 North. The Lionkol Main Drainage sustained limited damage during heavy storm flows. Repairs were focused on the rock structures downstream of the culverts conveying flows under Lionkol road. The main channel performed well with limited channel bed cutting and small (<1 foot [ft]) cut banks. During construction, Lionkol West underwent three separate heavy storm flows with a return interval between a 10- and 25-year storm, which provided a real-world test while an engineer was onsite to observe and make repair strategy changes where necessary.
Implications: The Lionkol Project fully implemented new methods in geomorphic mine land reclamation to achieve a sustainable reclaimed landscape which blends with native topography and provides for long-term stability against erosion.
Topics: Mining, Vegetation Recovery Data, Soil Data, Erosion Data, Hydrology Data, Reclamation Practices

Ingram, L.J., Stahl, P.D., and Anderson, J.D., 2007, The influence of management practices on microbial and total soil nitrogen, *in* Barnhisel, R.I., ed., American Society of Mining and Reclamation 24th Annual National Conference, Gillette, Wyo., June 2–7, 2007, Proceedings: American Society of Mining and Reclamation, p. 334–348.

DOI: https://dx.doi.org/10.21000/JASMR07010334
Background: Plant growth is limited in semi-arid environments, like Wyoming, and nitrogen (N) is generally the leading limiting nutrient factor. Mining and reclamation remove N from the soil and increase inorganic forms of N that cannot be readily used by plants. Soil microbes play an important role in N storage and are also impacted by mining and reclamation. It is unclear how various reclamation practices impact soil and microbial N in semi-arid conditions.
Objectives: The authors investigated the impacts of various reclamation practices on total N and N present in microbial biomass 10 years after reclamation of Wyoming coal mines.
Methods: Five reclaimed mines and undisturbed areas, all with comparable soil and vegetation types were identified in southern and eastern Wyoming. Three common practices were compared within two of the mines; these included (1) grazed versus ungrazed locations, (2) stockpiled versus direct hauled soil, and (3) shrub versus grass seed mix. A third mine allowed for comparison of stubble versus hay mulch. At all reclamation and undisturbed site pairs, soil was sampled at depths of 0–5 centimeters (cm), 5–15 cm and 15–30 cm from four points along three randomly located 100 meter (m) transects. Bulk density was determined at two points along each transect at depth intervals of 0–5 cm, 5–15 cm and 15–30 cm; these data were used to calculate N mass per hectare (mass/ha). Soil chemical and nutrient properties were also analyzed from the samples. Microbial biomass was quantified by the chloroform fumigation extraction method. Data were analyzed using analysis of variance (ANOVA).
Location: Five coal mines in southern and eastern Wyoming, USA
Findings: Across all compared practices, there was no consistent effect of reclamation practice on total N or N present in microbial biomass.
Implications: There is no one best practice for restoring total N during reclamation of coal mines. While the addition of N fertilizer provides the greatest certainty in addressing N deficient reclaimed soils, it is not commonly done across Wyoming coal mines for a range of reasons including cost and increased likelihood of weeds. Leguminous species, while able to provide “free” N and are commonly part of the reclaimed seed mix, typically provide little in the way of additional N due to a range of limitations including soil fertility as well as potential competition. Despite this, low N did not seem to reduce plant production and it is likely that over time, N will likely increase.
Topics: Mining, Soil Data, Reclamation Practices, GrayLit

Inman, T., 2016, An overview of natural gas well pad surface disturbances and techniques used to increase reclamation success within the Vermillion Basin, Wyoming: Corvallis, Oreg., Oregon State University, master’s thesis, 46 p.

Link (non-DOI): https://ir.library.oregonstate.edu/concern/graduate_projects/vq27zt60q
Background: The Vermillion Basin in Wyoming is a unique high-altitude desert with a long history of energy extraction. Natural gas development began in the 1940s and has disturbed thousands of acres with well pad, road, and pipeline construction. Well pad reclamation can be difficult in the basin due to poor quality topsoil, noxious weed invasions, and climate conditions. However, there are science-based techniques that can lead to successful reclamation if applied, managed, and monitored appropriately.
Objectives: The author described successful reclamation techniques for implementation in the harsh Vermillion Basin of Wyoming.
Methods: The author described the Vermillion Basin location, mining history, and need for appropriate reclamation efforts. They reviewed the basin’s vegetative, soil, recreational, livestock grazing, water, and wildlife resources. They discussed the socioeconomic and ecosystem implications of reclamation in the basin. They outlined proper reclamation protocol for the basin (for example, disturbance reduction, reseeding, invasive weed control, livestock grazing, soil rehabilitation, and long-term monitoring). They summarized recommendations for reclamation management in the basin.
Location: Vermillion Basin in southwest Wyoming, USA

Findings: The Vermillion Basin has unique natural and cultural resources that require tailored reclamation after oil and gas disturbance. Controlling invasive species like cheatgrass, halogeton, and black henbane are paramount for proper revegetation and ecosystem function. Closely managed livestock grazing, and prescribed burning could help restore soil organic material necessary for soil and vegetation community health. Utilizing proven best management practices is essential for reestablishing the basin's unique vegetation, soil, and water resources.
Implications: This document is a useful resource of reclamation planning recommendations for land managers, government agencies, and reclamation specialists working in the Vermillion Basin of Wyoming and could be applied to similar ecological areas.
Topics: Well Pad, Reclamation Policy, Reclamation Practices, Decision Support Tools, GrayLit

Iverson, L.R., and Wali, M.K., 1982, Buried, viable seeds and their relation to revegetation after surface mining: Journal of Range Management, v. 35, no. 5, p. 648–652.

Link (non-DOI): https://www.jstor.org/stable/3898656
Background: The plant species that emerge during the revegetation process on reclaimed mine sites is determined by two leading factors: the seed mix used during reclamation and the existing seedbank in the topsoil. To ensure desired species reestablishment, it is important to assess the seed bank and quantify viable seeds already present, of both desirable and undesirable species. This information can help evaluate whether topsoil is helpful in establishing the revegetation succession at the site and increase reclamation success.
Objectives: The authors assessed the local topsoil for use in reclamation by estimating the viable seed populations it contains and compare the contributions of migrating seed populations with the topsoil seed bank populations.
Methods: Topsoil seed bank populations were estimated at (1) two native mixed grass prairie sites adjacent to active mining sites (one grazed and one ungrazed), (2) a nearby 1-year-old stockpiled topsoil, and (3) a nearby fresh stockpile. Fifty sample points were randomly located across the grazed and ungrazed sites, and 18 sample points were located across each stockpile. At each point, 5-centimeter (cm) diameter cores were collected at 0–2.5 cm, 2.5–7.5 cm, and 7.5–15 cm depth intervals. The cores were set in a growth chamber for over 16 months to germinate seeds within them. Species were identified as early as possible. Data were grouped by four time periods based on emergence. Seed density means were calculated by site and depth, Shannon-Weiner diversity values were derived, and differences among sites were assessed using *t*-tests.
Location: Western prairie near Beulah, North Dakota, USA
Findings: The grazed site had the highest seed density (>7,700 seeds per square meter [seeds/m^2]) but 43 percent were weed species. The ungrazed site had just over half the density (3,900 seeds/m^2) with only 7 percent weedy species. Both stockpiles had significantly lower seed density than either prairie site. Seed density and diversity decreased with depth. Most seedling emergence occurred during the first four months after planting. Comparisons of seed bank species composition and vegetation on newly reclaimed surface mine sites illustrated dispersal over time (due to seed dormancy) and space (due to seed immigration).
Implications: Seed dispersal through immigration from nearby areas can lead to revegetation of species not present in the topsoil seed bank. However, topsoil is still important in the reclamation process by reintroducing species that were present on the landscape before surface mining occurred. Seed banks can continue influencing revegetation over time through varying seed dormancy and emergence.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Iverson, L.R., and Wali, M.K., 1982, Reclamation of coal mined lands—The role of Kochia scoparia and other pioneers in early succession: Reclamation and Revegetation Research, v. 1, p. 123–160.

Link (non-DOI): https://www.osti.gov/etdeweb/biblio/6957790
Background: Surface mining disrupts soil and plant communities. Revegetation succession is influenced by multiple variables, including pioneer species like *Kochia scoparia* along with planted *Agropyron* spp. grasses. The shifts in these species' presence and density alters overall plant species composition and is affected by soil properties and competition. Understanding succession on reclaimed surface mines is necessary for successful revegetation.

Objectives: The authors explored shifts in plant species composition and soil properties in the first four years after reclamation and proposed potential drivers of observed changes.
Methods: Five areas were used for the study, representing reclamation sites that were 1, 2, 3, and 4 years after reclamation on a mine site, plus one unmined location; all were within 3 kilometers (km) of one another, and had similar topography and history. In 1977, species composition data were collected using 50 randomly placed 50 × 50-centimeter (cm) quadrats at each site. An additional 392, 25 × 25 cm quadrats were used to sample plant growth, including measures of height, density, and biomass. Plants were harvested to assess aboveground biomass. Soil chemical and physical characteristics were also assessed. Soil samples were collected from the top 15 cm at each mined site at 6-week intervals throughout the 1977 growing season and the unmined site was sampled once in August 1977. In 1977, competition experiments were established using five replicate plots subdivided into three 1.5 square meter (m^2) sub-plots with one of three seeding treatments: *K. scoparia* only, *Agropyron* spp. only, or both species together. A separate autotoxicity field experiment was conducted by thinning *K. scoparia* plants in 2-year-old sites and applying one of two treatments to two sub-plots (0.5 m^2): *K. scoparia* with 10,000 plants/m^2 and *K. scoparia* thinned to 50 plants/m^2. Based on field observations of insect damage, stems of seven dominant species were examined for cocklebur weevil larvae. Five growth chamber experiments were conducted to further examine contributions of competition and allelopathy to shifts in plant composition. Bioassays of pioneer plants were also conducted to contribute to the allelochemical study.
Location: Missouri Plateau of the Great Plains Physiographic Province in western North Dakota, USA
Findings: Thirty species invaded the sites by four years after reclamation and species richness increased over time. *K. scoparia* was the most notable invader, with density increasing but growth decreasing over time. Native prairie species frequencies were highest by year four. Soil properties changed significantly over time and differed between mined sites and the undisturbed site. Total nitrogen (N) and organic matter increased, possibly due to added fertilizer. Thinning did not affect *K. scoparia* growth, and competition with *Agropyron* was limited, indicating autotoxicity may be a factor in *K. scoparia* growth decline. Growth chamber experiments showed decaying *K. scoparia* leaves to be toxic to some pioneer species.
Implications: Vegetation succession following reclamation is influenced by pioneer species establishment and allelochemical interactions and can be altered by harsh arid and semi-arid environmental conditions.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Iverson, L.R., and Wali, M.K., 1987, Mowing of annual colonizers to enhance revegetation after surface mining: Reclamation and Revegetation Research, v. 6, p. 157–161.

Link (non-DOI): https://www.fs.usda.gov/nrs/pubs/jrnl/1987/ne_1987_iverson_002.pdf
Background: Although mowing benefits agricultural, prairie, and wildlife reseeding efforts, it is not a common practice in management of reclaimed western mined lands, which often ends after fertilization and seeding. Mowing first-year colonizers, such as *Kochia scoparia* could enhance grass establishment and accelerate revegetation, especially since the species is known to decrease grass tillering after the first growing season due to shading.
Objectives: The authors evaluated the effects of mowing first-year *K. scoparia* on grass establishment on reclaimed surface coal mines in North Dakota.
Methods: The study area was recontoured, topsoiled, fertilized, and drill seeded with a primarily wheatgrass seed mix in September 1975 following protocols used by the Knife River Coal Company. Four 15 × 60-meter (m) plots were selected. In 1976, on three plots, vegetation was mowed on 15 July, 28 July, or 18 August to a 15 centimeters (cm) height then mulched and the fourth plot was left as a control. In 1977, biomass, density, and plant size were sampled in all four plots for *Agropyron* spp., *K. scoparia*, and *Salsola collina*.
Location: Near Beulah, North Dakota, USA
Findings: First- and second-year *K. scoparia* growth was typical for the area. Mowing, especially in late July and mid-August of the first growing season, significantly reduced *K. scoparia* density and biomass; significantly increased *Agropyron* spp. biomass; and had no effect on *S. collina*.
Implications: Mowing may hasten revegetation of desired grass species, especially if done in late summer of the first growing season. Implementing last summer first-season mowing could increase reclamation revegetation success.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Iverson, L.R., and Wali, M.K., 1992, Grassland rehabilitation after coal and mineral extraction in the western United States and Canada, *in* Wali, M.K., ed., Ecosystem rehabilitation, Volume 2—Ecosystem analysis and synthesis: The Hague, SPB Academic Publishing, p. 85–129.

Link (non-DOI): https://www.fs.usda.gov/nrs/pubs/jrnl/1992/ne_1992_iverson_001.pdf
Background: North American grasslands have seen a drastic increase in mining disturbance since the early 19th century with little regard for reclamation or rehabilitation of disturbed landscapes. A concern for rehabilitating mine-disturbed grasslands surfaced in the 1960s and 1970s, but reclamation presented problems of its own. Understanding grassland ecology and the history of mining and reclamation in these areas is important for directing future research to improve rehabilitation efforts.
Objectives: The authors reviewed literature on mining and reclamation on North American grasslands and recommended future research avenues to improve grassland reclamation.
Methods: The researchers discussed the geographical and environmental characteristics of North American grasslands, coal and mining disturbances on grasslands, rehabilitation of abandoned mines, problems associated with rehabilitating and reclaiming mines, and methods for minimizing these problems. They then compared pre- and post-reclamation grassland succession. Finally, the researchers outlined future research needs to improve grassland rehabilitation and reclamation efforts.
Location: This is a literature review and does not involve a specific field site location
Findings: Future research for improving grassland reclamation should focus on better understanding the effects of mining and reclamation on soil, vegetation, and ecosystem functions in these semiarid and arid landscapes. Example research directions include designing methods to reintroduce soil organisms post-mining, determining which cultural practices increase survival and growth of diverse plant communities, conducting genetic studies to identify plants best adapted to stressors post-mining, and using remote sensing and geographical information systems to inform and streamline reclamation assessments.
Implications: This review is a useful primer on the history and complications of grassland reclamation in North America and a reference for potential research avenues to improve reclamation methods.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Theory, Reclamation Practices

Jackson, L.J., 1991, Surface coal mines—Restoration and Rehabilitation: London, IEA Coal Research, 78 p.

ISBN: 92-9029-184-2
Background: Surface mining is an environmentally degrading operation that creates dust, noise, and a scar across the landscape that can persist for decades or even hundreds of years. Mining methods can reduce environmental impacts and carefully planned reclamation can help reestablish natural and functioning ecosystems.
Objectives: The author synthesized literature (largely published 1986–1991) on coal surface mining methods and reclamation protocol for reducing environmental damage, returning the land's productivity, and restoring a natural appearance.
Methods: Chapter one introduced the book's contents and objective. Chapter two reviewed surface mining activities and reclamation legislation in several countries worldwide. Chapter three considered pre-mining site characterization and reclamation and mining planning. Chapter four focused on overburden and soil material removal and replacement. Chapter five discussed revegetation of overburden and soil material, specifically plant species selection, planting techniques, and assessment methods.
Location: This is a literature review and does not involve a specific field site location. The authors acknowledge that the review is biased toward the United States, but also includes research from Canada, Germany, the United Kingdom, Spain, Australia, and South Africa.
Findings: In the United States, mining method varies by region and reclamation practices are guided by the Surface Mining Control and Reclamation Act. Mining planning should consider site characteristics like climate, topography, soils, overburden, vegetation and ecology, and land capability and use. Restoration planning should consider post-mining land use, spoil and soil handing, erosion control, landscape design, revegetation, and costs and benefits. Soil characteristics, removal, storage, handling, and replacement all affect revegetation outcomes. Soil rehabilitation methods could include irrigation and drainage, topsoil substitute, fertilizers, and soil amendments depending on site-specific characteristics. Revegetation methods and selected species will depend on the post-mine land use designation and may include ground cover plants, crops, and trees.
Implications: This review is a helpful introductory resource for land and reclamation managers interested in learning more about reclamation legislation and planning methods that mitigate the negative environmental impacts of surface mining.
Topics: Mining, Reclamation Policy, Reclamation Practices, Reclamation Monitoring, Reclamation Standards

Jacobs, J.S., Winslow, S.R., Clause, K.J., and Hybner, R., 2011, Seeded native shrub establishment on disturbed sites in southwestern Wyoming: Natural Resources and Environmental Issues, v. 16, Article 22, p. 1–5.

Link (non-DOI): https://digitalcommons.usu.edu/nrei/vol16/iss1/22
Background: Shrub presence in southwestern Wyoming is important for soil stability, plant and animal diversity, and wildlife habitat. Particular species play vital roles in the ecology of the region providing thermal security, nesting sites, and food for many species. Population expansion and development associated with energy exploration and extraction are threatening vital habitat for species in high elevation rangelands and sagebrush ecosystems. To promote ecosystem integrity and protect wildlife, adequate restoration of shrubs following disturbance is necessary. Since the 1950s researchers have studied native shrub species and developed accessions for conservation purposes. This research evaluated 16 different shrub species accessions to determine the best seed mixture and seeding method for establishing shrubs following energy extraction.
Objectives: The authors wanted to evaluate performance of different native shrub species important for wildlife establishment following restoration efforts. Additionally, researchers wanted to assess the effectiveness of different seeding methods and seed mixtures in reaching desired ecological diversity and structure.
Methods: A 37-month-old topsoil stockpile was re-applied to its former 1.5 hectare (ha) square oil and gas well pad. Sixteen accessions of different native shrub species were drill seeded into replicated single-species plots at 871,000 pure live seed per acre (PLS/ac). In adjacent plots, two seed mixes were also tested; a 15-species mix (40 percent grasses, 33 percent forbs, 27 percent shrubs) was drill seeded at 10.12 pounds (lb) PLS/ac, and a 10-species mix (20 percent grasses, 40 percent forbs, 40 percent shrubs) was either drill seeded at 5.18 lbs PLS/ac or hydroseeded at 10.34 lb PLS/ac. Two years after planting, emerged shrubs were counted to estimate density at three random locations within each treatment plot. Plant height and vigor were also quantified.
Location: A well-pad 30 miles south of Pinedale, Wyoming, USA
Findings: Over half of the shrub accessions (9 out of 16) successfully established after two years. *Atriplex aptera* and *A. canescens* had the highest densities with 6 plants per square meter (plants/m^2) and 4 plants/m^2, respectively. The other successful accessions had much lower densities ranging from 0.4 to 2 plants/m^2. Hydroseeding had the lowest shrub establishment (1,100 plants/ha), whereas broadcast seeding and drill seeding resulted in, on average, higher shrub densities especially for *Artemisia tridentata* ssp. *Wyomingensis, Atriplex aptera, Krascheninnikovia lanata,* and *Atriplex canescens.* However, drill seeding the 15-species seed mix resulted in 0 plants/ha for *A. tridentata* ssp. *Wyomingensis*.
Implications: Drill- or broadcast-seeding with the 10-species seed mix containing a higher proportion of shrubs can increase shrub density on reclaimed lands. For seed mixes similar to the 15-species mix, they should be broadcast seeded to increase shrub densities. Initial irrigation, if available, may improve chances of reclamation success. Increasing the presence of *A. canescens* at a site is important for wildlife and may facilitate establishment of sagebrush communities.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Jacobs, J.S., Winslow, S.R., Clause, K.J., and Parr, S., 2013, Native grass establishment and performance for well-pad reclamation in Wyoming: U.S. Department of Agriculture, Natural Resources Conservation Service, Plant Materials Technical Note, no. MT-90.

Link (non-DOI): https://nrcs.usda.gov/plantmaterials/mtpmstn11910.pdf
Background: Selecting the appropriate species for reclamation involves several layers of considerations including management goals, climate, topography, soils, and resource concerns. Selecting from seed sources that are locally adapted is important because native species may be sensitive to slight shifts in ecological or climatic conditions. The report focused on a particular well site that is important habitat for seasonal pronghorn antelope and year-round sage grouse.
Objectives: The authors evaluated 12 native grass species for establishment on a highly disturbed site with harsh growing conditions and assessed which varieties or accessions of the same species established under various conditions.
Methods: In 2002, a well pad was constructed on Bureau of Land Management (BLM) land then reclaimed three years later. During reclamation, stockpiled soil was re-applied after 37 months of storage, ripped to reduce compaction, and a fence was installed to reduce ungulate grazing. Multiple cultivars of twelve grass species (32 cultivars total) were individually seeded in four rows within 4 × 20-foot (ft) plots using a precision seeder delivering 30 pure live seed per foot (PLS/ft). Plant density was counted two, three, four, and five years after reclamation. Overall stand establishment was ranked from 1 to 9, with 1

indicating complete establishment. Plant vigor was rated on a similar 1 to 9 scale. Above-ground biomass was clipped from the middle 16 ft of the inner two rows of each plot in 2008 and from the middle 16 ft of the outer two rows 2010; this was dried and weighed. Data were analyzed using analysis of variance (ANOVA).
Location: A 3.8-acre gas well pad 30 miles south of Pinedale in Sublette County, Wyoming, USA
Findings: The tested native grass species established at different rates. Warmer and drier conditions during the growing season (compared to long-term averages) may have been responsible for overall low seedling emergence and survival. Plant density was highest in 2007 followed by 2010, 2008, and 2009. Thickspike wheatgrass had the highest density and prairie Junegrass had the lowest. Basin wildrye, western wheatgrass, slender wheatgrass, and bluebunch wheatgrass had high densities as well, but lower than thickspike wheatgrass. Basin wildrye had the highest biomass of any species.
Implications: Planting the top six species from this study (including thickspike wheatgrass, basin wildrye, western wheatgrass, slender wheatgrass, and bluebunch wheatgrass) during reclamation would promote grass establishment. While the tested species were diverse, they did not contain any early season nor any mid-seral species. Bluebunch wheatgrass, thickspike wheatgrass, and basin wildrye could be particularly important to establish for wildlife cover and forage. The paper provides specific accession recommendations for other grass species that should be used for planting in dry and hot conditions.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Jacoby, P.W., 1969, Revegetation treatments for stand establishment on coal spoil banks: Journal of Range Management, v. 22, no. 2, p. 94–97.

Link (non-DOI): https://www.jstor.org/stable/3896188
Background: Surface mining disrupts soil, plant, and aquatic communities not only through construction of open pits, but also the accumulation of large waste material called spoil. In semiarid environments such as Wyoming, lack of precipitation, heat, evaporation, and drought further complicate revegetation. Developing new reclamation techniques can improve reclamation success. One such technique initiated by the University of Wyoming was seeding spoil banks to test candidate species, treatments, and methods for revegetation.
Objectives: The author evaluated the success of various revegetation methods on differently aged surface coal mine spoil banks in a semiarid environment.
Methods: Spoil banks that were 3, 9, and 15 years after deposition were selected to assess the effects of weathering on their reclamation potential. Each spoil bank was hand-seeded with intermediate wheatgrass, crested wheatgrass, Russian wildrye, and smooth brome, then treatments of straw mulch, jute netting, and snow fence were applied in all possible combinations within 200 square foot (ft^2) areas. The snow fence treatment was intended to modify water resources, while mulch and jute netting were intended to modify seed microclimate. Treatments were applied in 1966 and evaluated after one year. Seedling density was measured in five sample areas and averaged across all samples within treatment. Treatment plots were compared to an undisturbed control site.
Location: Kemmerer coal fields in southwestern Wyoming, USA
Findings: Seedling density was higher in treatments sites across all age categories compared to the control; seedling density increased with bank age. Mulch combined with jute netting produced the highest seedling density across all age categories, except snow fence and jute netting on the youngest bank. Regarding treatment costs, all three treatments combined was the most expensive, and snow fence alone was the least expensive.
Implications: Surface coal mining spoil banks can be successfully revegetated, and such success increase with older, more weathered banks. Affecting the seed microclimate through jute netting and mulch is the most effective method for achieving high seedling density. However, spoil properties, like pH and soil texture, can also impact revegetation and should be assessed to aid determination of suitable planting options.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Janz, A., Whitson, I.R., and Lupardus, R., 2019, Soil quality and land capability of reclaimed oil and gas well pads in southern Alberta—Long-term legacy effects: Canadian Journal of Soil Science, v. 99, no. 3, p. 262–276.

DOI: https://doi.org/10.1139/cjss-2019-0020
Background: In Alberta, Canada, approximately 100,000 oil and gas well pads have been reclaimed since 1963, but no long-term monitoring or assessment protocol has been implemented. Because soil degradation can occur at multiple stages and soil depths during well pad construction, monitoring the lasting effects of these disturbances is an important step for ensuring

successful future land use and productivity. The Ecological Recovery Monitoring Project was established in the mid-2010s to develop protocols for monitoring and certifying reclaimed land in Alberta using the land suitability rating system as an assessment tool.

Objectives: The authors assessed the long-term effects of well pad reclamation on soil parameters and land capability as measured with the land suitability rating system.

Methods: Twenty-five reclaimed well pads certified from 1964–2011 were selected for the study. In 2015, approximately 2,500 soil samples were collected, which represented four soil depth intervals (0–15 centimeters [cm], 16–30 cm, 31–60 cm, and 61–100 cm) from 120 plots distributed across the 25 well sites, as well as 90 plots distributed among reference sites located around the perimeter of each well pad. Soil landscape properties were determined for each well site based on published survey data. The soil samples were analyzed for bulk density, pH, electrical conductivity (EC), and total organic carbon (C). Soil quality differences between well pad and reference plots were calculated using the rating system. Data were analyzed using multivariate covariance generalized linear modeling.

Location: Well pads within the Ecological Recovery Monitoring Project on cultivated land within the Dark Brown soil zone and mixed-grass natural subregion from Calgary to the US border in southern Alberta, Canada

Findings: Soil properties (except EC) and capabilities differed significantly between well pad and reference sites and varied among soil sample depths. pH was notably higher on well pad sites despite reclamation efforts to reduce pH. Certification date had a weak but significant effect on pH and total organic C in the 0–15 cm sample, bulk density and total organic C in the 16–30 cm sample, and pH in the 61–100 cm sample. Well pads had lower frequencies of land suitability rating system classes 1–3 and higher frequencies of 5–7 classes compared to reference sites, indicating reduced land capability on reclaimed well pads.

Implications: This study illustrates that in Alberta, reclamation alters land disturbed by oil and gas development but does not reestablish soil properties and land capability to pre-mine levels. This legacy effect of oil and gas disturbance needs further research to be fully understood and future studies could relate soil condition and land suitability rating system class to aboveground biomass and crop productivity.

Topics: Well Pad, Soil Data, Reclamation Practices, Reclamation Monitoring, Reclamation Standards

Jastrow, J.D., Miller, R.M., Rabatin, S.C., and Hinchman, R.R., 1984, Revegetation of disturbed land in arid ecosystems, chapter 2 *of* Dvorak, A.J., Ecological studies of disturbed landscapes—A compendium of the results of five years of research aimed at the restoration of disturbed ecosystems: U.S. Department of Energy, Office of Scientific and Technical Information, DOE/NBM-5009372 (DE85009372), p. 2-1–2.37.

Link (non-DOI): https://www.osti.gov/biblio/5506382

Background: Several problems are associated with rehabilitation of disturbed arid ecosystems, such as topsoil removal and replacement. It is unclear whether removing and replacing topsoil immediately, or storing topsoil for several years before reapplying, is more beneficial for vegetation reestablishment. This research was initiated in 1976, when little information existed regarding soil conditions of stockpiled soils, but it was assumed that stockpiling was detrimental to soil quality in arid and semiarid environments.

Objectives: The authors sought to determine if mining and reclamation procedures could be modified to improve desirable plant community establishment under arid conditions.

Methods: In 1976, five plots were established with three treatments: one plot with direct-applied topsoil, two plots with stored topsoil, and two undisturbed control plots. Direct-applied and stored topsoil plots were broadcast seeded in spring 1976 and drill-seeded (due to poor establishment) in fall 1976. In 1978–1982, plant species cover was estimated in all plots using the line-intercept method. The frequency of species occurrence and Shannon-Wiener diversity indices were calculated for each species. Soil conditions and characteristics were sampled and compared from treatment soils. Soil samples and vegetation cover classes were used to characterize undisturbed soil conditions and plant communities. Germination tests were conducted to evaluate native plant revegetation potential via seed and propagule reserves in the soil.

Location: Jim Bridger Mine (elevation 2,100 meters [m]; 7.5–30 centimeters [cm] precipitation annually) in the Wyoming Basin Province in Wyoming, USA

Findings: Within a 10-year period following direct applied topsoil, it may be possible to reestablish native plant cover equal to that of undisturbed areas. However, species diversity on disturbed sites will be harder to achieve. Native seed propagules in replaced topsoil may assist with native species reestablishment, however this should not be heavily relied upon. Seeding native species, as well as short-term irrigation or other soil-moisture enhancing methods, are likely necessary for successful vegetation reestablishment.
Implications: Land and reclamation managers of disturbed land in semiarid and arid environments should consider using direct-applied topsoil over stored topsoil and seeding native species to reestablish plant communities comparable to those on nearby undisturbed land. Such community reestablishment may take up to or more than ten years.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Jennings, S.R., Goering, J.D., and Blicker, P.S., 2007, Evaluation of organic matter compost addition and incorporation on steep cut slopes—Phase II test plot construction and performance monitoring: Montana Department of Transportation, prepared by Reclamation Research Unit, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Mont., 100 p.

DOI: https://doi.org/10.21949/1518165
Background: Revegetating steep slopes along highway corridors is a challenge faced by many State Departments of Transportation, where poor plant establishment can result in soil erosion and need for recurrent maintenance. Revegetation in Montana can be especially challenging on nutrient poor parent materials, including alluvial rock and glacial till (both common in western Montana), or marine shale (common in eastern Montana). Previous research in Phase I of this project by Jennings and others (2003; https://doi.org/10.21949/1518186) indicated that organic compost amendment may improve revegetation efforts and mitigate maintenance issues on problematic steep slopes. Evaluating various amendment application methods and the effect on vegetation establishment could improve roadside steep slope reclamation.
Objectives: The authors evaluated the efficacy of compost application and incorporation equipment and measured vegetation performance and erosional stability.
Methods: Three study sites were established, two along U.S. Highway 2 (at mileposts 69 and 77) on steep roadcuts in previously glaciated terrain, and a third at the U.S. 12 and I-94 interchange near Miles City. The site at milepost 69 was on very coarse textured soil, the site at milepost 77 was on fine-textured glacial lakebed soil, and the site near Miles City was on fine-textured gray shale. Five plots were established at the two sites along Highway 2, and each plot was assigned one of five treatments. At the site near Miles City, ten plots were established, and the same five treatments were applied, each with two replicates. Treatments were: (1) tillage and broadcast seeding control, (2) 2.54 centimeters (cm) compost incorporated with broadcast seeding, (3) 5.08 cm compost incorporated with broadcast seeding, (4) 2.54 cm compost blanket with broadcast seeding, and (5) 5.08 cm compost blanket with broadcast seeding. Plots were prepared, amended, and seeded in April 2004. Sites were seeded using a 9-species native seed mix that was tailored to the specific location. A composite soil sample was collected from each plot prior to construction and after 2 years of plant growth, to analyze soil chemistry, structure, and nutrient content. Compost was also sampled and analyzed at all sites. Vegetation and erosion were monitored within plots twice a year from 2004 to 2006. Erosion was quantitatively evaluated during each site visit.
Location: Mileposts 69 and 77 along U.S. Highway 2 approximately 60 kilometers (km) east of Libby in northwest Montana and the interchange of U.S. 12 and I-94 approximately 4.8 km east of Miles City in southeast Montana, USA
Findings: The blower truck was the best equipment for compost application and AEBI tractors for tillage. Compost addition improved organic matter content and expected long-term nutrient pools needed for microbial processes. Compost greatly enhanced vegetation performance, with only subtle differences between application methods (incorporated versus blanket). All compost application plots had reduced erosion, likely due to enhanced vegetation growth. While 2.54 cm of compost was effective, plant biomass was higher with an application rate of 5.08 cm.
Implications: Compost application can improve soil conditions, increase vegetation performance, and reduce erosion. Further monitoring of these Montana research sites will better inform long-term outcomes in response to compost application. Additional research along other highways could help to clarify appropriate application methods and rates a broader suite of projects which may occur on soil substrates differing from those studied here, and land and reclamation managers will need to assess site-specific conditions before implementing this study's suggested compost application methods.
Topics: Road, Vegetation Recovery Data, Soil Data, Erosion Data, Reclamation Practices, GrayLit

Jennings, S.R., Goering, J.D., Blicker, P.S., and Taverna, J.J., 2003, Evaluation of organic matter compost addition and incorporation on steep cut slopes, Phase I—Literature review and potential applicable equipment evaluation: Montana Department of Transportation, prepared by Reclamation Research Unit, Department of Land Resources and Environmental Science, Montana State University, Bozeman, Mont., 71 p.

DOI: https://doi.org/10.21949/1518186
Background: Revegetating steep slopes along highway corridors cannot be achieved by conventional salvaged topsoil replacement. Current protocol includes broadcast seeding and hydro-mulching bare slopes, which often leads to marginal plant establishment due to nutrient-poor rocky soils. Poor vegetation establishment leads to increased erosion, slope failure, noxious plant species growth, poor aesthetics, and overall increased maintenance costs. Soil organic matter (SOM) can increase vegetation production in nutrient-poor conditions, such as steep slopes. Identifying effective methods for establishing vegetation on steep highway cut slopes in Montana could increase success and decrease costs.
Objectives: The authors (1) conducted a literature review to determine possible optimal organic compost amendment rates, (2) evaluated potential equipment capable of applying and incorporating compost up to 10.1 centimeters (cm) on 2:1 (horizontal length to vertical rise) slopes, and (3) assessed possible field site locations for phase II.
Methods: A Technical Advisory Panel of state government and private sector experts on compost and revegetation was formed. A literature review of compost application studies was conducted; authors were contacted for additional information and research reports. State Departments of Transportation were queried in other states for experience conducting similar work. Applicable equipment for applying and incorporating compost on steep sites was reviewed, and several potential contractors and vendors with relevant experience or equipment were contacted. Potential research sites in northwestern Montana along U.S. Highway 2 were also assessed.
Location: This is a literature review and does not involve a specific field site location. However, potential study sites for phase II were identified along U.S. Highway 2 near Happys Inn in northwest Montana, USA
Findings: Compost is highly effective at increasing soil nutrients, enhancing vegetation production, and controlling erosion. Application rates vary from 2.5 to 10.1 cm depending on site-specific conditions; in general, deeper compost layers enable greater erosion control. On slopes 3:1 (horizontal length to vertical rise) or steeper slopes, a pneumatic blower is the recommended equipment for compost application. Other equipment includes dozers, loaders, tracked log skidders, snow cat utility vehicles, and wheeled tool carriers. It should be noted that slopes ^{3}2:1 have inherent dangers of roll-over or run-away. Phase II candidate research sites along U.S. Highway 2 near Happys Inn include a south-facing glacial till site (milepost 67) with approximate 65 percent slope steepness and a south-facing alluvial rock site (Elk Creek Road) with approximately 50 percent slope steepness. Additional potential research sites were identified in the Colstrip South Project.
Implications: Compost may enhance vegetation along steep highway cut slopes in Montana. For Phase II experimental results see Jennings and others (2007; https://doi.org/10.21949/1518165).
Topics: Road, Reclamation Practices, GrayLit

Johnson, C.K., and West, N.E., 1989, Seed reserves in stockpiled topsoil on a coal strip mine near Kemmerer, Wyoming: Landscape and Urban Planning, v. 17, no. 2, p. 169–173.

DOI: https://doi.org/10.1016/0169-2046(89)90024-8
Background: As required by law, all land disturbed by mining operations are to be restored and revegetated. In this process, large quantities of native seed are needed but diversity and quantity are limited. As a result, stripped and stockpiled topsoil piles are used as an inexpensive, diverse, and ecologically adapted seed source. However, little is known about whether seed viability declines with storage time and if depth within the stockpiled topsoil effects the number of viable seeds. Due to this, researchers examined the effect of extended storage time and depth on the number of viable seeds in stockpiled topsoil.
Objectives: Researchers assessed the impact of soil depth and stockpile age on seed viability for revegetation and reclamation purposes.

Methods: In 1982, soil was collected from five topsoil piles of different ages, two established in 1979, two in 1981, and one in 1982. Samples were collected at 25 points along three transects extending lengthwise over each topsoil pile. At each point, three cores were drilled and collected at 0.5-meter (m) increments using soil probes; soils from the same depth increments were combined into a single composite for each sample point. Seeds were separated from 100-gram subsamples of each composite core, soaked for 48 hours in a 0.1-percent aqueous solution of 2,3,5-triphenyl tetrazolium chloride, and then dissected and examined for metabolic activity. Each viable seed was identified to species.
Location: Elkol-Sorenson Coal Mine, owned by the Pittsburgh and Midway Coal Mining Company, near Kemmerer in southwestern Wyoming, USA
Findings: There was a significant difference in the number of seeds and species present between all possible pairs of topsoil piles except between 1979A and 1979B, and 1981 and 1982. There was no significant effect of depth on the number of seeds or number of species in any of the topsoil combination or individual piles, and soil depth did not affect seed viability. The older stockpiles (2 years old compared to 1 year old and fresh piles) had a greater number of viable seeds.
Implication: Stockpiled soil piles are thoroughly mixed during the stockpile process, resulting in no difference in seed density among different topsoil sampling depths. Depending on the stockpiling procedure, collected subsoil may bury seeds in the topsoil. Site specific factors such as pre-disturbance vegetation and soil collection method may have influenced the greater number of viable seeds observed in older stockpiles. The effects of topography and patchy vegetation/soil patterns on the landscape should be considered during revegetation and soil stockpiling.
Topics: Mining, Soil Data, Reclamation Practices

Johnson, K.L., and Fisser, H.G., 1990, Long-term evaluation of pipeline rights-of-way revegetation in the Big Horn Basin, Wyoming, *in* Planning, rehabilitation, and treatment of disturbed lands, Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings Mont., March 25–30, 1990, Proceedings: Bozeman, Mont., Montana State University, Reclamation Research Unit Publication no. 9003, v. 2, p. 355–363.

Link (non-DOI): https://archive.org/details/fifthbillingssym00bill/page/355/mode/2up
Background: Natural gas pipeline construction involves denuding a right-of-way (ROW) roughly 100 feet (ft) wide along the entire length of the pipeline, resulting in substantial disturbance to soil and vegetation communities. After constructing a pipeline through Wyoming's Big Horn Basin, Colorado Interstate Gas Corporation partnered with the University of Wyoming to research practical revegetation and habitat rehabilitation methods for use in the basin's semi-arid environment.
Objectives: The authors evaluated (1) plant species suitability for revegetation, (2) the effect of various seeding methods, and (3) environmental factors limiting vegetation establishment.
Methods: In fall 1972, 17 plots were established along a 100 mile (mi) long segment of natural gas pipeline ROW representing a diversity of vegetation and soil characteristics that can be found in the basin's semi-arid environment. The authors sampled and characterized soil texture class, percent organic matter, and pH at each plot. In November 1972, each plot was seeded using various methods with 16 grasses, seven forbs, and seven shrubs presumably adapted to the semi-arid environment. Species presence was assessed from1973 to 1976. Seedling germination and establishment were assessed in 1976, 1982, 1986, and 1989.
Location: A 100 mi segment of a natural gas pipeline ROW from Elk Basin to Lost Cabin in the Big Horn Basin of Wyoming, USA
Findings: There was no clear relationship between germination and plot or seeding method. In general, revegetation was more successful on plots with loamy upland soils and those with *Artemisia tridentata, Bouteloua gracilis,* and other grasses compared to plots with alkaline bottomland and saline upland soils. The only successful forb to establish (in only one plot) was *Medicago sativa*. Woody species establishment was limited except for *Ceratoides lanata*, and *Chrysothamnus nauseosus*.
Implications: This 17-year study reveals that plot-specific characteristics are extremely important for, and likely drive, revegetation success. Land managers should analyze soil chemical, physical, and structural characteristics in order to select appropriate revegetation species and develop a site-specific reclamation plan.
Topics: Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Johnston, D.B., 2011, Movement of weed seeds in reclamation areas: Restoration Ecology, v. 19, no. 4, p. 446–449.

DOI: https://doi.org/10.1111/j.1526-100X.2011.00785.x
Background: Microtopography and vegetation on the landscape influence seed dispersal. Disturbances and reclamation activities often smooth the soil surface and remove vegetation, and the consequences of these changes on the dispersal of invasive plants is unexplored. Understanding how disturbance and reclamation activities affect dispersal of undesirable plants like cheatgrass is important for minimizing competition and increasing native species cover on reclamation sites.
Objectives: The author assessed the dispersal capacity of cheatgrass seeds at newly reclaimed sites lacking vegetation or other dispersal obstructions.
Methods: Cheatgrass seed dispersal was monitored on bare soils shortly after a simulated well pad was stripped and leveled. Sterilized and fluorescently-marked cheatgrass seeds were placed on platforms at three sites in northwest Colorado. Dispersal distance from the platform was measured each night for two weeks.
Location: Grand Valley Mesa, Ryan Gulch, and Wagon Road Ridge in Garfield and Rio Blanco Counties in northwest Colorado, USA
Findings: Seeds traveled on average 2.4 meters (m), with 5 percent traveling more than 7.6 m and a maximum distance of 20.8 m. Bare soil enabled maximum seed dispersal that was 50 times greater than previously recorded distances in intact sagebrush communities.
Implications: Seed dispersal by cheatgrass occurs quickly and physical barriers or herbicides should be used to obstruct cheatgrass seed dispersal adjacent to reclaimed sites.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Reclamation Monitoring

Johnston, D.B., 2015, Downy brome (*Bromus tectorum*) control for pipeline restoration: Invasive Plant Science and Management, v. 8, no. 2, p. 181–192.

DOI: https://doi.org/10.1614/IPSM-D-14-00001.1
Background: Disturbances related to oil and gas development, such as the construction of roads and pipelines, create conditions that facilitate invasion of nonnative species. Therefore, invasive species management is a large part of reclamation efforts following a disturbance. Studies that examine effective control methods can help managers and contractors meet reclamation targets. This study experimentally tested ways to reduce cover of the invasive downy brome (*Bromus tectorum*) in the Wyoming big sagebrush ecosystem.
Objectives: The purpose of this study was to examine if herbicide and soil manipulation affect the presence of downy brome across six simulated pipeline disturbances.
Methods: The author created six simulated pipeline disturbances by removing topsoil and vegetation for two weeks and then replacing the topsoil. Soil manipulation treatments included: tracks from heavy equipment (control), mechanical disking, and rolling. The herbicide treatment, a mixture of imazapic, glyphosate, and methylated seed oil, was applied before or shortly after downy brome emergence. All treatments were seeded with a mix of grasses, shrubs, and forbs, several of which were local genotypes. Downy brome seed and seedling counts and the percent cover by all species were recorded in subsequent years. Soil density samples were collected and compared between pipelines and undisturbed areas. The seasonal time course of downy brome propagule pressure was quantified at each site using sticky traps.
Location: Piceance Basin in Rio Blanco and Garfield counties, Colorado, USA
Findings: Disturbed soil drastically decreased downy brome seedling density the spring after treatment. However, the reduction was temporary in areas without an herbicide treatment. Overall, the herbicide treatment reduced brome density during the first growing season and increased shrub cover after three years. Disking improved grass cover temporarily, but the effect was not apparent two and three years after the treatment. The rolling treatment did not influence downy brome cover, but negatively affected native shrub cover. Pipeline disturbances increased soil density. The propagule pressure of downy brome peaked in June to July, depending on site, with some seeds continuing to disperse until mid-September.
Implications: Knowledge on the timing and conditions of a disturbance are critical for successful reduction of downy brome and other invasive species. Disturbances occurring after downy brome has ceased to disperse (late September to November) may result in reduced downy brome density the following spring. Pipeline disturbances can increase soil density, and as downy brome is sensitive to slight soil compaction, this can aid downy brome control. Rolling treatments to further increase soil density ultimately decrease native plant cover and should not be used. Burying downy brome seeds and using an imazapic herbicide may allow native plants to regenerate after a disturbance and reduce the presence of downy brome.
Topics: Pipeline, Exotic Plant Data, Soil Data, Reclamation Practices

Johnston, D.B., 2016, Wildlife research report—Restoring energy fields for wildlife: Colorado Division of Parks and Wildlife, 63 p.

Link (non-DOI): https://cpw.catalog.aspencat.info/Files/2048/ViewPDF
Background: Sagebrush-steppe habitat is important for mule deer, greater sage-grouse, and other wildlife. Increased disturbance from gas development in the Piceance Basin may directly impact habitat suitable for wildlife and must be reclaimed. However, disturbance alters vegetation communities and increases the risk of cheatgrass and other invasive species establishment. This report summarizes six experiments aimed at controlling cheatgrass establishment and increasing native plant cover following disturbance.
Objectives: The authors assessed the conditions that lead to cheatgrass establishment in sagebrush-steppe ecosystems and tested a variety of treatments to reduce cheatgrass and increase native plant diversity across a variety of precipitation and ecological zones on simulated well pads and pipelines.
Methods: In 2008, reclamation experiments were established on six simulated well pads and pipelines. Seed traps were used to track the timing of cheatgrass seed dispersal. On lower elevation experiments, herbicides, seed dispersal barriers, and soil compaction treatments were tested. On middle elevation experiments, treatments tested included imazapic herbicide, super-absorbent polymer (a soil binding agent), soil surface x seeding method x mulch, and seed mixes. On a high elevation experiment, the effects of seeding, soil surface type, and mulch type were tested.
Location: Piceance Basin in western Colorado, USA
Findings: Pipeline disturbances had lower initial cheatgrass density than undisturbed areas. Plateau (imazapic) herbicide along pipelines increased big sagebrush establishment. However, too much herbicide injured native plants. Cheatgrass seeds dispersed from May until September. Soil compaction via rolling did not control cheatgrass. Super-absorbent polymer had conflicting impacts on vegetation composition at two sites, increasing perennial grass at one site and cheatgrass at the other. A soil binding agent reduced cheatgrass at one site. Window screen seed dispersal barriers increased perennial grasses and forb cover but did not control cheatgrass establishment. Plots that were seeded at high elevations had higher grass cover and forb cover than the non-seeded plots. However, unseeded plots had higher shrub cover. Soil roughening reduced cheatgrass establishment, while brush mulching increased shrubs, grasses, and perennial forbs. Roughened soil and use of Plateau herbicide in combination reduced cheatgrass sixfold. Seed mix type did not affect cheatgrass establishment, but the high-forb mix increased forb and shrub biomass.
Implications: Knowledge on the phenology and dispersal of cheatgrass seeds is important for managing this species. Late season disturbances may limit cheatgrass establishment in subsequent growing seasons because the disturbance may bury the seeds. Use of super-absorbent polymer and a soil binding agent should be investigated further to determine their appropriate use in reclamation and invasive plant reduction. Too much herbicide can have long term effects on plant establishment and their use should be limited and combined with soil roughening. Seeding with perennial grasses can slow recovery of shrubs due to competition. Brush mulch is beneficial for perennial plant establishment. Soil roughening and seed mixes with high forb and shrub proportions should be used.
Topics: Well Pad, Pipeline, Vegetation Recovery Data, Exotic Plant Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Johnston, D.B., 2019, Rough soil surface lessens annual grass invasion in disturbed rangeland: Rangeland Ecology & Management, v. 72, no. 2, p. 292–300.

DOI: https://doi.org/10.1016/j.rama.2018.10.010
Background: For reclamation to successfully reestablish big sagebrush plant communities, measures to control or limit competition from invasive species is necessary. Downy brome (*Bromus tectorum*) is a nonnative invasive grass species that often establishes at reclamation sites. It and other invasive species' success may be attributable to increased seed production and effective seed dispersal strategies, whereas native plants may have reduced recruitment and are less ruderal. Manipulating the soil topography, and thus the opportunity for dispersal, may reduce invasion of downy brome and other nonnative species. This study explored whether soil surface manipulations or woody mulch affected the ability of downy brome to successfully outcompete native species and disperse seeds.
Objectives: The author tested if soil manipulations and woody debris amendments (1) reduce the need for seeding during restoration, (2) limit seed dispersal of downy brome, and (3) interact to influence plant community structure and invasion vulnerability.

Methods: Simulated oil and gas pads were disturbed in 2008 with a bulldozer. Woody debris was stockpiled along with 15 centimeters (cm) of topsoil. During the 2009 growing season, plant growth was restricted using glyphosate isopropylamine salt. Three factors were replicated on the disturbed sites: microtopography (roughened or flat), woody debris (or nothing), and seeding a mix of four forbs, six grasses, and two shrubs (17.8 kilograms per hectare [kg/ha] or none). The roughening treatment was accomplished using a mini excavator that dug holes 100 × 60 × 30-cm deep and mounded soil next to the hole. The seeding treatment was applied by drill seeding or broadcast seeding depending on microtopography (seeding rate was the same for both methods). Dispersal onto woody debris was equal for flat, roughened, seeded, or unseeded treatments. Fencing was installed to keep out large herbivores. Vegetation percent cover was measured using the point intercept method in 2011–2014 along with adjacent undisturbed locations in 2011–2013. In a separate seed dispersal experiment, downy brome seeds were sterilized and coated with a fluorescent powder. Blacklights were used at night to locate seeds on flat versus roughened surfaces at the end of a round so as not to disturb a subsequent seed dispersal experiment.
Location: Piceance Basin in Rio Blanco and Garfield counties, Colorado, USA
Findings: Shrub cover increased over time but was reduced by seeding. Seeding increased grass cover and perennial forb cover and limited downy brome cover. Woody debris increased shrub and perennial grass cover and had a site-specific effect on perennial forbs. Soil roughening had site-specific effects on grass and forb production. The effect of woody debris mulch on downy brome was limited to unseeded plots in 2014, when it slightly increased downy brome cover. Other combinations of years and treatments were not significant. Soil roughening reduced downy brome cover from 13 percent to 2.5 percent in unseeded plots at the lowest elevation site, where downy brome had become most prevalent. In the dispersal experiment, soil roughening significantly reduced downy brome dispersal distance.
Implications: Seeding and soil roughening on oil and gas pads may reduce the presence of invasive grasses and promote native species establishment. However, seeding may initially reduce big sagebrush development due to competition. Changing the microtopography of soil may alter dispersal and competition and increase seed burial of invasive plants. Broadcast seeding and drill seeding similarly affect perennial plant establishment. Applying woody debris, composed of big sagebrush, may also facilitate faster big sagebrush recovery.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Johnston, D.B., and Chapman, P.L., 2014, Rough surface and high-forb seed mix promote ecological restoration of simulated well pads: Invasive Plant Science and Management, v. 7, no. 3, p. 408–424.

DOI: https://doi.org/10.1614/IPSM-D-13-00087.1
Background: After disturbances, big sagebrush systems are often dominated by weedy annuals like downy brome or rhizomatous grasses rather than a diversity of native shrubs and grasses. However, controlling for downy brome limits the type of plants that can be restored. Functional group diversity is a keystone of ecological restoration as it underlies ecosystem function and stability and contributes to sage-grouse conservation.
Objectives: This study aimed to test the effects of (1) microtopography (rough with brush mulch versus flat with straw mulch), (2) seed mix (high-forb versus balanced), and (3) herbicide (140 grams [g] imazapic ammonium salt per hectare [ai/ha] versus none) on downy brome control and perennial plant establishment.
Methods: Well pad disturbances were simulated in 31 × 52-meter (m) plots in September 2008 by clearing vegetation, then stripping and stockpiling the top 15 centimeter (cm) of soil. Subsoil was leveled and kept weed-free until August 2009 when topsoil was reapplied. The plots were ripped to 30 cm, disked, then experimental treatments were applied. Three factors, each with 2 levels, were fully crossed in a factorial design for a total of eight treatments; the three factors were (1) surface (rough/brush or flat/straw), (2) native seed mix (high-forb, 75 percent forb, balanced, or 40 percent forb by seed number), and (3) herbicide (imazapic or none), with three replicates on each site. In addition to the seed mix, big sagebrush seed was collected within 100 m of each site and hand-broadcast on top of the snow in all plots in December 2009. Ambient downy brome seed rain was measured from 2009 to 2011 using seed rain traps. Vegetation cover was assessed using five 1 square meter (m^2) plots in disturbed sites and six point-intercept 10 m transects in control sites. Biomass was assessed in June through August 2012.
Location: Four sites in the Piceance Basin: Grand Valley Mesa (39.46° N., 108.06° W.), Sagebrush (39.83° N., 108.30° W.), Mountain Shrub (39.78° N., 108.33° W.), and Wagon Road Ridge (39.82° N., 108.46° W.) in western Colorado, USA
Findings: In most cases, all annual cover was nonnative, and all perennial cover was native. Perennial grass cover and biomass were significantly higher in the balanced seed mix versus the high-forb mix, while forb cover, forb biomass, and shrub biomass were higher in the high-forb mix. Seed mix had no effect on downy brome. The rough surface/brush mulch treatment reduced downy brome when combined with imazapic at a heavily invaded site and reduced downy brome without herbicide

at a vulnerable but uninvaded site. The rough surface/brush mulch treatment increased cover and biomass of perennial grass on some sites in some years. The effect of imazapic on perennial grass was site dependent, but generally reduced grass cover and biomass.
Implications: Applying mostly forb and shrub seeds at a high rate (1,600 seeds/m^2) can promote restoration of diverse plant communities without causing an increase in downy brome or weedy annual forbs. Rough/brush treatments have the capacity to reduce downy brome potentially without the application of herbicides that harm non-target plants. Careful application of herbicide is recommended.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Jones, G.P., 2005, Survey of tall sagebrush vegetation on stabilized sands in the Jack Morrow Hills Coordinated Management Area, BLM Rock Springs Field Office, Wyoming: University of Wyoming, Final Report for Assistance Agreement KAA010012 Task Order KAF020013, prepared by Wyoming Natural Diversity Database, 81 p.

Link (non-DIO): https://www.uwyo.edu/wyndd/_files/docs/reports/wynddreports/u05jon04wyus.pdf
Background: In Killpecker Dune Field, southwestern Wyoming, stabilized sand dunes support unusually tall shrub vegetation with unique composition and structure compared to other stabilized sand dunes in Wyoming. The Bureau of Land Management (BLM) designated much of this tall sagebrush vegetation as the Jack Morrow Hills Coordinated Management Area. This designation was largely out of concern for how potential development of petroleum resources might negatively affect elk and other wildlife.
Objectives: BLM Rock Spring's Field Office partnered with University of Wyoming's Natural Diversity Database to (1) develop a project to document species composition and structure of tall sagebrush vegetation, (2) examine the effects of various disturbance types on the vegetation, and (3) investigate the impacts of elk grazing on the herbaceous understory.
Methods: In 2002 and 2003, a random set of points was selected across five disturbance categories within elk habitat: undisturbed light elk-use, undisturbed heavy elk-use, burned areas, pipeline corridors, and active petroleum wells. Sampling consisted of 13 sub-plots nested within a 20 × 50-meter (m) macroplot at 56 sampling locations. Measurements included herbaceous canopy cover by species, shrub heights, ground cover, elk droppings, and a separate measurement of shrub canopy cover for each entire microplot. The author photographed the macroplot, described the vegetation, and recorded surface material, soil texture, slope steepness, and aspect.
Location: Elk herd boundaries in Jack Morrow Hills Coordinated Management Area, Wyoming, USA
Findings: Total plant canopy and shrub canopy cover was greatest in undisturbed plots, with the least cover in burned plots and the plots of active well-pads. Forbs exhibited a nearly opposite pattern, with the greatest cover found in active well pads and burned areas and the lowest in undisturbed plots. Undisturbed plots had significantly more total plant canopy cover and absolute shrub canopy cover but did not have significantly greater coverage of forbs or grasses. Disturbance type was correlated with the number of individual species present in a plot, for example, burned plots had little or no *Artemisia tridentata* ssp. *tridentata* and intermediate amounts of *Chrysothamnus viscidiflorus* ssp. *viscidiflorus*. Disturbance, in small areas of tall sagebrush, had only a modest effect on the richness of vascular plant species, with active well-pads having the fewest species compared to other plots. Disturbance, in large areas with tall sagebrush, did reduce species richness. Generally, disturbances resulted in a reduction of sagebrush cover, total shrub cover, and the height of vegetation for some time. Exotic species were present across 36 percent of the sample plots but accounted for minimal canopy cover. There was no relationship between elk pellets and density of herbaceous canopy cover. However, there was an inverse relationship between herbaceous cover and shrub canopy. Undisturbed plots had significantly greater amounts of bare soil.
Implications: The large number of exotic plants on active well-pads suggests that increased disturbances in tall sagebrush vegetation could result in an increase of exotic plants. A tall sagebrush overstory should recover in disturbed areas given enough time. Height and density of the sagebrush overstory affect herbaceous undergrowth. Elk browsing in this system does not impact the species composition or amount of cover of the herbaceous understory. Elk could potentially use the tall sagebrush to hide and browse herbaceous vegetation in nearby open areas.
Topics: Well Pad, Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Kapolka, N.M., and Dollhopf, D.J., 2001, Effect of slope gradient and plant growth on soil loss on reconstructed steep slopes: International Journal of Surface Mining, Reclamation and Environment, v. 15, no. 2, p. 86–99.

DOI: https://doi.org/10.1076/ijsm.15.2.86.3416
Background: Reclamation of hard rock mines, like open pit talc mines, in the western United States requires revegetation of steep slopes. Soil erosion on these slopes can negatively impact revegetation and watershed quality. Rock cover and plant growth, aided by cover soil application, can reduce erosion. The Office of Surface Mining and Reclamation in Denver, Colorado, developed the Revised Universal Soil Loss Equation (USLE) 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands; a computer model used to estimate long-term soil erosion rates based on local environmental conditions.
Objectives: The authors evaluated (1) the effect of slope gradient and plant growth on soil loss on steep slopes of an open pit talc mine, (2) the effect of cover soil applications on plant growth on the same slopes, and (3) whether Revised USLE 1.06 can predict soil loss on high altitude steep slopes.
Methods: An experimental design was established with four slopes of different gradients (25 percent, 30 percent, 40 percent, and 50 percent) divided into four plots with different cover soil depths (0 centimeters [cm], 15 cm, 30 cm, and 45 cm) for a total of 16 plots. Runoff and sediment were captured in troughs at the base of each plot and measured every two weeks. Sediment was removed, dried, and measured sediment on a milligram per hectare (mg/ha) basis. Cover soil and subsoil were analyzed for organic matter percentage, electrical conductivity (EC), pH, coarse fragment percentage, texture, and concentration of sodium (Na), calcium (Ca) and magnesium (Mg). All plots were broadcast seeded with the same seed mix and planted with cover crops *Triticum aestivum* and *Hordeum vulgare* during first season. Hourly precipitation was measured with a rain gauge and datalogger. The Erosion Conditions Classification System Montana Revised Method was used to quantitatively describe rill formation. Measurements of the reclaimed surface included plant canopy cover, basal cover, and rock cover, and aboveground production by lifeform. Correlation analysis was used to analyze the data; datasets which did not have a normal distribution were transformed prior to analysis. Revised USLE 1.06 was used to calculate predicted soil loss rates with site-specific variables.
Location: Treasure Mine, 15 miles east northeast of Dillion, Montana, USA
Findings: Soil loss increased as slope gradient approached 40 percent then decreased as the gradient increased to 50 percent. Soil loss decreased over time and was lower on plots without cover soil. The presence of cover soil, regardless of application thickness, resulted in more plant cover and biomass than non-cover soil slopes. Revised USLE 1.06 underestimated soil loss during both years of the study and could not account for soil lost due to rill formation, though it was more accurate at predicting first year soil loss after the addition of a rill formation factor.
Implications: Revised USLE 1.06 is useful for long-term planning of revegetation on reclaimed high elevation steep slopes resulting from mining, but it is not accurate in predicting soil loss on unvegetated slopes. Cover soil is helpful in reestablishing vegetation on these steep slopes. Slopes with gradients greater than 40 percent may be more successfully revegetated in the long-term due to decreased erosion.
Topics: Mining, Vegetation Recovery Data, Soil Data, Erosion Data, Reclamation Practices

Karo, R.A., 2006, Seneca surface coal mines—A 40-year case study in reclamation techniques—Triumphs and failures—Two studies of shrub establishment, *in* Barnhisel, R.I., ed., 7th International Conference on Acid Rock Drainage and 23rd Annual Meeting of the American Society of Mining and Reclamation, St. Louis, Mo., March 26–30, 2006, Proceedings: American Society of Mining and Reclamation, p. 922–934.

DOI: https://dx.doi.org/10.21000/JASMR06020922
Background: Seneca Coal Company operates three mines in northwest Colorado and, as of 2005, was responsible for reclaiming 4,000 acres for post-mine wildlife habitat and livestock grazing. Prior to mining, the land had been overgrazed and weeds had proliferated. Steep slopes leading to high erosion and climate conditions further complicated reclamation efforts. Regardless, reclamation efforts were implemented, and test plots were established to monitor best practices for shrub reestablishment.
Objectives: The authors assessed results of two reclamation efforts at mines owned by the Seneca Coal Company.

Methods: For study no. 1, vegetation cover was sampled in reclaimed areas using a point-intercept method at 50 paired points along randomly placed 50-meter (m) transections. Herbaceous production was sampled using 0.5 square meters (m^2) circular plots. At one site (Seneca II–Wadge Pasture), woody plant density was sampled along 50 m transections and all shrubs and sub-shrubs were counted in 2 × 50 m quadrats. Reclaimed areas were compared to undisturbed reference sites. For study no. 2, test plots were established in which to evaluate best methods for shrub reestablishment and growth; treatments included varying depths of topsoil, fencing/non-fencing, direct seeding, and seedling transplantation. Test plots were sampled for vegetation using a point-intercept method along 30 m transects.
Location: Seneca II, Seneca II–Wadge Pasture, and Yoast mines in northwest Colorado, USA
Findings: In study no. 1, total vegetation cover and herbaceous production were higher, but woody plant density was lower, at the reclaimed Wadge Pasture compared to the reference site. For study no. 2, in general, fencing increased shrub density, average height, and cover, particularly for browse species such as bitterbrush. However, one plot in study no. 2 had stem density lower in the fenced area.
Implications: Despite a semi-arid climate, steep slopes, and previously grazed land with a high prevalence of weeds, reclamation efforts successfully reestablished vegetation and shrubs. Results from fencing tests indicated that reduced browsing by fence installation can increase shrub density, however non-fenced areas can still promote modest shrub growth.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Kaszuba, J.P., and Buys, M.W., 1993, Reclamation procedures for produced water spills from coalbed methane wells, San Juan Basin, Colorado and New Mexico, *in* Society of Petroleum Engineers/Environmental Protection Agency Exploration and Production Environmental Conference, San Antonio, Tex., March 7–10, 1993, Proceedings: Society of Petroleum Engineers, p. 309–318.

DOI: https://doi.org/10.2118/25970-MS
Background: Natural gas wells in the Fruitland Formation in the San Juan Basin produce large volumes of water, which can adversely affect soil and vegetation when spilled in transit to water disposal wells. Specifically, this water contains elevated levels of sodium and chloride that alters soil chemistry and inhibits plant growth.
Objectives: The authors determined the chemical composition of water in the Fruitland Formation, characterized the soil types of production areas, evaluated the effect of produced water on those soils, and recommended reclamation procedures for the region.
Methods: The authors performed standard chemical analyses on injection well water from six production areas in the northern basin, and analyses in eight other areas in the northern basin without injection wells (representative samples of produced water from the well head were used instead). They used U.S. Department of Agriculture soil surveys to determine soil types for Rio Arriba, San Juan, and La Plata Counties. For each production area, they collected a minimum of two soil samples for each soil type and analyzed it for 10 parameters to determine baseline soil properties. A general review of saline, sodic, and saline-sodic soils was provided, including soil properties and impact on vegetation. To determine salt impacts on soil properties and vegetation, the authors sampled soil at spill sites where discharges of produced water occurred in 1988 and 1989. Soil was sampled at seven out of 11 spill sites in a production area in Rio Arriba County, New Mexico and analyzed for the same 10 parameters previously selected. For each spill site, the soil type, time elapsed between spill and soil collection, number of barrels of produced water spilled, vegetation of the spill site, and physical condition of the soil were described, and the soil was characterized as either saline, sodic, or saline-sodic. Gypsum amendments were applied to treat sodic or saline soils, with rates dependent on soil type. Free sodium was removed by leaching with water along with amendment application. A follow-up sampling scheme to determine if soils are still sodic or saline for sites with slow recovery was outlined.
Location: Fruitland Formation coal beds of the San Juan Basin and natural gas production areas in Rio Arriba and San Juan Counties, New Mexico, and La Plata County, Colorado, USA
Findings: Water across the San Juan Basin was characterized as brackish and saline, and in the south basin as brine. Produced water from all production areas had elevated levels of total dissolved solids, bicarbonate, sodium, and chloride; untreated, this water was unsuitable for domestic, livestock, and irrigation use. Rio Arriba predominantly consisted of sandy loams and clay loams; San Juan County, thin to thick loams, sandy loams, and silty and sandy clay loams; and La Plata County, thin sandy loams, thick clays, loams, and clay loams. Saline-sodic soils were the most impacted soil type from Fruitland water discharges. Soil type, spill volume, and topography all determined the severity of water discharge impact on the soil.
Implications: The study suggests that chloride and sodium from produced water can create high levels of soluble salts and exchangeable sodium in soils, which in turn can increase soil pH. If produced water is spilled, soil samples must be collected to determine if saline or sodic conditions are present at the spill-site. Impacted soils need to be reclaimed promptly by leaching

water after applying amendments of gypsum and mulch or manure; if allowable, leach water should be impounded on-site. To make sure sites are reclaimed successfully, soil samples should be collected at two specific intervals of time after amendments are applied; additional amendments and sampling should be completed until sites are fully reclaimed. For New Mexico, seeding salt-tolerant grasses and shrubs from July 1 through September 15 is recommended. Revegetation strategies in Colorado should be more nuanced due to variability in topography and rainfall.
Topics: Well Pad, Soil Data, Reclamation Practices, Reclamation Monitoring, GrayLit

Kiger, J.A., Berg, W.A., Herron, J.T., Phillips, C.M., and Atkinson, R.G., 1987, Shrub reestablishment in the mountain shrub zone, *in* Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation, Billings, Mont., March 17–19, 1987, Proceedings: American Society of Mining and Reclamation, Reclamation Research Unit Report no. 8704, p. 375–380.

DOI: https://doi.org/10.21000/JASMR87010375
Background: The mountain shrub vegetation type dominates the landscape of many surface mine coal sites in northwestern Colorado in the 6,500–8,200-foot (ft) elevation range. These shrubs are necessary browsing substrate and cover for deer and elk and reestablishment post-mining disturbance is important.
Objectives: The authors evaluated shrub reestablishment 9 to 11 years after reclamation and outlined reclamation practices for successful revegetation of shrub species on a surface coal mine in the mountain shrub zone of Colorado.
Methods: Reclamation on the mine involved pushing off brush, stripping the top 1–2 inches (in.) of soil, removing the next foot of soil, then redistributing soil over the research area. Deer, elk, and rodent exclosure fencing was installed. Three replicate 10 × 20 ft plots were established. Select plots were direct seeded with a shrub seed mix containing bitterbrush, oak, service berry, snowberry, grasses, and forbs; other plots were hand broadcast with shrub species only to compare shrub survival and growth under each exclosure condition. Seedling and mature shrub transplant experiments were also conducting using a subset of shrub species. Based on shrub growth and survival results, reclamation practices to successfully reestablish shrub densities Colorado state criteria were discussed.
Location: Colowyo Coal Mine in western Colorado, USA
Findings: Direct seeding successfully reestablished serviceberry and snowberry, though individuals were small even after 9 to 11 years. Direct seeding did not reestablish oak or chokecherry. Transplanting seedlings had low reestablishment (8–21 percent depending on species). Transplanting mature shrubs was moderately more successful, especially for serviceberry and snowberry.
Implications: Competition with grass limited shrub reestablishment. Intensive management at the Colowyo site is necessary to ensure successful revegetation. Similar surface coal mine reclamation land in Colorado can learn from the Colowyo site experiment when designing reclamation and revegetation protocols.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Kirby, D.R., 2003, Managing for plant diversity on reclaimed grasslands, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society for Surface Mining and Reclamation, p. 1533–1540.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2003/1533-Kirby.pdf
Background: Reestablishing native grasslands after surface mining is difficult in the Northern Great Plains due to high diversity, limited seed sources, harsh climate, and competitive introduced and annual species. Competitive cool-season grasses often dominate reclaimed grasslands, especially during the first few growing seasons. Livestock grazing may be a useful technique for slowing cool-season grass establishment and allowing more diverse and native revegetation succession.
Objectives: The author evaluated the effects of early season grazing on two grasses (Japanese brome and smooth brome) on reclaimed grasslands in western North Dakota.

Methods: The Glenharold Mine was seeded in 1989 and grazed in 1997 and 1998. In 1992, 1995, and 1998, randomly located transects were sampled. Basal cover and species composition were estimated using the ten-pin point-frame method. In 1995 and 1998, aboveground herbaceous yield was estimated within 0.25 square meter (m^2) quadrats. The Indian Head Mine was seeded in 1986 and grazed 1994 through 1998. Vegetative cover was estimated using the ten-pin point-frame method and aboveground herbaceous yield was collected in 0.25 m^2 quadrats.
Location: Glenharold Coal Mine near Stanton and Indian Head Coal Mine near Zap in west central North Dakota, USA
Findings: At Glenharold Mine, Japanese brome cover and yield decreased to almost 0 percent by 1998 and warm season grass cover and yield increased. At Indian Head Mine, smooth brome cover decreased to almost 0 percent by 1998 and warm season grass cover and yield increased.
Implications: Livestock grazing can successfully reduce cool-season grass species domination on reclaimed grasslands in the Northern Great Plains. For the best results, grazing should be implemented 2 to 3 years after seeding.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Knapik, L., 1992, Assessment of pipeline soil reclamation success, *in* The Industry/Government Pipeline Reclamation Success Measurement Workshop, Calgary, May 11–12, 1992, Proceedings: Reclamation Research Technical Advisory Committee, Canada, p. 9–17.

Link (non-DOI): https://inis.iaea.org/search/search.aspx?orig_q=RN:25006065
Background: Assessing reclamation requires standard methods and comparisons of success. Pipeline right-of-way (ROW) reclamation may be influenced by several perspectives and approaches, such as the “design standard approach” or the “soils first approach.” Once an approach is selected, a set of measurements and expectations, informed by State and government regulations, can help guide and assess reclamation efforts.
Objectives: The author discussed pipeline ROW soil reclamation methods and assessments.
Methods: The author introduced assessment and measurement terms and specific definitions. They reviewed popular perceptions present in screening assessments of pipeline right-of-way reclamation. They discussed the role of equivalent land capability in expectations of reclamation success. They reviewed to-date reclamation approaches focusing on the “soil first approach,” methods, measurement tips, and standards for comparison.
Location: This is a review paper and does not involve a specific field site location
Findings: Screening assessments visually check that reclamation standards have been met and may be influenced by several perspectives focused on soil structure, change over time, complexity, or vegetation/soil interactions. The “soils first approach” focuses on soil as the reclamation priority and requires selecting appropriate soil variables for assessment, factoring in ecoregion characteristics, following in-field measurement protocol, and selecting appropriate comparison standards.
Implications: This article is a helpful introduction for land managers in determining best strategies for monitoring pipeline soil reclamation success.
Topics: Pipeline, Reclamation Theory, Reclamation Monitoring, GrayLit

Koper, N., Molloy, K., Leston, L., and Yoo, J., 2014, Effects of livestock grazing and well construction on prairie vegetation structure surrounding shallow natural gas wells: Environmental Management, v. 54, no. 5, p. 1131–1138.

DOI: https://doi.org/10.1007/s00267-014-0344-5
Background: Shallow gas wells have the potential to alter vegetation structure and ecosystem interactions. Vegetation near reclaimed well pads is short and sparse. To properly reclaim these areas for wildlife and restore ecosystem function, managers need to understand what factors are impeding revegetation near well pads.
Objectives: The authors tested three competing hypotheses that might explain existing trends in vegetation near reclaimed wells: (1) crested wheatgrass abundance near wells drives vegetation dynamics, (2) the residual effects of well construction affect vegetation growth, and (3) livestock are attracted to wells and alter vegetation structure.

Methods: The study was conducted on 27 well pads, aged 1–44 years, and 9 control sites. The well pads were stratified and selected to include various well densities in the region. Vegetation height and density, litter depth, percent bare ground, and nonnative plant abundance were measured to quantify habitat structure. Fecal pat sample counts were conducted along transects to quantify cattle abundance and activity.
Location: A mixed grass prairie within 100 kilometers (km) of Brooks (50°35′ N., 111°53′ W.), Alberta, Canada
Findings: Crested wheatgrass was higher near wells, but this did not explain the effects of wells on vegetation structure. Litter depth was higher near wells, indicating that time since reclamation affects vegetation dynamics (hypothesis 2). Cattle abundance was higher closer to wells, and this distance correlated with changes in vegetation structure (hypothesis 3).
Implications: Cattle behavior and the residual effects of well construction explain patterns in habitat structure near shallow gas wells and must be addressed for successful reclamation. Additionally, these effects go beyond 40 meters (m) from a well site and may be exacerbated by continual cattle presence. To reduce the impact of livestock on reclamation efforts the authors suggest attracting cattle away from wells with alternate food sources, water, and rubbing posts.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Wildlife/Habitat Data, Reclamation Theory, Reclamation Practices

Lancaster, J., Neville, M., and Hickman, L., 2012, Long-term revegetation success of industry reclamation techniques for native mixedgrass prairie: Prepared for Petroleum Technology Alliance Canada (PTAC), 92 p.

Link (non-DOI): https://auprf.ptac.org/wp-content/uploads/2015/12/ptac-gl-09-9167-50-mixedgrass-report-final-may-2012.pdf
Background: Energy development threatens Alberta's native mixedgrass prairies. Understanding the revegetation process following reclamation is necessary for protecting this sensitive ecosystem from future energy development disturbance. Three energy project sites—Husky Majorville Sweet Gas Gathering System, Cypress Pipeline, and Merry Flats Sweet Gas Gathering System—provide examples of revegetation up to seven, 11, and 12 years after reclamation in two of Alberta's ecodistricts. Reviewing reclamation methods and revegetation results from these projects can inform best practices for future reclamation projects.
Objectives: The authors wanted to provide industry and regulatory agencies in Alberta with results and key conclusions on the long-term recovery of native mixedgrass prairie after energy industry disturbance to encourage industry environmental stewardship on threatened native prairie landscapes.
Methods: Background information was provided on the case-study projects' regulatory histories, energy development construction, and reclamation methods. Details on monitoring and assessment methods were provided for all three case-study projects. Revegetation strategy success over time was reviewed for all sites. Lessons learned regarding long-term mixedgrass prairie recovery success, data gaps, and recommended future research were discussed.
Location: Husky Majorville Sweet Gas Gathering System project in the Majorville Uplands Ecodistrict and Cypress Pipeline and Merry Flats Sweet Gas Gathering System projects in the Cypress Uplands Ecodistrict, Alberta, Canada
Findings: Successful minimal disturbance construction techniques were employed at all three sites, including winter/dry ground construction, adherence to traffic control plans, topsoil replacement within 48 hours after stripping, and two-strip graveling on tracks to reduce erosion. After 11–12 years since reclamation at the Cypress Uplands projects, vegetation cover ranged from 54 to 70 percent and did not differ between treatments and undisturbed sites (nor did litter cover). There were no traces of agronomic crop cover, and plant communities (though dominated by rough fescue) began to resemble undisturbed sites. After seven years since reclamation, range health and plant communities at the Majorville Uplands project were in the process of resembling undisturbed sites. No seeding occurred at this site (natural recovery was the vegetation strategy); western wheatgrass, northern wheatgrass, green needle grass, and sedge species played an important role in initial revegetation. Further research should include assessments at a wider variety of ecological range sites, explore revegetation of larger diameter pipelines, and determine the most appropriate revegetation strategy for long-term success.
Implications: This is a comprehensive report based on long-term data collection that provides a model for reclamation of future energy development on native prairie landscapes, both in Alberta and other areas with prairie ecosystems experiencing oil and gas development.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Léger, A.M., 2020, Mulch and compost for restoration of soil health in a semi-arid rangeland: Tucson, Ariz., University of Arizona, master's thesis, 116 p.

Link (non-DOI): https://repository.arizona.edu/handle/10150/648636
Background: Reclaiming degraded semiarid rangelands involves reestablishing soil health to increase plant growth. Due to inherently low nutrient content and water holding capability, degraded dryland soils require amendment application. Determining the appropriate amendment type and application method are important for reestablishing desired soil conditions and meeting reclamation goals.
Objectives: The author evaluated locally available soil organic amendments for their ability to improve soil health indicators and vegetation cover and abundance on a degraded semiarid rangeland.
Methods: Four experimental blocks were established, each with five 2 × 3-meter (m) plots with one of the following treatments: (1) unseeded control, (2) seeded control, (3) 15−20 centimeters (cm) mesquite branch mulch, (4) 3 cm compost (chipped yard waste and organic dairy manure) overlain with a 15−20 cm mesquite branch mulch, or (5) 6 cm compost mulch overlain with 15−20 cm mesquite branch mulch. All treatments were seeded with a mix of native perennial grasses, except the unseeded control. Moisture and temperature sensors were installed, and three pairs of anion/cation membranes were placed in the top 5 cm of soil in each treatment to assess soil moisture, temperature, and nitrogen (N) availability. Bulk soil samples were collected at the end of each growing season for analysis of soil carbon (C), N, texture, electrical conductivity (EC), pH, soil aggregate stability, and soil microbial activity. Plant cover, abundance, and species composition were measured for each treatment. To assess changes in bulk soil organic carbon (SOC), soil was collected 3 and 16 months after amendment treatment application. Data were analyzed using multivariate analysis of variance (MANOVA).
Location: Altar Valley (latitude 31.8183° N., longitude -111.4117° W.) of Pima County, Arizona, USA
Findings: Regarding soil moisture, mesquite mulch alone did better in the hottest and driest times of year when there were small rain events intercepted by the thick applications of compost, though compost still had a positive effect on increasing soil moisture. Compost increased the size of individual establishing plants and had few, big grasses compared to mulch alone, which had many small grasses & forbs. Higher applications of compost (6 cm) were more similar to the control treatments in terms of available N compared to other treatments (mulch alone and mulch+3 cm compost). Mesquite mulch combined with compost increased SOM and clay and silt sized aggregates.
Implications: Mesquite mulch amendment would likely benefit from an uneven compost application between 3 cm and 6 cm that would allow better infiltration during the more frequent small rain events common in the study's ecoregion. Where, when, and how mesquite mulch and compost are applied has important implications for their success in reclamation. Land and reclamation managers in semiarid environments should consider mesquite mulch as an option for improving soil conditions and revegetation efforts.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Lichthardt, J., and Weaver, T., 1990, Effect of seeded grass, soil texture, and salinity on steppe community composition-eighth year observations of a three-factor experiment, *in* Planning, rehabilitation, and treatment of disturbed lands, Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, Mont., March 25–30, 1990, Proceedings: Bozeman, Mont., Montana State University, Reclamation Research Unit Publication no. 9003, v. 2, p. 291–301.

Link (non-DOI): https://archive.org/details/fifthbillingssym00bill/page/291/mode/2up
Background: Mine reclamation projects can serve as grounds for experimental testing of ecological theories on factors that affect community characteristics. Temperature, moisture, substrate, and plant species are thought to impact community characteristics and, by using reclamation projects, scientists can distinguish between the effects of climate and soil factors.
Objectives: The authors assessed the effects of soil characteristics (texture and initial salinity) and species on community characteristics and production on land undergoing reclamation in a steppe climate.
Methods: Eighteen soil pads were established at the Spring Creek Coal Mine to represent three soil types (clay, loam, and sand) crossed with two levels of soil salinity (addition of a 4:1 mix of calcium chloride:sodium chloride or no addition). Twelve grasses were planted on each pad at 1,080 pure live seed per square meter (PLS/m^2), including seven native species, four nonnative species common in land reclamation, and wheat. Electrical conductivity was measured as a salinity index

upon establishing the soil pads and periodically afterward. Soil was characterized by texture, organic matter, cation exchange capacity, pH, saturated paste extraction, nitrate, phosphorous (P), potassium (K), and micronutrients) Water holding capacity at experiment initiation was measured and standing crop biomass (grams per square meter [gm/m^2]) was assessed during the second, fourth, and eighth study years.
Location: Spring Creek Coal Mine near Decker, Montana, USA
Findings: Standing crop of the nonnative *Elymus angustus* community was highest due to accumulation of coarse (ungrazable) stems. Standing crop of all other grass communities and species was greater on sandy and loamy soils compared to clayey soils; standing crop varied significantly by species. Standing crop was lower on salted compared to unsalted plots but not significantly different. Weed invasion differed with texture, salinity, and species planted.
Implications: Soil characteristics like salinity and texture impact the productivity of plant species and their communities as a whole following mine reclamation. Understanding these factors before reclamation is useful for planning successful reclamation efforts and selecting species most likely to reestablish.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Liesenfeld, Z.J., 2013, Investigation of sagebrush reclamation success on reclaimed bentonite mined lands, chap. 2 *of* Investigation of sagebrush reclamation success on reclaimed bentonite mined areas in the Big Horn Basin (Wyoming, USA): Laramie, Wyo., University of Wyoming, master's thesis, p. 23–57.

Link (non-DIO): https://www.uwyo.edu/wrrc/_files/docs/theses_dissertations/liesenfeld_zachary.pdf
Background: Bentonite mining across the Big Horn Basin of northcentral Wyoming has disturbed Wyoming big sagebrush steppe habitat. Reestablishment of sagebrush communities in mined areas has been limited due to semi-arid weather and poor soil conditions. Wyoming big sagebrush is a critical species for ecosystem function in sagebrush steppe and serves as food for mule deer and pronghorn. Prior to this study, assessments of successful reestablishment of big sagebrush in this region was limited.
Objectives: The author assessed if current and historical reclamation efforts in the Big Horn Basin have successfully reestablished the presence of Wyoming big sagebrush in sagebrush steppe disturbed by bentonite mining and assess the value of reclaimed habitat for sage grouse.
Methods: The author identified 85 reclaimed bentonite mine sites (10–35 years since initial seeding) for assessment. They measured sagebrush community characteristics using a combination of line intercept, point intercept, and belt transect methods with a frequency transect design at mine sites and undisturbed native reference sites. They sampled soil at each mine site from three randomly located soil pits and depths of 0–15 centimeters (cm) and 15–30 cm. They compared mine site soil samples with U.S. Department of Agriculture Natural Resources Conversation Services soil survey data for reference sites. They assessed sage grouse habitat suitability based on sagebrush height and canopy cover and compared between mine and reference sites. They used a two-group *t*-test to compare mine and reference sites.
Location: Big Horn Basin, northcentral Wyoming, USA
Findings: Overall, mine sites had lower sagebrush density, cover, and height compared to native undisturbed sites, though some older sites had sagebrush values statistically similar to undisturbed sites. Age since reclamation was more influential than soil characteristics on sagebrush presence. The majority of reclaimed mine sites did not meet requirements for suitable sagebrush habitat.
Implications: Successful reestablishment of sagebrush steppe habitat in studied areas of the Big Horn Basin has been limited. Implementing more advanced techniques for sagebrush establishment, such as seeding on snowbanks or around precipitation events, developing site-specific methods, and including sagebrush in seed mixes, would increase success.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Wildlife/Habitat Data, Reclamation Standards, GrayLit

Liesenfeld, Z.J., 2013, Observations of sagebrush reestablishment field trials implemented by bentonite mine reclamationists, chap. 3 *of* Investigation of sagebrush reclamation success on reclaimed bentonite mined areas in the Big Horn Basin (Wyoming, USA): Laramie, Wyo., University of Wyoming, master's thesis, p. 58–75.

Link (non-DIO): https://www.uwyo.edu/wrrc/_files/docs/theses_dissertations/liesenfeld_zachary.pdf
Background: Experimental field trials can be helpful in exploring new methods for reestablishing Wyoming big sagebrush for bentonite mine reclamation. Technologies like seed coating, supplemental watering gels, drip irrigation, site-specific seeding, and mycorrhizal inoculation can be used in small sample plots before implementing on larger scales.
Objectives: The author compared various reclamation test planting field trials used to reestablish Wyoming big sagebrush on lands previously mined for bentonite.
Methods: The author identified sites where varying methods of sagebrush reestablishment had been implemented including planting seeds pre-treated with moisture-holding cellulose gel (Zeba), laying jute netting coconut mats, adding gel moisture packets, installing drip irrigation, transplanting mature sagebrush, hand seeding sagebrush in depressions and swales for water retention, and hand seeding sagebrush into snowbanks during winter. They photographed ground surface at trial sites in five marked 1 square meter (m^2) quadrats from approximately 1 meter (m) above ground level. They quantified ground cover present in 1 m^2 quadrats using Sample Point software focusing on sagebrush and combining all other species into functional group categories.
Location: Reclaimed bentonite pits in Lovell and Greybull, Wyoming, USA
Findings: The gel moisture pack trial yielded the highest sagebrush canopy cover (49.4 ± 9.6 percent) followed by Zeba coated seed and mycorrhizal inoculation (41.2 ± 10.4 percent), hand broadcast Zeba coated seed with no jute netting (40.2 ± 8.5 percent), mature sagebrush transplant (39.4 ± 4.6 percent) hand broadcast Zeba coated seed with jute netting (23.4 ± 10.9 percent), drip irrigation trial no. 1 (10.8 ± 1.5 percent), Zeba coated seeding (10.0 ± 2.6 percent), hand broadcast into snow banks (8.8 ± 3.5 percent), and drip irrigation trial no. 2 (6.6 ± 0.7 percent).
Implications: While some experimental trials were successful on the small scale, they would present time- and labor-intensive challenges on the large scale. The most productive and applicable test trials involved broadcast seeding with coated seed and mycorrhizal inoculation. These test trials provide useful information for future management of bentonite land reclamation. Reclamationists should consider site-specific characteristics and funding resources when choosing the most effective big sagebrush reestablishment method.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices, GrayLit

Lovell, M.C., Rideout-Hanzak, S., Ruppert, D.E., Acosta-Martinez, V., Smith, F.S., Maywald Stumberg, P., Pawelek, K.A., Falk, A.D., and Wester, D.B., 2018, Soil seed banks in stock-piled topsoils in the western Rio Grande Plains, Texas: Ecological Restoration, v. 36, no. 3, p. 226–237.

DOI: https://doi.org/10.3368/er.36.3.226
Background: The effect of topsoil removal and stockpiling on seed banks is poorly understood. The goal of this study is to assess the value of stock-piled topsoils for restoration of disturbed sites based on seed bank characteristics.
Objectives: This study (1) evaluated seed bank richness, seedbank size (number of seedlings), and species composition of stock-piled topsoil as a function of soil depth and pile age, and (2) compared seed banks of stock-piled topsoil to adjacent undisturbed topsoils to assess stockpiling as a site restoration tool.
Methods: Stockpiled topsoils and adjacent non-disturbed topsoils were assessed at four depths at five times (June and August 2013, and April, May, and July 2014) following stock-pile construction. The seed banks of soil samples were assessed for richness, size, and composition using the seedling emergence method that facilitates germination.
Location: Two private ranches in the Southern Texas Plains ecoregion in La Salle County near Cotulla, Texas, and Dimmit County near Catarina, Texas, USA
Findings: Seed bank size and species richness were affected by sampling date and collection depth. Seed bank size and richness generally decreased with lower soil sampling depths. The August sampling date had the highest seed bank size and richness. Differences between stock-piled and adjacent soils varied by site, with one site showing marked reductions in size and richness at the stock-piled soils, and the other site showing fewer differences. These site-specific differences likely reflect differences in surrounding vegetation.

Implications: Stock-piled topsoil acts as a valuable reserve of native seeds that can positively affect restoration efforts. Seed bank size was affected by the season when stockpiles were constructed and sampled, and the weather immediately preceding construction and sampling, more than stock-pile age. No difference in seed bank characteristics were found after 18 months of storage in the stockpile.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Lupardus, R.C., Azeria, E.T., Santala, K., Aubin, I., and McIntosh, A.C.S., 2020, Uncovering traits in recovering grasslands—A functional assessment of oil and gas well pad reclamation: Ecological Engineering, v. 143, supplement, 14 p.

DOI: https://doi.org/10.1016/j.ecoena.2019.100016
Background: Oil and gas development has negatively impacted millions of hectares of the North American Great Plains, threatening biodiversity and ecosystem function. Reclamation of disturbed grasslands is necessary; however, most monitoring is short term, incorporates generalized recovery standards, and fails to adequately assess the long-term health and recovery of reclaimed grasslands. In Alberta, reclamation methods have improved but no standardized monitoring protocol has been established. Appropriate assessment of Alberta's oil and gas land reclamation is necessary for future post-mine land productivity and monitoring protocols could serve as models for assessing reclamation across the Great Plains.
Objectives: The authors examined the long-term recovery of taxonomic, trait, and functional composition of plant communities on reclaimed oil and gas well pads to identify biological and edaphic factors, as well as possible trait-environment relationships, affecting recovery.
Methods: Eighteen study sites were sampled; each included a reclaimed well pad (ranging from 8 to 30 years post-reclamation) and an adjacent undisturbed reference site. Sites were categorized as pre- or post-1993, as these time periods required different reclamation criteria. In summer 2013, plant community composition and soil characteristics were assessed in reference and well pad sites using 10 square meter (m^2) soil plots, 25 m^2 shrub plots, 0.25 m^2 vascular plant plots, and 0.25-hectare (ha) census plots. Reference sites had four of each plot and well pad sites had five of each plot (except census plots). A set of morphological, physiological and (or) phenological traits related to species' colonization potential and sensitive to oil and gas disturbance were selected using the Traits of Plants in Canada database. Data were analyzed using a variety of statistical matrices and principal component analysis (PCA) methods.
Location: Dry Mixed-grass Natural Subregion of southern Alberta, Canada
Findings: Species richness and diversity did not statistically differ between well pad and reference sites or across reclamation time periods; however, >70 percent of reclaimed well pads contained introduced species. Plant height; seed weight; hemicryptophytes; abundant and semi-abundant seed production; short distance wind and animal dispersal mechanisms; hydric, mesic, and xeric water preferences; and native and introduced status differed between well pads and references sites. Mean and median soil pH, bulk density, and electric conductivity were lower and total organic carbon (C) higher on references compared to well pad sites; trends also varied by soil depth. Long-term impacts of oil and gas disturbance and reclamation were present regardless of reclamation time period, suggesting new criteria were not necessarily "better" in the long-term.
Implications: In Alberta, improved reclamation criteria did not result in significantly different results from previous criteria. Results are subject to site-specific conditions, indicating that individual land managers' decisions can largely impact reclamation outcome. Additionally, long-term monitoring is necessary to assess reclamation success and grassland recovery.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Standards

Lupardus, R.C., Battigelli, J., Janz, A., and Lumley, L., 2021, Can soil invertebrates indicate soil biological quality on well pads reclaimed back to cultivated lands? (Revised April 19, 2021): Soil and Tillage Research, v. 213, article 105082.

DOI: https://doi.org/10.1016/j.still.2021.105082
Background: Soil mesofauna (body width 0.1–0.2 millimeters [mm]) mediate a number of soil processes and play an important role in soil health and function. Oil and gas well pad construction greatly disturb soil and mesofauna communities, the effects of which can last for decades. Soil physio-chemical properties and the soil mesofauna community could serve as indicators of post-reclamation condition and guide ecological recovery assessments of reclaimed lands.
Objectives: The authors compared cropland and oil and gas reclaimed cropland to determine (1) if individual or combined crop type, age class, reclamation criteria, soil type, and disturbance history influenced mesofauna abundance, (2) if mesofauna community abundance correlated with belowground physio-chemical properties or with the presence of major mesofauna taxa, and (3) if reclamation efforts, plus additional annual cultivation activities, ameliorate the biological effects of oil and gas disturbance.

Methods: Twenty-five study sites (mostly within the Dark Brown soil zone), each consisting of well pad and reference areas, were selected to represent a population of >37,000 reclaimed, certified, and inactive well pads on cultivated land. In 2015, physio-chemical soil samples were collected from 24 of the 25 sites from within four 10 square meter (m^2) plots on each reference area and five 10 m^2 on each well pad at four soil depths (0–15 centimeters [cm], 16–30 cm, 31–60 cm, and 61–100 cm). In 2015, nine mesofauna samples were collected per study site (four in each reference area and five in each well pad area). Mesofauna were identified by phylum, class, order, or family depending on group with the exception of *Acari* (classified to order or suborder) and *Collembola* (classified to order). Sites were grouped by disturbance type, crop type, reclamation age, reclamation criteria, and soil type and analyzed using various multivariate and univariate techniques.
Location: Mixed-grass Natural Subregion in southwest Alberta, Canada
Findings: Well pads had stronger relationships among mesofauna groups and among mesofauna and soil properties compared to references areas. Reference areas had lower pH and bulk density and higher total organic carbon (C) compared to well pads; the oldest reclamation group (35–50 years post-reclamation) differed the most from reference areas. Overall, cultivation masked disturbances from oil and gas activities. Differences in soil physio-chemical properties (for example, bulk density, pH, total organic C) between well pads and reference areas were not reflected in the mesofauna community assembly data, indicating that community composition based on taxonomically broad mesofauna data may not be an adequate method for assessing reclamation success and recovery. *Acari:Collembola* ratio is likewise not a good indicator of biological recovery. However, individual mesofauna taxa abundance and density correlated with soil physio-chemical properties and may be a more useful metric.
Implications: There is too much variation in mesofauna community composition due to seasonal cultivation activities, time, and crop management practices to use it as a metric for assessing reclamation success. Future research should look at finer taxonomic scales of mesofauna and the relationships between crop yield, crop type, and soil biotic community.
Topics: Well Pad, Soil Data, Reclamation Monitoring, Reclamation Standards

Lupardus, R.C., McIntosh, A.C.S., Janz, A., and Farr, D., 2019, Succession after reclamation—Identifying and assessing ecological indicators of forest recovery on reclaimed oil and natural gas well pads: Ecological Indicators, v. 106, p. 1–14.

DOI: https://doi.org/10.1016/j.ecolind.2019.105515
Background: Canada's boreal forests undergo a number of human-induced disturbances, like oil and natural gas development, that impact forest health and succession. Reclamation of oil and gas development in Alberta has improved over time but is still poorly monitored for success and resulting land capacity. Understanding the rate of recovery and successional patterns in forests disturbed by oil and gas development is essential for ensuring that post-mine conditions meet reclamation criteria and return ecosystem function and health to comparable pre-mine levels.
Objectives: The authors assessed and compared vegetation recovery on decommissioned and reclaimed well pads to undisturbed forested sites and identified above- and below-ground indicators of forest recovery.
Methods: Two-hundred and seventy sample plots were selected within 30 study units in a *Populus tremuloides*, *Picea glauca*, and coniferous/deciduous mixed wood forest with *Pinus banksiana* and *Pinus contorta* stands; plots represented 27 ecological site types based on soil characteristics, nutrients, moisture, and vegetation structure. In 2014, sample sites were clustered using a reclamation protocol that included well pads that ranged in age from 7 to 48 years post-reclamation as well as adjacent reference sites for comparison. Each study site included the well pad and undisturbed reference. Soil and vegetation recovery on reclaimed well pads was characterized using a suite of physical, chemical, and biological indicators. Soil was sampled at 0–15 centimeters (cm), 15.1–30 cm, 30.1–60 cm, and 60.1–100 cm depths. Sites were categorized by type (reclaimed versus reference), natural subregion, forest stage, forest type, and time since reclamation and 62 above- and below-ground properties were analyzed using multivariate statistics.
Location: Central Mixedwood and Lower Foothills Natural Subregions in central Alberta, Canada
Findings: Only two reclaimed well pads had plant community composition similar to reference sites. Eighteen well pads resembled treeless grasslands; two of those well pads were >35 years post-reclamation, suggesting that oil and gas development slowed plant succession. The 10 remaining well pads appeared to be on arrested recovery trajectories. Reclamation significantly affected soil bulk density, soil pH, noxious plant species, canopy cover, grass cover, woody cover, litter/fermentation/humus depth, introduced species richness, and live tree basal area; these metrics were identified as ecological indicators of recovery.
Implications: In Alberta, oil and gas well pad reclamation has lasting effects on forest succession that can persist for decades and slow natural forest succession and recovery. Implementing detailed monitoring protocols can ensure reclamation is successful and meets certification requirements. This study suggests possible ecological indicators that could be used to develop monitoring protocols.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Monitoring, Reclamation Standards

Mason, A., Driessen, C., Norton, J., and Strom, C., 2011, First year soil impacts of well-pad development and reclamation on Wyoming's sagebrush steppe: Natural Resources & Environmental Issues, v. 17, no. 1, article 5, p. 29–34.

Link (non-DOI): https://digitalcommons.usu.edu/nrei/vol17/iss1/5
Background: Wyoming's arid and semi-arid sagebrush steppe ecosystem has low resilience to disturbances from energy development due to a number of constraints related to limited rainfall. On natural gas well pads, soil is stripped, stockpiled, respread, and seeded for reclamation. This process is suspected to disrupt soil structure, which is key in protecting labile organic carbon (C) and nitrogen (N). Disruption can mineralize C and N and change their dynamics within soil organic matter (SOM) pools. SOM is intrinsic to ecosystem stability, from providing nutrients for plant growth to increasing water holding capacity in the soil.
Objectives: The authors assessed the effects of well pad development (stripping, stockpiling, and respreading) and stockpiling depths on C and N dynamics.
Methods: Nine well pad sites dispersed among three natural gas field were identified for the study sites; each included three stockpiles, three recently recontoured well pads, and three adjacent undisturbed areas. Soils were sampled from each location in 2009 and 2010. Stockpiles at Jonah and Wamsutter gas fields were <1 year old and were <5 years old at the Pinedale Anticline (Anticline) gas field. At three randomly selected points on the piles, soil cores were augured and bulked by five depth intervals: 0–5 centimeters (cm), 5–20 cm, 20–100 cm, 100–200 cm, and 200–250 cm. The stockpile soils were respread at their associated well pads and seeded for reclamation in fall 2009. The soils at each reclaimed well pad and at the adjacent undisturbed reference areas were sampled at three random points along three 32-meter (m) transects, stratified and composited by three depth intervals: 0–5 cm, 5–20 cm, and 20–30 cm. Soil samples were analyzed by gravimetric moisture content, mineral N, and labile organic C and N. Aerobic incubations yielded mineralizable N and C after 14 days.
Location: Pinedale Anticline, Jonah, and Wamsutter natural gas fields, Wyoming
Findings: Initial stripping of topsoil disrupts the soil structure and increases the labile organic C and N as compared to undisturbed reference sites. Labile organic C and N concentrations increased with stockpile depth. Mineral N was significantly greater for reclaimed treatments than in undisturbed and stockpile treatments at all three sites. Following respreading of stockpiled soil, a large increase of N occurred. N increases and becomes available in each phase of disturbance and, although not statistically significant, N and labile organic C were reduced with each phase of disturbance. At Anticline, labile organic N concentrations were significantly lower in both the stockpile and reclaimed treatments than in the undisturbed Anticline reference site. At the other two sites, however, labile organic N concentrations were statistically higher than the undisturbed reference sites. Reclaimed well pads at all sites had significantly lower labile organic C concentrations than at the undisturbed reference areas. Jonah and Wamsutter sites exhibited the greatest loss of labile organic C and N upon respreading stockpiled soil, whereas this loss occurred during stockpiling at Anticline.
Implications: Labile organic C and N decrease after stockpiling and respreading, likely due to mineralization and subsequent loss to the environment. Mineralization (and loss of nutrients) increases with each disturbance activity and is greater with respreading and tilling for seeding. Disturbance affects the ability of micro- and macro-aggregates to retain soil nutrients. Following disturbance increased N and mineral nutrients might increase weed production. Less destructive stripping/spreading methods can conserve soil structure and mineral nutrients. Cover crops and C additions can additionally immobilize and retain mineral N.
Topics: Well Pad, Soil Data, Reclamation Practices, GrayLit

Matthees, H.L., Hopkins, D.G., and Casey, F.X.M., 2018, Soil property distribution following oil well access road removal in North Dakota, USA: Canadian Journal of Soil Science, v. 98, no. 2, p. 369–380.

DOI: https://doi.org/10.1139/cjss-2017-0141
Background: The creation of roadways from oil and gas development can impact soil properties, reduce nutrient availability, alter vegetation, and negatively impact the ecological resilience of the surrounding ecosystem. This study examined reclamation of roads associated with oil and gas development, and how soil properties are affected and recover over time.
Objectives: The authors examined how soil properties were affected by removed and reclaimed roadways of different ages compared to the surrounding undisturbed area.

Methods: The authors measured on and off-road soil properties along transects perpendicular to 16 restored roads in two ecological sites with two soil types (thin loam and sand). They measured the distributions and means of measured particle size distribution, gravel content, infiltration rate, pH, electrical conductivity (EC), sodium absorption ratio (SAR), calcium carbonate ($CaCO_3$) content, and soil organic matter (SOM) at each point along the transect. Bayesian statistical models were used to better understand the spread and variation in soil properties.
Location: Little Missouri National Grasslands (between latitudes 46°15′24.7″ N.–47°19′36.0″ N., and longitudes 103°36′49.7″ W.–103°21′7.9″ W.) in Billings County, North Dakota, USA
Findings: Model output illustrated that soil physical properties (texture and infiltration rate) and chemical properties (pH, $CaCO_3$, EC, and SAR) varied between the two soil textures studied as well as by distance from road center. SOM was lower on roads than adjacent undisturbed sites. Soil pH was higher on roads, and clay content was 3–4 percent higher on roads. Neither SAR nor EC varied with distance from the road. Time since road removal had little clear influence on soil texture and no influence on infiltration rates on road restoration projects as old as 15 years; the influence of time on soil chemical properties was variable by attribute measured and soil type.
Implications: Changes in SOM and pH can have lasting impacts on the capacity for restored roads to return to pre-disturbance conditions and match the surrounding ecosystems. Additionally, reduced cover of vegetation from altered soil properties can affect hydrology, increase erosion, limit habitat for wildlife, and restrict landscape productivity. More research is needed on other road removal techniques and restoration practices that can improve soil conditions and successful reclamation.
Topics: Road, Soil Data, Reclamation Practices

May, M., 1975, Moisture relationships and treatments in revegetating strip mines in the arid west: Journal of Range Management, v. 28, no. 4, p. 334–335.

DOI: https://doi.org/10.2307/3897793
Background: Strip mining in arid environments drastically alters soil moisture, which, due to climatic conditions, can be difficult to reestablish for revegetation and reclamation efforts. Mining operations that incorporate phytotoxic material into the spoil, overburden characteristics, and saline and sodic soils further complicate successful vegetation reestablishment post-mining. Several treatment solutions exist, and it is the land manager’s responsibility to ensure reclaimed land is useable for future generations.
Objectives: The author discussed soil moisture issues associated with strip mines in arid environments and possible treatment solutions.
Methods: The author outlined mining activities that lead to reduced soil moisture in arid environments. They reviewed several treatments that may alleviate soil moisture deficits. They briefly discussed the positive and negative aspects of topsoil, spoil, and overburden as revegetation materials for use in reclamation.
Location: This is a review article and does not involve a specific field site location
Findings: Possible solutions for increasing soil moisture on disturbed arid lands include irrigation, mulches (for example, asphalt, jute or excelsior netting, straw, sawdust, chemical materials), and snow fencing (where topography is appropriate). Covering overburden with topsoiling is not a solution in and of itself and, in some cases, spoil or overburden may have better water holding and base exchange capacities than topsoil for vegetation reestablishment. Though topsoil may contain native seed propagules, making revegetation easier, these species are often associated with secondary succession and may outcompete desired species for limited water resources.
Implications: This article is a helpful resource for land and reclamation managers of disturbed arid lands and discusses many soil-moisture related issues that should be considered in reclamation planning.
Topics: Mining, Soil Data, Reclamation Practices

McGeehan, S.L., 2008, Alternatives to topsoil—A five-year case study in mine site revegetation, *in* Brummer, J.E., ed., High Altitude Revegetation Workshop No. 18, Fort Collins, Colo., March 4–6, 2008, Proceedings: Colorado Water Resources Research Institute Information Series no. 107, p. 2–31.

Link (non-DOI): http://hdl.handle.net/10217/69248
Background: Coeur d’Alene Mining District of northern Idaho has insufficient amounts of topsoil for reclamation use. For this reason, a variety of amendments had to be considered for topsoil replacement. Research has shown that compost, limed biosolids, yard waste, and woody materials can all have positive impacts on revegetation of reclaimed mines.

Objectives: The author evaluated the effectiveness of various topsoil replacement amendments for revegetation of reclaimed mines.
Methods: A test site on a mine was regraded and ten 20 × 100-foot (ft) test plots were established, separated by 3 × 2 ft berms. Treatments were applied in the plots, including (1) topsoil control, (2) 0.75 biosolid:1 woodash, (3) 1 biosolid:1 woodash, (4) Potlatch log yard waste, (5) Kiwi Power fibers, (6) Eko compost, (7) Glacier Gold compost, (8) Biosol, (9) Glacier Gold log yard waste, and (10) fertilizer control. Plots were monitored from 2003 to 2007. Percent plant cover was measured using a cover-point optical projection scope at 100 points along one transect and plant density was measured at two locations within each plot. Erosion was assessed using 10 × 20 ft erosion traps and surface runoff was collected for content analysis. A cost evaluation was conducted, including "actual" and "normalized" costs.
Location: Silver Dollar Mine (47°30.22′ N., 115°59.39′ W.) in the Coeur d'Alene Mining District in northern Idaho, USA
Findings: Most amendments decreased pH (6.3–8.3) compared to controls. Erosion was minimal during the study across all test plots. Runoff contents differed across treatments relative to amendment nutrient contents. All treatments successfully promoted self-sustaining plant cover and were dominated by either grass (amendments with high nitrogen [N] availability) or forbs. Plant density increased to year 4 of the study (2006) then tended to decrease.
Implications: Depending on site-specific conditions and desired vegetation outcomes, a variety of soil amendments in place of topsoil can successfully revegetate reclaimed mine lands. For example, if grass is the desired dominate vegetation, land managers should consider soil amendments high in available N.
Topics: Mining, Vegetation Recovery Data, Soil Data, Erosion Data, Reclamation Practices, GrayLit

McIntosh, A.C.S., Drozdowski, B., Degenhardt, D., Powter, C.B., Small, C.C., Begg, J., Farr, D., Janz, A., Lupardus, R.C., Ryerson, D., and Schieck, J., 2019, Protocols for monitoring ecological recovery of reclaimed well pads on grasslands: Journal of the American Society of Mining and Reclamation, v. 8, no. 3, p. 91–173.

Link (non-DOI): https://doi.org/10.21000/JASMR19030091
Background: Monitoring and understanding oil and gas reclamation outcomes is dependent on scientifically rigorous and reliable protocols. Long-term and widespread use of such protocols allows for temporal and spatial comparisons and a more complete picture of reclamation success. By developing and implementing such protocols, land managers, scientists, reclamation professionals, and government agencies can standardize soil, vegetation, and landscape data collection and assess biological indicators of reclamation success.
Objectives: The authors developed a rigorous, scientifically robust, and financially sustainable monitoring protocol to collect soil, vegetation, and landscape data on reclaimed oil and gas well pads on Alberta grasslands.
Methods: A sampling overview was provided, including plot establishment and layout, site sketching, and photographic documentation. The authors described both a vegetation sampling protocol (including vegetation type classification methods, measuring shrubs, plant, and lichen cover, and performing vascular plant bryophyte, and lichen surveys), and a soil sampling protocol (including how to determine number of samples, measuring litter/fermentation/humus depth, collecting bulk density, measuring penetration resistance, and determining soil organic matter (SOM), electrical conductivity (EC), and pH. Visual graphics for various sampling locations within survey plots were provided. Personnel and data management were also discussed.
Location: This is a methods paper and does not involve a specific field study location; however, it does discuss oil and gas well pad reclamation protocols specific to grasslands in Alberta, Canada.
Findings: Successful and repeatable data collection requires strict adherence to protocols and attention to detail. Each sampling metric requires a specific datasheet and field method. Properly training and managing data collection staff is paramount to data quality and integrity. Long-term and widespread use of these protocols has the potential to develop a robust database of reclamation metrics and outcomes.
Implications: This protocol for collecting data and monitoring oil and gas well pad reclamation of grassland ecosystems may be useful for land managers, reclamation researchers and government agencies.
Topics: Well Pad, Reclamation Monitoring

McKell, C.M., 1989, Reclamation of disturbed lands in Glen Canyon National Recreation Area, *in* University of Wyoming National Park Service Research Center Thirteenth Annual Report, 1989: Wyoming Scholars Repository, v. 13, article 14, p. 70–73.

DOI: https://doi.org/10.13001/uwnpsrc.1989.2787
Background: Reestablishment of vegetation after disturbance in Glen Canyon National Recreation Area requires the most ideal conditions. Rarely do seeds naturally germinate in the canyon's harsh environment. Properly locating successful test plots is paramount for experimental revegetation studies.
Objectives: The author reviewed literature to determine successful test plots and project planning for revegetation studies in Glen Canyon National Recreation Area.
Methods: In 1989, on-site assessments were conducted to establish study sites at the view outlook dam approach in Page, Arizona, and on an abandoned road near a disposal area at Hall's Crossing marina. Soil compaction at the Page site was assessed to determine necessary preparation before transplanting for revegetation. Native grasses, forbs, and shrubs (including *Juniperus osteosperma* and *Artemisia tridentata*) were propagated in the Weber State College greenhouse to be transplanted in winter or early spring (December 1989 through March) of 1990.
Location: Two sites (Page and Hall's Crossing marina) in the Glen Canyon National Recreation Area in Arizona, USA
Findings: Appropriate sites and species were identified. This article outlines the study design, but implementation had yet to begin at the time of publication.
Implications: Revegetation studies should take great care to identify well suited sites and species for use in experimental tests to ensure applicable results.
Topics: Mining, Targeted Plant Recovery Data, Reclamation Practices, GrayLit

McKenna, P.B., Lechner, A.M., Phinn, S., and Erskine, P.D., 2020, Remote sensing of mine site rehabilitation for ecological outcomes—A global systematic review: Remote Sensing, v. 12, no. 21, 34 p.

DOI: https://doi.org/10.3390/rs12213535
Background: Mine reclamation is often assessed using on the ground vegetation and soil monitoring protocol. Remote sensing technology offers an opportunity to compliment, or even replace, field monitoring programs with large scale, landscape level monitoring capacity. However, the effectiveness of remote sensing techniques has not been synthesized across scientific and reclamation literature.
Objectives: The authors systematically reviewed and assessed remote sensing studies of vegetation dynamics on reclaimed mines between 1970 and 2019 and discussed future application for remote sensing technology.
Methods: Researchers used Scopus and a systematic approach with select keywords to conduct an online search of papers published between 1970 and 2019 then narrowed down applicable papers based on relevant criteria. Each paper was categorized based on study type; the objectives of each paper were summarized; publication metadata were recorded; and a database was compiled which summarized important variables such as commodity, sensors, spatial extent, classification method, temporal scale, and indices used. The contribution to ecological outcomes of each paper was determined by categorizing each study based on the International Society for Ecological Restoration's ecological recovery wheel. The literature review search results were synthesized and future applications for monitoring reclamation vegetation progress with remote sensing technology were suggested.
Location: This is a literature review and does not involve a specific field site location, however, the review included studies conducted across the world.
Findings: A total of 99 papers were included in the final assessment. The number of papers on remote sensing for reclamation vegetation monitoring has grown exponentially over the publication period and spanned 19 countries of study. The commodity discussed in the majority of papers was coal mining (62 percent) and the sensors used were Landsat (50 percent), though the last decade has seen an increase in the range of sensors used. Fifty-nine papers (63 percent) addressed the sub-attribute of spatial mosaic on the Society for Ecological Restoration's ecological recovery wheel.
Implications: Remote sensing technology has widespread applications for monitoring vegetation on reclaimed mine lands but is notably underutilized. Future studies should look to broaden the use of remote sensing to additional areas of the Society for Ecological Restoration ecological recovery wheel and work to standardize remote sensing monitoring methods to ensure accurate assessment of reclamation outcomes.
Topics: Mining, Reclamation Monitoring

McNearny, R.L., and Wheeler, K.R., 1995, Knight Mine reclamation—A study of revegetation difficulties in a semi-arid environment: International Journal of Surface Mining and Reclamation, v. 9, no. 3, p. 113–119.

DOI: https://doi.org/10.1080/09208119508964730
Background: The Knight Mine in Utah was an underground coal mine in operation from 1977 to 1980. BHP Petroleum acquired the mine in 1985 and initiated reclamation following the Federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) and the Interim Regulations administered by the Utah Division of Oil, Gas, and Mining. Sustained efforts to reestablish vegetation have continued though proved unsuccessful.
Objectives: The authors reviewed and discussed the difficulties in reestablishing vegetation during reclamation of the Knight Mine as a case study for future research.
Methods: Based on inspection reports and interviews, original reclamation efforts were summarized as they occurred in two stages. Stage 1 was initiated in 1987 after regrading contours by applying 8–18 inches (in.) of stockpiled topsoil and fertilizer. The reclamation area was hydroseeded with a seed mix containing grasses, forbs, and shrubs, and covered with straw. Stage I revegetation met requirements, although one area contained kochia (*Kochia scoparia*). Stage II was initiated in 1990 with the removal of a sediment pond and a culvert. Stage II protocol was similar to that of Stage I, except due to a lack of topsoil, subsoils and mulch were used as surface cover. Native revegetation of the swale area after Stage II was unsuccessful and dominated by nonnative kochia, halogeton, and lambsquarters. This continued through 1992 and, despite reseeding that fall, kochia continued to dominate. The authors evaluated the successful 1987 and unsuccessful 1990 and 1992 seedings to determine factors that may explain the different outcomes.
Location: Knight Mine, southcentral Utah, USA
Findings: The seed mix, seeding method, fertilizer, cover, and topsoil verses subsoil application were not significant factors in revegetation success or failure. A dry period in 1993 may have resulted in unsuccessful revegetation after the 1992 seeding but the data are not specific enough to draw conclusions. The leading factor that affected revegetation success was likely the ability of *K. scoparia* to outcompete desired native species for soil moisture. *Kochia scoparia* was already present in the seedbank and has characteristics favorable for germination in disturbed areas, which influenced its dominance in revegetated areas.
Implications: During reclamation, land managers should consider the pre-existence of undesirable species like kochia in the seedbank and design methods for reducing their germination. For example, herbicide used may reduce kochia and other undesirable species presence in the seedbank.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Meikle, T.W., and Weilage, K., 2009, AM-colonized plant materials for mined-land reclamation, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, p. 799–814.

DOI: https://dx.doi.org/10.21000/JASMR09010799
Background: Arbuscular mycorrhizal fungi (AMF) have been shown to increase plant survival, enhance seedling growth, and increase growth under nutrient and drought stress. Techniques for inoculating nursery plants with AMF that are then outplanted for mine reclamation could increase revegetation success while reducing cost. Nursery environments vary and cultural practices may not result in adequately colonized inoculated plants. Streamlining nursery inoculation practices to ensure successful AMF inoculation is necessary for repeatable and desired reclamation revegetation outcomes.
Objectives: The authors produced AMF plant material under different nursery fertilization regimes then evaluated seedling stock field performance to determine AMF inoculation best practices.
Methods: Three separate sites for field trials were selected. The field trail layout, monitoring methods, and species present differed at each site due to time and budgetary constraints. Plant material was grown under three treatments: (1) "Traditional Fertilization Regime," consisting of fertilizers applied on a minimum weekly basis, (2) "Slow-Release Fertilization Regime" +inoculum that augmented growth media with the slow-release fertilizer, and (3) "Slow-Release Fertilization Regime" without inoculum; the third treatment was implemented only at two sites. Before outplanting, a subset of plants was sampled to

determine mycorrhizal colonization rates per procedure. All sites used a randomized complete block experiment design with mycorrhizal and non-mycorrhizal treatments. Data were analyzed using analysis of variance (ANOVA) or by interpreting simple means and standard variation.
Location: An abandoned logging landing in the Bureau of Land Management's (BLM) Cascade-Siskiyou National Monument in Oregon; agricultural land at the Montana State University–Western Agricultural Research Center near Corvallis, Montana; and waste rock material at Rio Tinto's Kennecott Utah Copper Concentrator near Magna, Utah, USA
Findings: Growth rates were higher at the Utah than Oregon and Montana sites, possibly due to existing soil fertility. The Utah site was former agricultural land with more nutrient-rich topsoil while parent soil material at the other sites had been largely removed. Survival was highest at the BLM site in the Slow-Release Fertilization Regime+inoculum though no substantial differences were observed among treatments at the Utah and Montana sites. Survival results were likely related to a range of benefits (for example, phosphorus (P) and nitrogen (N) resources, drought, and disease tolerance), site factors, or production practices before outplanting.
Implications: AMF-inoculated plants exhibited higher growth when grown in soil with higher nutrient content indicating growth may be more dependent on outplanting soil conditions or AMF species adaptability than inoculation treatment alone. Greenhouse AMF inoculation practices can affect plant survival and growth results and should be carefully considered by land and reclamation managers in reclamation protocols.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Merrill, S.D., Liebig, M.A., Hendrickson, J.D., and Wick, A.F., 2018, Soil quality and water redistribution influences on plant production over low hillslopes on reclaimed mined land: International Journal of Agronomy, v. 2018, 12 p.

DOI: https://doi.org/10.1155/2018/1431054
Background: In the northern Great Plains of the United States, coal surface mining creates mine spoil with increased sodium and clay content, conditions that complicate revegetation. Experiments with soil salvage and respreading across soil wedges have revealed interactions between landform water redistribution and soil depth. Existing vegetation and climate variables further affect revegetation success. Results have influenced reclamation requirements, but questions regarding the soil quality concept still remain.
Objectives: The authors examined the effects of soil quality measurements, water redistribution, plant species, and soil structure on hillslope vegetation on a reclaimed coal mine.
Methods: Soil wedges were created at two experimental sites in 1976 on coal mines with sodic soils. At a coal mine near Zap, North Dakota, a double wedge was created over levelled mine spoil by crossing A-horizon topsoil gathered from a nearby area with three B- and C-horizon subsoils of varying qualities, using two replicates each combination. At a coal mine near Stanton, North Dakota, a wedge of subsoil was created over levelled mine spoil and crossed with three consistent depths of topsoil (0 meters [m], 0.2 m, and 0.6 m). Each strip treatment was divided lengthwise and seeded in 1976 with four crop treatments in a randomized pattern with replicates; seeded species differed by site. Vegetation was harvested yearly for productivity measurements; the harvests from 1978 and 1979 were used for analysis because those were years without drought at both sites. Soil was sampled at five depth intervals to determine sodium absorption ratio (SAR), electrical conductivity (EC), pH, soil organic carbon (SOC), phosphorus content, texture, and available water content (AWC). At each point where vegetation was harvested, soil quality index was calculated using all soil properties except texture. Water content was measured to assess downslope water redistribution and a water redistribution index was calculated. Correlations between soil properties and calculated indices were assessed, the effect of soil properties on plant yields were analyzed using one-way analysis of variance (ANOVA) and regression.
Location: Reclaimed surface coal mines near Zap (47°14′33″ N., 101°51′1″ W.) and Stanton (47°15′30″ N., 101°20′55″ W.) North Dakota, USA
Findings: At the Zap mine, the effect of subsoil on productivity differed by plant group, and regressions of species yields indicated effects of water redistribution on plant productivity. At Stanton, yields responded more to soil depth than water redistribution. At both sites, the effects of hillslope, water redistribution, and soil quality and plant production differed across species.
Implications: Soil quality assessments should not be limited to the dynamic profile near the surface, but consider properties of the entire rooting zone, including soil depth and chemical properties of subsoils, as well as hydrologic processes such as the effects of topography on water redistribution, as these conditions impact revegetation and plant productivity. Especially in subhumid and semiarid areas, plant use of water deeper in the soil profile can be critical to its growth.
Topics: Mining, Target Plant Recovery Data, Soil Data, Hydrology Data, Reclamation Practices

Miller, R.M., 1984, Microbial ecology and nutrient cycling in disturbed arid ecosystems, *in* Dvorak, A.J., ed., Ecological studies of disturbed landscapes—A compendium of the results of five years of research aimed at the restoration of disturbed ecosystems: U.S. Department of Energy, Office of Scientific and Technical Information, DOE/NBM-5009372 (DE85009372), p. 3-1–3-29.

Link (non-DOI): https://www.osti.gov/biblio/5506382
Background: Removing topsoil and replacing it or another suitable plant growth material during mine land reclamation is required by Federal law. However, the quality of these materials is often unknown, as is their impact on above- and below-ground ecosystem processes and functions. Understanding soil recovery following reclamation is necessary for reestablishing soil conditions that support long-term self-sustaining above- and below-ground growth. In 1975, Argonne National Laboratory set up multiple field studies at mines in the western and midwestern United States to better understand if successful reclamation of areas disturbed by mining could be met within federal and state time constraints. In 1977, further studies were initiated to focus on edaphic conditions and soil symbionts such as vesicular-arbuscular mycorrhiza (VAM).
Objectives: The author investigated various topsoil handling methods and the associated microbial implications of each method for reestablishing below-ground ecosystem functions at an active coal mine in a shrub-steppe ecosystem.
Methods: A variety of field trials were initiated to investigate interactions among VAM, plant communities, and soil conditions using the same direct-applied, stored topsoil, and undisturbed control plots as in Jastrow and others 1984 (https://www.osti.gov/biblio/5506382). Root samples were selected to characterize VAM by species, soil samples were collected to explore VAM infection potential, and small snow fences were installed to test the effects of increased moisture on VAM infection potential. Survival dynamics of mycorrhizal fungi were assessed by assaying different aged topsoil stockpiles. Soil treatment effect on mycorrhizal infection potential, soil chemical properties, and soil physical characteristics of native undisturbed soil were analyzed. The effectivity of endemic mycorrhizal endophytes was investigated. A synecological study of soil microfungi to investigate the effects of topsoil handling and storage methods was conducted. Decomposition rates across soil treatments was assessed to determine the effects of disturbance. Soil treatments were sampled for soil carbon (C) and nitrogen (N) pools.
Location: Jim Bridger Mine (elevation 2,100 meters [m]) in the Red Desert in Wyoming, USA
Findings: Mycorrhizae were an essential component of undisturbed and later several plant communities. VAM was not essential for early stages of plant community development, thereby playing a secondary role in ecosystem recovery; however, they were and are necessary for long-term plant survival and determining successional direction. Topsoil handling procedure influenced long-term resource dynamics of soil C and N resources pools. While decomposition rates across soil handling treatments appeared unaltered, the microbial community composition differed by treatment, which could have unknown long-term effects.
Implications: Land and reclamation managers should consider assessing topsoil for VAM and other fungi communities before spreading to maximize revegetation outcomes.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Miller, R.M., Carnes, B.A., and Moorman, T.B., 1985, Factors influencing survival of vesicular-arbuscular mycorrhiza propagules during topsoil storage: Journal of Applied Ecology, v. 22, no. 1, p. 259–266.

DIO: https://www.jstor.org/stable/2403343
Background: Understanding natural ecosystem resiliency to disturbance, such as surface coal mining, is important for designing appropriate reclamation plans. Research suggests vesicular-arbuscular mycorrhiza (VAM) fungi are important for healthy soil and plant communities. Reclamation often involves removing topsoil and stockpiling it for later revegetation use. Assessing the relationship between stockpile duration and VAM presence is important for understanding the viability of stockpiled topsoil for successful revegetation goals.
Objectives: The authors assessed the survival of VAM, and factors affecting survival, in stockpiled topsoil of various ages (0.5–6 years old).
Methods: Twelve soil samples were collected using a bucket auger (three samples at four different depths) from eight topsoil stockpiles aged 0.5, 0.8, 1, 2, 3, 5, 5.5, and 6 years old. Samples were sieved and portions were used for chemical and physical analysis. Remaining sample portions were used for VAM bioassay and propagule density counts following the methods of Moorman and Reeves (1979, at https://doi.org/10.2307/2442619). Osmotic potentials, soil texture, soil pH, and organic

carbon (C), nitrogen (N), phosphorous (P), nitrate-N, and ammonia-N content were assessed. VAM spores were counted using the sucrose density gradient method. Mycorrhizal inoculation percent was regressed on soil age and the authors assessed correlations between various soil properties and VAM infection percentages in bioassay.
Location: Surface coal mine and power plant operation in the Red Desert (latitude 40°45′59″ N., longitude 108° 33′04″ W.) of Wyoming, USA
Findings: Bioassay results indicated no noticeable change in VAM propagule count until 2 years after stockpiling, at which time the count decreased. Variables related to soil moisture, but not chemistry, were significantly related to VAM propagule survival.
Implications: Soil-water potential is an important factor for VAM survival, with inoculation potential increasing as soils have more negative osmotic potentials down to -2 megapascals (MPa), (but little relationship in soils with more extreme values) and, therefore, soil water potential is an important property related to the viability of topsoil stockpiled for reclamation. Land managers considering using stockpiled topsoil over 2 years old should assess the pile for soil moisture variables before applying to disturbed land for revegetation efforts.
Topics: Mining, Soil Data, Reclamation Practices

Minnick, T.J., and Alward, R.D., 2015, Plant-soil feedbacks and the partial recovery of soil spatial patterns on abandoned well pads in a sagebrush shrubland: Ecological Applications, v. 25, no. 1, p. 3–10.

DOI: https://doi.org/10.1890/13-1698.1
Background: In sagebrush ecosystems, soil organic carbon (SOC) often displays spatial patterns consistent with vegetation and interspace patterns. Spatial patterning of vegetation and bare ground in semiarid systems can increase water use and plant productivity, whereas loss of this patterning is indicative of lower ecosystem stability and desertification or transitions from grassland to shrubland. Facilitative feedbacks between vegetation and soil create resource islands on the landscape, where SOC is an indicator of soil quality and ecosystem health.
Objectives: This study aimed to understand how soil spatial patterns recovered following ground-clearing disturbances related to oil and gas development. Specifically, the authors sought to (1) quantify the spatial distribution of SOC on disturbed and undisturbed sites, (2) investigate the relationship between spatial patterns of SOC to resource islands developed by plants, and (3) determine the relationship between facilitative-to-competitive ratios of different species and functional groups and spatial SOC patterns.
Methods: A chronosequence, including eight reclaimed or abandoned natural gas well pads (dated between 1961 and 2008), was established for the study. At each site, a 9 × 12 meter (m) main plot was established for sampling. Within the plot, 112 soil samples were obtained. Plant species presence and functional types were recoded where each soil core sample was taken. Sampling occurred from late May to mid-June 2009. SOC was determined using the Walkley-Black method.
Location: Rio Blanco County, Colorado, USA
Findings: Disturbed and undisturbed sites had significantly different SOC spatial patterns. At reference sites SOC under plant canopies was much higher than in the interspaces and on well pads completed before 1995. In the youngest well sites (1995–2008), there was no difference in SOC under perennial plants and in the interspaces (these sites are characterized by low plant cover).
Implications: None of the well sites displayed SOC spatial patterning consistent with reference sites, even after 47 years. However, in the older well sites, there was soil-vegetation feedback, where SOC was greater under shrubs compared to interspaces (resource islands). Recovery of SOC and initiation of a resource island was related to whether or not there was a perennial grass or perennial shrub. Species of shrub may also be important due to the differences in the ratio of canopy to rooting diameter.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices

Mitchem, M.D., Dollhopf, D.J., and Harvey, K.C., 2009, Reduced-impact land disturbance techniques for natural gas production, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, pp. 816–831.

DOI: https://dx.doi.org/10.21000/JASMR09010816
Background: Drill pad construction typically involves a cut-and-fill procedure that results in costly revegetation and soil remediation. Environmental characteristics, such as slow revegetation due to limited rainfall and harsh soil substrates exacerbate remediation efforts. Site and seedbed preparation techniques used in cut-and-fill may elevate bulk soil density, which in turn limits plant growth. Oak mats, in contrast, can be used to distribute the weight of drilling equipment, eliminate excavation, and reduce the total area impacted. Oak mats are constructed using 25-centimeter (cm)-wide oak planks spaced at 2.5 cm intervals; three layers of planks are arranged perpendicularly, creating a 15 cm thick mat. Sections of oak mat are fit together using a tongue-and-groove method and placed directly on top of soil and vegetation during drilling. They can be reused, with an anticipated longevity of 3 to 5 years of continual use.
Objectives: The authors evaluated whether oak mats could help minimize soil and plant disturbance associated with natural gas drill pad construction by quantifying vegetation recovery following oak mat removal, determining the soil bulk density change after removal, and evaluating the cost-benefit of oak mats as compared to cut-and-fill techniques.
Methods: In June 2007, vegetation data were collected using the Daubenmire method on 43 Jonah Field oak-mat removal sites and at adjacent undisturbed rangeland sites. An additional subset of removal sites from 2006–2007 were monitored to record vegetation change across growing seasons. Two 15.2-meter (m) (50 feet) transects were randomly placed in the disturbed area and two within adjacent undisturbed rangeland and used to measure plant species, species richness, species density, plant canopy cover, and ground cover classes using a 50 square centimeter (cm^2) Daubenmire frame placed every 3.05 m (10 feet) along one side of the transect. Soil dry bulk density was measured using Troxler nuclear density and a moisture gauge at six random locations in each drill pad prior to placement of oak mats and at one reference site outside of the drill pad area. The same depths and locations were remeasured after the removal of oak mats.
Location: Jonah natural gas field, Sublette County, Wyoming
Findings: Overall grass density increased in oak mat removal areas as compared to reference areas, but grass canopy did not. Between 2006 and 2007, there was a significant increase in grass cover and density, but not in forb density and cover. Mean forb density and cover between oak mat removal sites and reference sites were statistically similar across the whole study. Shrub density and cover were lower following oak mat removal, but there was an increase in shrub cover and density between 2006 and 2007. Weed presence on reclaimed sites with oak mats was generally lower than cut-and-fill sites. Across the 38 mat removal areas, mean soil bulk density values changed -2.9 percent (0–5.1 cm depth), 2.2 percent (0–15.3 cm depth), and 3.7 percent (0–30.5 cm depth). Following mat removal, no average soil bulk density values exceeded the 1.65 grams per cubic centimeter (g/cm^3) threshold established by the U.S. Department of Agriculture (2001, at https://jornada.nmsu.edu/files/RSQIS4.pdf) for rangeland environments. While construction and reclamation costs of oak matted drill pads are generally less than cut-and-fill pads, especially for sloped sites below a 10 percent grade, drilling costs are generally higher at oak matted drill pads.
Implications: Oak mats benefit grass establishment by potentially crushing competing shrubs and improving seed germination of grass species. Additionally, oak mats can aid in soil moisture retention to keep forb populations stable. While shrub populations were negatively affected by oak mats, disturbance may benefit shrub production and other vegetation types in the long term by removing old shrubs and creating a mosaic type landscape. Matted drill pad sites greatly reduce environmental impact on the landscape and should be adopted as (1) the cost of oak mats drops and (2) matted drill pads are mandated by State and Federal agencies.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Mummey, D.L., Stahl, P.D., and Buyer, J.S., 2002, Soil microbiological properties 20 years after surface mine reclamation—Spatial analysis of reclaimed and undisturbed sites: Soil Biology & Biochemistry, v. 34, no. 2002, p. 1717–1725.

Link (non-DOI): https://www.mpgranch.com/file/174/download?token=l5GJth-6
Background: Surface mining disturbs highly sensitive soil microbial communities essential for terrestrial ecosystem functions such as nutrient cycling, energy transfer, and long-term ecosystem stability. Understanding the effects of surface mining spatially on microbial communities can provide insight into best reclamation methods for reestablishing as much of the natural microbial processes as possible and inform assessments of reclamation success.
Objectives: The authors examined the differences in soil microbial communities of disturbed and undisturbed communities, specifically fatty acid methyl esters (fatty acids) and microbial biomass carbon (MBC).
Methods: A reclaimed site that had been seeded with a mix of native and non-native species and an adjacent undisturbed site which was dominated by *Artemisia tridentata,* Wyoming big sagebrush, were selected for comparison. Within two sample plots per site, 29 soil samples representing a 5–10-centimeter (cm) depth interval were collected and stored at 4 °C until analysis. The samples were lyophilized and centrifuged for fatty acid analysis of total biomass. MBC was measured and calculated using the chloroform fumigation-extraction technique. To determine soil organic matter (SOM) content, 10 grams (g) of soil were extracted and filtered. Canopy cover was estimated using the Daubenmire canopy-coverage method. Data were analyzed using univariate statistical analyses, linear correlation, and geostatistical spatial methods.
Location: Pathfinder Uranium Mine, Shirley Basin of southeastern Wyoming, USA
Findings: Total plant cover was not significantly different between disturbed (reclaimed) and undisturbed sites, but plant species diversity was significantly lower at reclaimed sites. Soil texture and water content differed between reclaimed and undisturbed sites. SOM content, MBC, and all fatty acid biomarkers were significantly lower at reclaimed sites. Relationships among SOM, MBC, and fatty acid differed at reclaimed compared to undisturbed sites. MBC and fatty acid were spatially autocorrelated in reclaimed sites only. SOM content spatial autocorrelation varied by type at both reclaimed and undisturbed sites.
Implications: Surface mining disturbance on microbial soil communities can be detected at least 20 years after reclamation and negatively impacts fatty acid methyl esters, MBC, and SOM contents, along with plant community diversity. Fully understanding the impact of surface mining disturbance on soil communities requires analysis of spatial and temporal scales.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Muñoz-Rojas, M., Erickson, T.E., Dixon, K.W., and Merritt, D.J. 2016, Soil quality indicators to assess functionality of restored soils in degraded semiarid ecosystems: Restoration Ecology, v. 24, no. S2 (special issue), p. S43–S52.

DOI: https://doi.org/10.1111/rec.12368
Background: Restoring disturbed soil and vegetation communities is paramount to reestablishing functioning ecosystem processes following open-cut and strip-mining operations, especially in semiarid and arid environments where soil systems are fragile. Adequately assessing soil function requires understanding which processes and properties are best representative of soil quality and can serve as indicators. These indicators are broad across all soil types and include chemical and physical characteristics. Further refining methods for assessing soil quality indicators may improve restoration success and reduce assessment costs.
Objectives: The authors developed a set of soil quality indicators for reconstructed soils in a semiarid environment and used them to evaluate new assessment methods.
Methods: A 7.9-hectare (ha) restored mine site which was 4 years post-restoration was divided into two subareas distinguished by growth medium: 3 ha were covered with nearby topsoil and 4.9 ha were covered in a lateritic waste material. After the growth mediums were respread, a mix of native legumes, grasses and trees was broadcast seeded. An undisturbed natural shrub-grassland ecosystem was selected as a reference site. Six 2 square meter (m^2) plots were established in each restored subarea and in the reference site; in each area, three were vegetated plots and three were non-vegetated/bare ground plots. Three samples were collected of the top 5 centimeters (cm) of soil from each plot and bulked for one composite sample per plot. Proposed indicators for soil condition were analyzed, including those related to soil physicochemical properties (available water capacity, percent sand, percent silt, percent clay, bulk density, electrical conductivity (EC), soil organic carbon (SOC), total nitrogen (N), organic carbon (C): nitrogen (N), and total available phosphorus) and those related to soil microbial status

(total microbial biomass, total bacteria, total fungi, pseudomonas, actinomycetes, gram (+) bacteria, gram (−) bacteria, and mycorrhizal fungi). Microbial respiration was also determined using the 1-day carbon dioxide (CO_2) test. Data were analyzed using one-way analysis of variance (ANOVA) and principal component analysis (PCA).
Location: A 7.9-ha restored iron ore mine site in the Pilbara interim biogeographical region (22°03′S., 118°07′E.–23°19′S., 119°43′E.) of north-western Australia
Findings: In general, soil physical, chemical, and microbial indicators were significantly different across growth mediums and varied depending on vegetation or bare ground cover. Soil organic C, C:N, and microbial density and activity were highly sensitive indicators for detecting differences among reconstructed and undisturbed reference site soils. The 1-day CO_2 test was a cost-effective evaluation method. While restored soils with both growth mediums appeared to be recovering, soil functionality was still drastically different from undisturbed references sites.
Implications: The selected soil quality indictors and new methods evaluated in this study are effective for assessing the quality and functionality of disturbed mining soils in semiarid environments.
Topics: Mining, Soil Data, Reclamation Practices

Musselman, R.C., Shepperd, W.D., Smith, F.W., and Asherin, L.A., 2014, Survival and growth of aspen and serviceberry planted on reclaimed surface mined land with landscape fabric and irrigation: Journal of the American Society of Mining and Reclamation, v. 3, no. 1, p. 16–40.

DOI: https://doi.org/10.21000/JASMR14010016
Background: Revegetation of previously mined lands in the semi-arid western United States is complicated by poor soil and dry weather conditions. Reestablishing clonal reproducing species like quaking aspen (*Populus tremuloides*) and western serviceberry (*Amelanchier alnifolia*) is further complicated by roots (from which new individuals sprout) that are removed from the soil by the mining process. Attempts to transplant individuals has failed due to the lacking root system and water availability.
Objectives: The authors evaluated the effects of landscape fabric (applied during tree planting) and irrigation on reestablishment and survival of native aspen and serviceberry on previously mined land.
Methods: Aspen and serviceberry were separately hand-planted using standard weed barrier landscape fabric following machine planting techniques on topsoil that had been stored then placed at a depth of 1 meter (m) on all sites during 2007. A strip plot design was used, with five sites as plots and 16 treatment rows (8 rows of serviceberry and 8 of aspen) within plots as strips. Rows within each plot were randomly assigned application or no application of landscape fabric. Half of the planted individuals of each species were watered every two weeks from mid-June through early September during the first growing season (2008). Growth and survival were measured at the end of the growing season and physiological status of aspen in the first growing season was recorded. Topsoil was analyzed for organic matter content, texture, electric conductivity, sodium absorption ration, acid-base potential, and moisture.
Location: Reclaimed surface mines (Yoast and IIW) near Hayden, Colorado, USA
Findings: Aspen growth and survival was higher in response to the application of landscape fabric compared to irrigation. Serviceberry survival, but not growth, increased with the application of landscape fabric. Additionally, serviceberry did not response to irrigation.
Implications: While this study focused on the reestablishment of aspen and serviceberry in high altitude semi-arid reclaimed surface mines, the conclusions can be applied at a broader scale. Landscape fabric is a cost-effect method for increasing aspen growth and survival though it is not as successful at increasing serviceberry growth. Irrigation is not necessary for reestablishing these species and may not be cost-effective at other sites.
Topics: Mining, Target Plant Recovery Data, Soil Data, Reclamation Practices

Musslewhite, B.D., Buchanan, B.A., Ramsey, T.C., Hamilton, J.S., and Luther, J., 2001, Creating diverse wildlife habitat at La Plata Mine, northwestern New Mexico, A case study—Part 2, soils and vegetation, *in* Barnhisel, R.I., Buchanan, B.A., Peterson, D., and Pfeil, J.J., coordinators, Land reclamation, a different approach—18th Annual National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mex., June 3–7, 2001, Proceedings: American Society of Mining and Reclamation, p. 18–25.

DOI: https://doi.org/10.21000/JASMR01010018
Background: Post-mining land use informs reclamation planning. Reestablishing functional wildlife habitat to restore biodiversity after mine disturbance is an increasingly important issue in reclamation. To develop a reclamation plan promoting biodiversity, it is important to document the pre-mine ecology and habitat characteristics.
Objectives: The authors discussed a reclamation plan for the BHP La Plata Mine and its specific methods and goals as a case-study of reclamation focused on wildlife habitat.
Methods: Baseline soil and vegetation inventories were conducted, and the area was surveyed for wildlife use. A reclamation plan was developed which included three broad topics: (1) landscape design, soil reconstruction, and vegetation community establishment, (2) integrating the post-mine landscape, and (3) characteristics to guide reestablishment of pre-mine biodiversity.
Location: BHP Minerals La Plata Mine in northwestern New Mexico, USA
Findings: Four reclamation land types were identified (upland shrub north aspects, upland shrub south aspects, grassland, and drainage), each associated with four vegetation types and specific soil textures. Pre-mine inventories informed the development of land type-specific seed mixes to ensure plant biodiversity. Topsoil thickness of less than 15 centimeters (cm) is best for shrub reestablishment, while thickness of >30 cm is best for native grass reestablishment.
Implications: Traditional reclamation planning often focuses on productivity, but biodiversity is more important when wildlife habitat is the post-mine land-use. The La Plata Mine reclamation plan takes into account biodiversity reestablishment and can serve as an example for other situations in which wildlife habitat is designated as the post-mine land-use.
Topics: Mining, Vegetation Recovery Data, Soil Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Naeth, M.A., 1990, The impacts of grazing regime on revegetation after pipeline construction in a Canadian mixed prairie ecosystem, *in* Planning, rehabilitation, and treatment of disturbed lands, Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, Mont., March 25–30, 1990, Proceedings: Bozeman, Mont., Montana State University, Reclamation Research Unit Publication No. 9003, v. 2, p. 373–379.

Link (non-DOI): https://archive.org/details/fifthbillingssym00bill/page/n1/mode/2up
Background: Rangeland revegetation after linear disturbances, such as natural gas pipeline right-of-way (ROW) construction is difficult because cattle often overgraze and trample revegetation attempts. Grazing regimes must be carefully monitored to ensure successful plant establishment and long-term growth.
Objectives: The author assessed the effects of grazing (early and late season) on revegetation following natural gas pipeline construction under different construction activities and different aged pipeline ROW.
Methods: In a native mixed prairie rangeland, four 100 × 135-meter (m) sites within 4 kilometers (km) of one another were selected. Each site spanned five parallel pipeline ROW segments that had been installed in 1957, 1963, 1968, 1972, and 1981, plus segments of undisturbed prairie on either side of the corridor containing the ROWs. The 1968, 1972, and 1981 ROWs were seeded with a mix of introduced species, and the 1957 and 1963 ROWs were unseeded. Two of the sites were grazed in the early season (May through July) and two in the late season (August through October). In 1982 and 1983, 100, 0.1 square meter (m^2) quadrats were used to visually estimate basal area for individual species, bare ground, live vegetation, and litter, within each ROW and undisturbed segment at each site. Plant species frequency for all species was calculated. In the 1981 ROW, 25, 1 m segments were randomly selected among each of four seeded rows, within which all native and introduced plants were counted for calculating plant density. Data were analyzed using chi square tests.

Location: Mixed prairie within a natural gas pipeline corridor roughly 225 miles east of Calgary (51°N, 112°W.), Alberta, Canada
Findings: Pipeline construction dramatically reduced vegetation cover. Native species plant density was higher under late season grazing compared to early season grazing. Grazing regime notably affected *Agropyron pectiniforme* and *Descurainia sophia*; both species were dominant with late season grazing but decreased with early season grazing. Other introduced species were less affected by grazing regime. Older ROW species composition (1957) did not differ significantly from the undisturbed control.
Implications: Grazing regime affects native plant species and should be considered when trying to reestablish vegetation following natural gas pipeline and other similar disturbances. Late season grazing is more favorable for native species, and rotating grazing seasons may be the most productive overall strategy.
Topics: Pipeline, Vegetation Recovery Data, Reclamation Practices, GrayLit

Naeth, M.A., Cohen Fernández, A.C., Mollard, F.P.O., Yao, L., Wilkinson, S.R., and Jiao, Z., 2018, Enriched topographic microsites for improved native grass and forb establishment in reclamation: Rangeland Ecology and Management, v. 71, no. 1, p. 12–18.

DOI: https://doi.org/10.1016/j.rama.2017.08.004
Background: Revegetation of disturbed grasslands is limited by many factors, including low seed germination and seedling reestablishment success. Topographic microsites, or unique biotic and abiotic conditions including cracks, depressions, ridges, plant litter, surrounding vegetation, and rocks, can assist germination and seedling establishment and increase revegetation success. Soil amendments can increase revegetation by retaining moisture, preventing erosion, or creating nutrient rich soil conditions. Reclamation could benefit from better understanding the relationships and interactions among various microsites and soil amendments, and their impacts on revegetation success on disturbed grassland ecosystems.
Objectives: The authors evaluated whether various topographic microsites with or without soil amendments could increase seed germination and seedling establishment on reclaimed grasslands.
Methods: Research sites were established at three historically disturbed grasslands: Mattheis Ranch on a grazed pivot irrigation site, Elk Island on a landfill, and Devonian Botanic Garden on an oil well site; reclamation history of each site varied. At all sites, existing vegetation was removed with herbicide and tillage and study sites were fenced in to prevent grazing. A complete randomized design was used cross topographic microsites (mound, pit, and flat control) with soil amendments (erosion control blankets, straw, hay, manure, hydrogel, and an untreated control) within 2 square meters (m^2) plots using five replicates (90 total plots at each site). A mix of seven native grasses and forbs was hand broadcast at a rate of 50 pure live seed per square meter (PLS/m^2) for each species. Soil volumetric water content and temperature were measured with 5TE sensors and EM50 data loggers. New emergents, live plants, and dead plants were counted for each seeded species throughout the field season. Canopy cover was visually assessed for each species at the end of the growing season. Data were analyzed with permutational three-way analysis of variance (ANOVA), student's t-tests, and two-way parametric ANOVA.
Location: Mattheis Ranch, Elk Island National Park, and Devonian Botanic Gardens (all reclaimed grasslands) in Alberta, Canada
Findings: There was no interaction between microsite and amendment on soil temperature or water content. Effects of microsite and amendment on seed germination were dependent on, and varied among, sites. Seedling survival was low (>60 percent for grasses, 75 percent for forbs) and consistently lowest on mounds. Plant cover was not significantly higher with any of the amendments relative to the control. Overall, amendment and microsite did not have an additive impact on revegetation.
Implications: Topographic microsite and soil amendment, both of which can benefit revegetation, worked independently of each other and were highly dependent on site. Land managers should assess site-specific conditions (for example, existing topographic microsites and soil characteristics) when considering soil amendment to aid in revegetation.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Reclamation Practices

Naeth, M.A., White, D.J., Chanasky, D.S., Macyk, T.M., Powter, D.B., and Thacker, D.J., 1991, Soil physical properties in reclamation: Prepared for Alberta Land Conservation and Reclamation Council (Reclamation Research Technical Advisory Committee), Report no. RRTAC 91-4, 226 p.

Link (non-DOI): https://era.library.ualberta.ca/items/7ca3da27-3531-47c0-9f7a-7fa9747ed4a6
Background: Surface coal mining, pipeline, and wellhead construction, and oil sands extraction are, and will continue, altering soil conditions in the province of Alberta, Canada. To design appropriate reclamation plans, a complete understanding of the impacts of these disturbances on soil properties is necessary. To develop the most accurate report for industry use, researchers in Alberta hosted a Soil Physical Properties Workshop in 1990. This workshop, followed by an in-depth literature review, guided research that identified and described soil physical properties and recommended measurement techniques for reclamation in Alberta.
Objectives: The authors provided current technical information to government and industry staff for use in preparation of reclamation approvals and development of guidelines and operating procedures.
Methods: The authors briefly reviewed soil properties and field methods. They described selected soil properties and highlighted interrelationships among them, including structural properties (texture, bulk density, porosity characteristics and size distribution, air permeability, aggregate characteristics and distribution, and consistence) and behavioral processes (soil water movement, infiltration, hydraulic conductivity and permeability, heat capacity, thermal conductivity and diffusivity, strength, and composite properties). They reviewed the effects of development and management practices on selected physical properties of soil and reviewed strategies for dealing with changes in soil properties. They included transcripts of workshop group discussions, questions, and notes. Future research was recommended.
Location: This is a review report and does not involve a specific field site location, but it does discuss research specific to Alberta, Canada
Findings: Understanding of soil physical properties and measurement techniques is limited. Measurement techniques have pros and cons and should be selected based on site-specific conditions and available resources. The degree to which soil properties are affected or changed depends on disturbance type and severity. Future reclamation should consider reestablishing not just soil chemical properties, but also physical, biological, and mineralogical properties, as they are integral to soil condition and behavior.
Implications: This report is a useful tool for land managers, especially in Alberta, seeking to better understand the functions and importance of soil properties and how reclamation can reestablish them post-disturbance.
Topics: Mining, Well Pad, Pipeline, Soil Data, Reclamation Practices, Reclamation Monitoring

Narten, P.F., Litner, S.F., Allingham, J.W., Foster, L., Larsen, D.M., and McWreath, III, H.C., 1983, Reclamation of mined lands in the western coal region: U.S. Geological Survey Circular 872, 56 p.

DOI: https://doi.org/10.3133/cir872
Background: Reclamation of coal mines is a major public concern that regulatory agencies and the mining industry have made a variety of attempts to address. Monitoring and assessing reclamation effectiveness are integral in determining which reclamation methods and attempts produce desired outcomes in the long run. In 1978, a group of scientists from multiple Federal agencies sampled 22 reclaimed coal mines across seven states in the western United States to determine revegetation outcomes, assess environmental impacts, and estimate future reclamation progress.
Objectives: The authors compared data across multiple reclaimed mines in the western United States to assess reclamation effectiveness and propose estimations of future reclamation success.
Methods: The authors reviewed the definition, goals, process, and history of reclamation, as well as a brief history of mining, in the western United States. Historical and environmental data were compiled from 22 mines including: mining and reclamation initiation dates, pre- and post-mine land use, climatic factors (growing season, temperature, and precipitation), topography and elevation, and pre- and post-mine growing medium, vegetation, species diversity, and productivity. Regional characteristics (that is, landform, climate, geology, soils, and vegetation) were summarized, as well as site-specific characteristics (that is, weather, soil moisture, drought, landform, overburden, toxic substances, soils, topsoiling, biological factors, vegetation, and operational differences) that affect reclamation were summarized. The authors proposed estimates of reclamation effectiveness over time.
Location: Data compiled from 22 reclaimed coal mines in 17 locations across North Dakota, Montana, Wyoming, Colorado, Utah, Arizona, and New Mexico, USA

Findings: While overall long-term reclamation success was too complex to predict with specificity, general guidelines can exist for determining potential reclamation success based on environmental characteristics. Comparing across sites, those with higher moisture availability and stabilized land surfaces experienced a slow species-diverse natural recolonization pattern and are predicted to meet or exceed pre-mine productivity. While no sites reached optimal revegetation, all sites were in intermediate successional stages. Continued disturbances by humans, vehicles, and livestock slowed revegetation, and drier sites were much more sensitive to these and any other environmental factors which slowed revegetation.
Implications: This report is a useful reference for land managers and agencies implementing reclamation in the western United States but should be compared to more current reports that may include reclamation technological and methodological advances.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Nauman, T.W., Duniway, M.C., Villarreal, M.L., and Poitras, T.B., 2017, Disturbance automated reference toolset (DART)—Assessing patterns of ecological recovery from energy development on the Colorado Plateau: Science of the Total Environment, v. 584–585, p. 476–488.

DOI: https://doi.org/10.1016/j.scitotenv.2017.01.034
Background: Assessing ecological recovery of restored oil and gas wells requires an appropriate reference site to approximate what the well pad would look like if it had not been developed. Well pad recovery over time can be assessed by comparing it to adequate reference sites. Using remote sensing to target impacted and reference areas on the Colorado Plateau provides a tractable approach to assess recovery.
Objectives: This study aimed to develop and apply DART (Disturbance Automated Reference Toolset) to assess ecosystem recovery after oil and gas well-pad development. Specifically, the authors propose a method to monitor spatial and temporal patterns of ecosystem recovery in an automated fashion using remote sensing and soil-geomorphic ecological mapping.
Methods: Well pad recovery was assessed using remotely sensed indicators of dryland ecosystem function including bare soil and perennial vegetation cover. DART was used to identify reference sites based on soil and geomorphic conditions near disturbed sites. Once reference sites were identified, the Soil Adjusted Total Vegetation Index (SATVI) was used to compare disturbed and undisturbed sites. DART was again used to compare reference to disturbed sites to determine degree of recovery. DART results were validated by comparing remotely sensed data with field data.
Location: Colorado Plateau, including areas in Utah, Colorado, Arizona, and New Mexico, USA
Findings: Half of the well pads had poor recovery with New Mexico sites recovering more slowly than Utah. Values from DART for bare ground and foliar cover were correlated with field data. DART captured a moderate amount of variation in bare ground cover (26–55 percent) and foliar cover (26–41 percent) between disturbed well pads and undisturbed reference sites. Lower recovery areas were identified in grasslands, shrublands, arid canyon complexes, warmer areas with more summer precipitation, and state administered areas.
Implications: DART is a useful tool for identifying appropriate reference sites to gauge oil and gas well pad recovery. DART can identify differences in recovery based on ecological and climate differences at a regional scale. Use of DART can enable land managers to appropriately direct resources to low recovery sites following reclamation. The accuracy of DART to detect recovery patterns may be skewed by invasive species, rehabilitation practices, land use differences during disturbance, and other biophysical variables. Other remote sensing indices may perform better in wetter and greener environments than Soil Adjusted Total Vegetation Index.
Topics: Well Pad, Vegetation Recovery Data, Reclamation Monitoring, Reclamation Standards

Nelson, C.W., Unc, A., Lombard, K., Lucero, M., and Perkins, S., 2014, Impact of seed exposure to plant material on plant growth and development on remediated arid lands: Journal of the American Society of Mining and Reclamation, v. 3, no. 1, p. 41–69.

DOI: https://doi.org/10.21000/JASMR14010041
Background: Surface mining remediation often involves overlaying disturbed areas with topsoil that was either previously collected from the site and stored, or freshly collected from a nearby area. Both topsoil types are expected to contain plant and microbial residuals that aid in reestablishing plant communities. In the arid western United States, overlay topsoil is often depleted of microbial residues, thereby requiring the addition of these residues. Understanding the role of plant-microbial interactions in seed germination is important for ensuring successful remediation efforts.

Objectives: The authors aimed to (1) identify the impacts of various topsoil amendments on germination rates between plant species and the importance of pre-planting seed disinfection, and (2) examine the impacts of seed treatment and exposure to plant material on seed development in a controlled environment.
Methods: One of two germination treatments were applied to 800 seeds, using 400 seeds for each treatment: (1) a positive control following U.S. Department of Agriculture protocols and (2) dehulling and disinfecting the naked caryopsis in Zerotol. Native plant material was collected from undisturbed reference sites and ground to a mulch-like consistency. Soil and spoil were collected from stockpiles at the mine site. Deoxyribonucleic acid (DNA) extraction kits were used to assess the fungal and bacterial components in the native plant material, soil, and spoil. Seeds were germinated in soil and spoil following one of three treatments: untreated seeds serving as a control (Treatment A), disinfected seeds (Treatment B), or disinfected seeds with an added 1 gram (g) of native plant material mix (Treatment C). Dates of germination were recorded for each individual plant and heights of the seedlings were recorded three times per week. Results were analyzed separately for each plant species using analysis of variance (ANOVA) and Tukey's honest significant difference.
Location: Plants for the native plant material mix were collected from undisturbed reference sites at the Navajo Coal Company's Navajo Mine surface coalmine near Fruitland, New Mexico. Spoil and soil were collected from stockpiles at the Navajo Mine. Seeds were disinfected at the New Mexico Department of Agriculture Seed Lab and germinated in a greenhouse.
Findings: Germination response to treatment differed significantly among species. For instance, dehulling and disinfection decreased germination for three species (*Krascheninnikovia lanata, Bouteloua gracilis*, and *Atriplex canescens*), increased germination for two species (*Sarcobatus vermiculatus* and *Pleuraphis jamesii*) and had no effect on four species (*Sporobolus airoides, Sphaeralcea munroa, Achnatherum hymenoides*, and *Atriplex confertifolia*). Only *S. airoides, B. gracilis*, and *P. jamesii* germinated consistently across treatments and these were used for final data analysis. The interactive effect of soil x disinfection treatments on multiple plant growth parameters varied widely among the three species. DNA analysis of the microorganisms present in untreated seeds, treated seeds exposed or not exposed to native plant material mix, and native plant material mix showed wide differentiation among groups.
Implications: Seed disinfection and supplemental native plant material mix impact seed germination and plant growth; however effects are species-specific and variable. A field planting following this same experimental design would provide a better understanding of the effectiveness of disinfection and supplemental material in surface mining reclamation efforts.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Neuman, D.R., Blicker, P.S., Goering, J.D., and Pigors, R., 2006, Assessment of effects of amendments on vegetation performance at a bentonite minesite after 25 years, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and American Society of Mining and Reclamation, p. 592–608.

DOI: https://dx.doi.org/10.21000/JASMR06010592
Background: Revegetation of bentonite mines in the semi-arid climate of the Northern Great Plains is complicated by the saline and sodic properties of bentonite clays in mine spoils and the unavailability of cover soil. Amending soils or adding cover soil over spoils are the general methods for reclamation. Experiments with soil amendments and fertilizer application on reclaimed bentonite mines in South Dakota initiated in the 1980s provide an opportunity to assess treatment success 25 years later.
Objectives: The authors determined which of 15 reclamation treatments implemented 25 years prior resulted in the "best" vegetation and compared vegetation characteristics and soil properties to previous research conducted eight years after reclamation.
Methods: An original set of 135 experimentation plots were revisited for this study; they represented 15 total treatments which tested a variety of fertilizer types and application rates that were replicated three times. Treatments 1–12 were applied in 1980, treatments 13–15 were applied in 1986. In spring 2005, the vegetation establishment in all plots was qualitatively scored as good, fair/good, fair, poor/fair, or poor. All plots receiving the highest ratings were identified and used for further evaluation of vegetation and soil attributes. Within these plots, the authors determined canopy cover by life form (perennial grass, annual grass, and perennial forb) using the Daubenmire cover class method within ten 20 × 50-centimeter (cm) frames and harvested vegetation in 25 square centimeter (cm^2) frames placed in the same location. They attempted to identify all plants growing in plots to the species level. The authors sampled soil from one plot within each treatment at 0–5, 5–10, 10–20, 20–38, 38–76, and 76–152 cm depths and analyzed the samples for pH, electrical conductivity (EC), sodium absorption ratio (SAR), and soluble calcium (Ca), magnesium (Mg), and sodium (Na) concentrations. Rooting patterns of existing vegetation were described while collecting soil samples.
Location: Reclaimed bentonite mine near Belle Fourche, South Dakota, USA

Findings: There was no apparent effect of initial fertilization (at any rate) on vegetation establishment in 2005 (25 or 19 years after experiment initialization) for any of the 15 treatments. The authors identified three treatments receiving the highest cumulative qualitative vegetation establishment ratings: (1) manure at 112 milligrams per hectare (mg/ha) +sulfuric acid at 20 mg/ha, (2) gypsum at 6.7 mg/ha +calcium dichloride at 17.2 mg/ha, and (3) magnesium chloride brine+1.2 mg/ha. Average total canopy cover was not significantly different among treatments, but plant community composition was, in that perennial grasses dominated plots treated with brine, and perennial forbs (especially *Kochia prostrata*), dominated the gypsum and manure treated plots. Overall, only three to seven of the 18 species seeded into the plots were present 25 years later; many species present had immigrated in. Aboveground biomass differed significantly among treatments and was greatest on the gypsum/calcium dichloride plots. In soil trenches, the authors observed that rooting depth was similar for the manure and gypsum treatments, and greater for the brine treatment (56 cm); non-decomposed manure was also noted in plots where it was added. In 2005, SAR, EC and ion (Ca, Mg, Na) concentrations were markedly reduced in plots treated with manure, were not changed in the plots treated with brine after they were last measured 16 years prior (1989), and SAR was slightly reduced in the gypsum treatment compared to initial values.
Implications: Using soil amendments for reclamation of bentonite mines can result in higher revegetation, depending on the amendment composition. Persistent, non-decomposed manure may indicate reduced nutrient cycling in that treatment, making its success questionable.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Niemann, K.O., 2018, The use of unmanned aerial vehicles (UAV's) to monitor industrial sites and reclamation—Example of oil and gas well sites: Victoria, British Columbia, University of Victoria, Department of Geography, 29 p.

Link (non-DOI): https://www.bcogris.ca/projects/assessing-the-potential-of-uas-based-drones-and-multisensor-data-in-monitoring-the-reclamation-of-well-sites/
Background: Unmanned Aerial Vehicles (UAVs) are a relatively new technology available to the energy industry for monitoring site operations. This miniaturization of imagery-capturing technology allows for high quality data collection and processing that can aid in developing better informed and site-specific reclamation planning. Various UAV platforms exist, and it is important to determine the most appropriate one for a given project based on objectives, type of data being collected, budget and time constraints, and permitting restrictions.
Objectives: The author used UAV technology and multiple sensors to collect, process, and produce high resolution data imagery of gas well sites in British Columbia.
Methods: The author reviewed various UAV platforms, sensor payloads (type of data collected) camera types, and processing software. They briefly outlined Canada's regulatory environment and UAV permitting restrictions. They detailed the Fort St. John Project methods, in which five gas well sites in various states of deconstruction and reclamation were selected and on which imagery data were collected September 11–15, 2017, with a DJI Matrice 600 Pro hexacopter with a 12-megapixel red, green, blue imagery (RGB) camera, Headwall Nano Hyperspectal Imaging Sensors (IS), and Velodyne VLP 16 lidar system for collecting multiple sensory data types. Due to weather conditions, the full suite of sensory data was not collected at all five sites. For the data collected, point clouds were classified, standard class designations were assigned, and ground was differentiated from vegetation to extract the digital elevation model. Lidar, digital elevation model, RGB, normalized difference vegetation index (NDVI), and orthophoto images were developed and compared across sites and sensory types.
Location: Gas wells north of Fort St. John in northern British Columbia, Canada
Findings: Due to permitting regulations, data collection occurred too late in the season and weather conditions (high winds and rain) restricted full sensory data suite collection at all sites. As a result, imagery outputs varied by site. Long shadows produced by low sun angles also complicated data collection and quality. IS senescence data could not be collected due to the later than expected data collection dates. Despite regulatory and weather setbacks, high-resolution landscape level imagery was collected that provided detailed information on well site conditions.
Implications: While UAV is a useful technology available for widespread public use, knowledgeable and skilled operators are essential for quality data collection. Canada's strict permitting regulations limit using UAV technology to its full capacity at this time. However, preparing for permitting and weather setbacks may alleviate these issues and lead to high quality imagery data collection for better informed reclamation planning.
Topics: Well Pad, Vegetation Recovery Data, Reclamation Monitoring, GrayLit

Nolan, N.E., Kulmatiski, A., Beard, K.H., and Norton, J.M., 2015, Activated carbon decreases invasive plant growth by mediating plant-microbe interactions: AoB Plants, special issue, Published by Oxford University Press for Annals of Botany Company, v. 7, 12 p.

DOI: https://doi.org/10.1093/aobpla/plu072
Background: There are several reasons nonnative, weedy plants can dominate on disturbed soils. Disturbed soils tend to have high resource (water, nitrogen [N]) availability, low soil density, and different communities of soil organisms. It may be necessary to manipulate these soil conditions to increase native plant growth and decrease nonnative weedy plant growth in disturbed soils, such as those used for energy development. Sugar and sawdust have been used to increase native plant growth by decreasing soil N availability. Soil compaction has been used to slow the growth of weedy plants. In this paper, activated carbon (AC) was used to change plant-microbe interactions in a way that increases native plant growth and decreases nonnative, weedy plant growth. AC binds the organic molecules that are used by plants, bacteria, and fungi to recognize and affect each other. AC has been used successfully in small plots and here it was tested in larger, 15 × 15-meter (m) plots.
Objectives: The authors (1) tested how effective AC is at reestablishing native plant communities on a large scale, (2) determined the minimum amount of AC need to achieve this, and (3) determined if AC works by stopping allelopathy or by changing plant-microbe communication.
Methods: In a semi-arid, shrub-steppe habitat, seven 15 square meter (m^2) plots were established in each of nine abandoned-agricultural fields that were dominated by nonnative, weedy plants. Using a completely randomized design, seven treatments were applied to the plots: five concentrations of coal-based AC (0, 100, 400, 700, and 1,000 grams per square meter [g/m^2]), one wood-based AC (1,000 g/m^2), and a complete control with no disturbance or AC. AC (300 mesh fine-powder) was applied with a push seed spreader and mixed into the top 15 centimeters (cm) of soil with two passes of a disc-harrow. A native seed mix was broadcast using a hand seed spreader at 5.6 g/m^2. The point-intercept method was used to assess vegetation response to AC treatments. Soil cores were extracted at random points within the plots receiving 0 g/m^2 AC, 1000 g/m^2 AC, and complete control plots. A buried bag technique was used to assess N cycling rates on the 0 g/m^2 AC, 100 g/m^2 AC, 1,000 g/m^2 AC, and complete control plots. A greenhouse experiment was conducted to determine the mechanism by which AC functioned by planting one native and one nonnative plant species together in pots with either live soil with AC, sterile soil with AC, or a control live soil. Data were analyzed by repeated-measures, subsamples, and three-way factorial analysis of variance (ANOVA).
Location: Methow Valley (48°37′ N., 107°10′ W.), Washington, USA, and a greenhouse
Findings: AC decreased nonnative plant growth and increased native species plant growth, especially at concentrations of >400 g/m^2. In the greenhouse experiment, AC appeared microbially mediated. Wood-based AC had more variable results across years than coal-based.
Implications: Mixing coal- or wood-based AC into shallow soils is a costly reclamation method but, even at minimum levels of 400 g/m^2, it can help reduce plant-microbe interactions that benefit nonnative species and reestablish native species on disturbed lands. AC does not provide resources to heterotrophic organisms and is not expected to slow nutrient cycling rates as reduced organic compounds (sugar and sawdust) would; rather, AC is likely to negatively affect growth of invasive species by binding the organic molecules that allow communication among soil organisms involved in positive plant-microbe interactions. AC may be available for free from water treatment facilities.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Ogle, P.R., and Redente, E.F., 1988, Plant succession on surface mined lands in the west: Rangelands, v. 10, no. 1, p. 37–42.

Link (non-DOI): http://hdl.handle.net/10150/640271
Background: Plant succession on surface mines does not follow a natural progression and can take decades to establish a sustainable community. Reclamation can assist in a more natural succession through a number of methods, though immediate reestablishment of plant communities is not possible. Reestablishing self-sustaining native vegetation communities is necessary for meeting the requirements of the Surface Mining Control and Reclamation Act.
Objectives: The authors' objective was to review reclamation methods for reestablishing plant succession on reclaimed surface mines.
Methods: The authors briefly discussed the natural succession process on mine spoils. They reviewed the roles of organisms (soil biota, plants, and animals), soil origin, and topography in reclamation. They reviewed reclamation techniques including grading, topsoil replacement, species selection, mulching, planting methods, and irrigation. They briefly discussed post-reclamation management practices.

Location: This is a review paper and does not involve a specific field site location
Findings: Regardless of reclamation methods, vegetation reestablishment goals depend on and differ by the designated post-mine land use. Long-term monitoring and management are necessary for ensuring plant succession leads to the desired community diversity.
Implications: This review is a helpful resource of basic reclamation practices often used to reestablish plant succession. Land managers can apply these methods based on site-specific conditions and revegetation goals.
Topics: Mining, Reclamation Theory, Reclamation Practices

Ohsowski, B.M., Dunfield, K., Klironomos, J.N, and Hart, M.M., 2018, Plant response to biochar, compost, and mycorrhizal fungal amendments in post-mine sandpits: Restoration Ecology, v. 26, no. 1, p. 63–72.

DOI: https://doi.org/10.1111/rec.12528
Background: Aggregate mining is a worldwide industry causing large-scale environmental disturbances. In Canada, sand plain prairie ecosystems are diminishing due to sand excavation, which negatively impacts soil microbial activity and plant community health. Restoring natural and functioning soil is paramount to conserving sand plain prairies, and will likely require a soil amendment, such as compost or biochar, as well as microbial inoculant, like arbuscular mycorrhizal fungi (AMF). Determining the appropriate amount and (or) combination of each amendment is important for restoration success.
Objectives: The authors assessed the effects of compost, biochar, and AMF inoculum (alone and combined) on grassland plant species growth in post-mine sandpits.
Methods: Two long-term field trials were conducted, one using plant plugs and one using seeding. For both, eight grassland plant species were examined. For the plant plug trial, plants were grown in a greenhouse and inoculated with 20 arbuscular mycorrhizal fungi (AMF) *Rhizophagus irregularis* spores at the time of seed sowing. Ten non-inoculated and ten inoculated plugs were randomly selected from each species to assess root colonization. In May 2010, 10.2 square meter (m^2) plots were established to use in a fully factorial randomized design which crossed plugs (inoculated or not) with three factors: (1) biochar (no amendment, 5 tonnes per hectare [t/ha] biochar, 10 t/ha biochar), (2) compost (no amendment, 20 t/ha compost), and (3) AMF inoculation (with or without), with ten replications of each unique combination (120 total plots). Seventy-two plugs were planted per plot; control plots received no amendment and non-inoculated plant plugs. Measurements included AMF quantification, soil nutrient measurements, and estimation of plant biomass. For the seed application trial, the same plot amendment protocol was followed; factor levels for biochar and compost were replicated once (72 total plots). AMF was applied through a liquid medium (1,000 spores/m^2) following seeding, raking and compaction. Plant cover was estimated using photos in the software SamplePoint. Data were analyzed with linear mixed effect models in R.
Location: Recently active sand extraction site (0.5 ha; 42°40′17″ N., 80°28′45″ W.; elevation 211 meters [m]) near Port Rowan, Ontario, Canada
Findings: Inoculated greenhouse plugs and field roots had higher levels of AMF root colonization compared to non-inoculated plugs and field roots. In the plant plug trial, compost and compost+biochar amendments significantly increased plant biomass, but AMF inoculation had no significant effect; biomass also differed among species. In the seed application trial, compost significantly increased plant cover but biochar and AMF had no significant effect. The highest plant cover occurred with AMF inoculation combined with high compost application.
Implications: Co-amendment of compost and biochar (20 t/ha +10 t/ha) was more effective at increasing plant biomass, and AMF field inoculation combined with compost (20 t/ha or 40 t/ha) increased plant cover. These amendments and microbial inoculant are effective and practical restoration methods for increasing grassland plant growth following sandpit excavation mining.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Padró, J.-C., Carabassa, V., Balagué, J., Brotons, L., Alcañiz, J.M., and Pons, X., 2019, Monitoring opencast mine restorations using Unmanned Aerial System (UAS) imagery: Science of the Total Environment, v. 657, p. 1602–1614.

DOI: https://doi.org/10.1016/j.scitotenv.2018.12.156
Background: Remoting sensing technology is an option for characterizing environmental conditions, mapping, and monitoring opencast mine restoration. Depending on the desired resolution quality, a variety of sensors mounted to Unmanned Aerial Systems (UAS) can be employed. Though permits regarding UAS may vary by country, typically there are few regulations in

non-urban environments, such as reclaimed mines. Current UAS remote sensing technology has a geometric theoretical basis using Global Navigation Satellite Systems to georeference images, and a radiometric theoretical basis using the visible and near infrared regions, both with their own drawbacks.
Objectives: The authors evaluated a new UAS tool and assessed how UAS imagery could provide quantitative spatial data to monitor mine restoration progress.
Methods: A Parrot Sequoia optical sensor with four spectral bands mounted on a small drone was used to capture aerial imagery of the 64,386 square meter (m^2) study area with a spatial resolution of 9 centimeters (cm). In situ ground-truth reflectance was measured with a portable field spectroradiometer. Imagery was oriented using Agisoft PhotoScan v.1.4.1 photometric software and imagery was radiometrically corrected using MiraMon Remote Sensing and Geographic Information System (RS&GIS) software. Land cover was categorized as mine wastes, topsoil, tree cover, shrublands, grasslands, or remaining shadows using k-nearest neighbor classification algorithm.
Location: Active calcareous sandstone quarry in central Catalonia (latitude 41°41′35″ N., longitude 1°49′43″ E.), Spain
Findings: Radiometric correction and ground-truth radiometric measurements had an R^2>0.9, though bias of up to 7 percent did need correction. Automatic land cover categorization was 94 percent accurate.
Implications: UAS technology is a cost-effective and time-efficient way to monitor mine restoration progress with detail and resolution as fine as 9 cm. Land managers, reclamation researchers, and mining and consulting companies could benefit from the use of UAS technology for restoration monitoring and assessing.
Topics: Mining, Vegetation Recovery Data, Reclamation Monitoring

Palliggiano, D., Baizhigitova, A., Pavanel, E., Marconi, M., Howard, P., Reed, T., Sali, J., and Pedroni, P.M., 2012, Addressing and managing reliance and potential impacts on biodiversity and ecosystem services of oil and gas global operations, *in* International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Perth, Australia, September 11–13, 2012, Proceedings: Society of Petroleum Engineers, 11 p.

DOI: https://doi.org/10.2118/155445-MS
Background: Biodiversity is an important consideration when reclaiming lands disturbed by oil and gas development. A company involved in hydrocarbon (oil and gas) exploration and production, "eni," has operations worldwide at both onshore and offshore locations and is committed to conserving biodiversity and ecosystem function in all site operations through science-based site-specific assessments. Fauna and Flora International (FFI) partners with eni to develop company best practices based on applied ecology and for implementation across the globe.
Objectives: The authors outlined eni's approach to managing the company's operations while maintaining biodiversity and ecosystem services (BES).
Methods: In 2003, BES best practices were developed with FFI to manage on and offshore operations. The practices were piloted in Italy, Ecuador, and Norway, which lead to development of targeted Biodiversity Action Plans and updated Environmental Social and Health Impact Assessment standards. In 2010, the partnership began focusing on implementing BES practices at operations worldwide.
Location: Hydrocarbon onshore and offshore operations in Agri River Valley, Italy; Amazon Rainforest, Ecuador; Barents Sea, Norway; north slope tundra, Alaska, USA; tropical forest and coast habitats, Congo; and arid habitat, Pakistan
Findings: For successful implementation, BES best practices require: (1) use of the Mitigation Hierarchy to frame operational effects on both BES and efficient management, (2) an ecological focus, (3) landscape and site-specific BES surveys, (4) continuous improvement, (5) solid partnerships between oil and gas companies and conservation non-governmental organizations (NGOs), and (6) transparent dialogue with stakeholders.
Implications: Oil and gas development alters the landscape and can impact biodiversity and ecosystem services during both the operation and reclamation phases. Best practices, developed in partnership with environmental groups, can lessen the impact of development on the environment and lead to more successful reclamation efforts.
Topics: Well Pad, Reclamation Standards, Decision Support Tools, GrayLit

Parker, L.W., Elkins, N.Z., Aldon, E.F., and Whitford, W.G., 1987, Decomposition and soil biota after reclamation of coal mine spoils in an arid region: Biology and Fertility of Soils, v. 4, p. 129–135.

DOI: https://doi.org/10.1007/bf00256986
Background: Natural succession on strip mined land in arid and semiarid regions is slow and requires reclamation intervention, which focuses on plant communities. However, revegetation is dependent on nutrient-rich soil. A robust soil microflora community is essential for functioning soil, and the recovery of these organisms following mining in semiarid and arid environments could serve as an index of soil development and reclamation assessment.
Objectives: The authors assessed the development of soil biota on mine spoils of various ages and one unmined site.
Methods: Four mine sites reclaimed between 1976 and 1979, plus one unmined site, were selected for the study; all were dominated by pinyon-juniper woodlands and big sagebrush. During reclamation of the study sites, spoil was backfilled, landscaped, contoured, and covered with approximately 15 centimeters (cm) of topsoil. The site was then fertilized, disked, drill seeded with an introduced seed mix containing nonnative species, broadcast seeded with a native seed mix, and mulched with 2.2 megagrams per hectare (Mg/ha) barley straw. Researchers collected five replicate spoil samples (4.5 × 10 cm deep) at each site and enumerated bacteria and denitrifiers and measured fungal lengths. At each site, 13, 20 square centimeter (cm^2) bags containing 10 grams (g) each of fresh barley straw were buried at a 5 cm depth and removed 37, 85, and 127 days after burial. Bags were used for nematode extraction, nitrogen (N) analyses, microbial estimates, microarthropod extraction, and mass loss. Plant standing crop was estimated at the end of the growing season. Data were analyzed using analysis of variance (ANOVA).
Location: McKinley Coal Mine (elevation 2,073 meters [m]) near Gallup, New Mexico, USA
Findings: Denitrifiers were highest in the 1- and 2-year sites; the latter did differ significantly from the unmined site. Nitrifying bacteria were higher on all reclaimed sites compared to the unmined site. Total soil bacteria were highest, and not significantly different, on the 1-year and unmined sites. Decomposition rates were highest on the unmined site. Population densities of bacteria, fungi, and protozoans were similar on the 4-year and unmined sites but higher on the 1-year site. Microarthropod taxa and densities in the barley straw bags were higher on the unmined compared to reclaimed sites and higher than in the soil samples. Standing crop values were highest on the 4-year site.
Implications: Soil microfauna and vegetation on reclaimed arid and semiarid lands likely recover at different rates. Straw mulch may promote microflora reestablishment initially, but over time could decrease bacterial numbers. Soil microbial community monitoring can be used as an assessment of reclamation success and soil function.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Parmenter, R.R., and MacMahon, J.A., 1987, Early successional patterns of arthropod recolonization on reclaimed strip mines in southwestern Wyoming—The ground-dwelling beetle fauna (Coleoptera): Environmental Entomology, v. 16, no. 1, p. 168–177.

DOI: https://doi.org/10.1093/ee/16.1.168
Background: Mine reclamation is often focused on reestablishing vegetation communities; few studies have explored the impacts of reclamation on wildlife, and even fewer have explored the impacts to arthropods. Arthropods can greatly influence soil characteristics, which in turn affect vegetation, so understanding how arthropod communities respond to reclamation over time is important for ensuring long-term ecosystem recovery.
Objectives: The authors examined the successional patterns of, and vegetation characteristics associated with, ground-dwelling beetles on different aged, reclaimed surface coal mines and compared beetle trophic structure on reclaimed land with that on undisturbed land.
Methods: Seven sites were selected that had been revegetated at 1-year intervals beginning in 1977. The 1977–1979 sites did not receive topsoil; the 1980–1983 sites did. All sites were drill seeded with a native seed mix and received limited fertilizer and irrigation. In 1983, a 120-meter (m) transect was established on each site and vegetation was measured within a 0.5 square meters (m^2) metal frame placed at 25 randomly selected sample points along the transect. Pitfall traps (25 on each site) were used to sample ground-dwelling beetles. Traps were set up and left continuously open from June to November 1983 and collected from at 4- to 6-week intervals. Beetle specimens were preserved in 70 percent propanol and identified to species. Beetle species richness, diversity, species dominance curves, and trophic groups (based on diet) were assessed by site. Data were analyzed using a hierarchical cluster analysis and nonlinear regressions.

Location: Seven reclaimed sites on the Kemmerer Mine near Kemmerer (41°43′0″ N., 110°37′0″ W.) in southwestern Wyoming, USA
Findings: Most sites were dominated by only a few beetle species. Beetle assemblages differed between reclaimed sites and the undisturbed site, driven mostly by differences in trophic groups; reclaimed sites had more fungivores and insect-carrion feeders and fewer herbivores, predators, and dung feeders than the undisturbed site. These differences may have been due to mining disturbance severity and its impact on soil organic resources. On reclaimed sites, beetle assemblages differed between sites with and without topsoil application. On sites with topsoil beetle diversity increased with time since reclamation while the opposite trend occurred on sites without topsoil; these patterns are possibly due to changes in plant communities over time. When looking at herbivorous beetle species only, there was a significant positive relationship between plant and beetle species richness.
Implications: Reclamation efforts are unlikely to reestablish pre-mining beetle communities so comparing the two may not be an adequate measure of reclamation success. Long-term studies would help elucidate changes in beetle assemblages over time and provide a clearer understanding of the impact of reclamation on arthropod communities.
Topics: Mining, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Practices

Parmenter, R.R., MacMahon, J.A., Waaland, M.E., Stuebe, M.M., Landres, P., and Crisafulli, C.M., 1985, Reclamation of surface coal mines in western Wyoming for wildlife habitat—A preliminary analysis: Reclamation and Revegetation Research, v. 4, no. 2, p. 93–115.

Link (non-DOI): https://www.osti.gov/etdeweb/biblio/5965985
Background: Since the Surface Mining Control and Reclamation Act, research on succession and rehabilitation of mined land in environments with moderate to well-balanced moisture has increased, leading to reclamation practices focused on reestablishing native vegetation (assuming animal reestablishment will follow). These practices are based on basic energy exchange in ecosystems (that is, plants provide food for herbivores, herbivores provide food for carnivores). However, energy exchange in semi-arid and arid ecosystems has multiple paths and reclamation methods likely should be based on the study of both plant and animal communities.
Objectives: The authors established a long-term research project to discover ways of accelerating plant and animal succession on disturbed lands in semi-arid and arid ecosystems by examining the early succession trends in plant and vertebrate communities.
Methods: Study sites were selected on seven surface coal mines which were reclaimed in 1-year intervals since 1977. In August 1983, 120 meter (m) transect lines were established in plots at each site, with 25 sample points along each line. A 0.5 square meter (m^2) sampling frame was places at each point and used for visually estimating percent cover of each species and ground litter. During late spring and early summer, live traps and mark-recapture methods were used to record rodent species richness. On control plots, a grid system of 225 Sherman live-traps baited with food were set out for four days and checked every morning. On experimental plots, a “web” trapping design consisting of 12 traps at 6 m intervals was set out for three days and checked every morning. Species, sex, age, parasite presences and reproductive condition were recorded on all rodents captured. Shrew and invertebrate presence were monitored using 25 pit-fall traps at each site, which were checked monthly from June to November. Direct observations of scat, tracks, and burrows were used to quantify other mammals such as lagomorphs, carnivores, and ungulates. Bird species presence, behavior, and nest presence were surveyed during breeding season. Pit-fall traps and summer surveys were used to record reptile and amphibian presence. Vertebrate species were categorized as “resident” (home ranges in a single mine plot) or “non-resident” (occasionally used plots as foraging areas but not restricted to the area).
Location: Pittsburg and Midway coal mines 8 kilometers (km) southwest of Kemmerer, Wyoming, USA
Findings: Eight species of shrubs, 30 forbs, and 15 grass species were recorded. Control plots had more species compared to experimental plots. Forbs (mainly pioneer species) dominated percent cover the first three years post-seeding, after which grass cover became dominant. Plant diversity increased in the first year and later stabilized due to increased dominance of a few grass species. Twenty-four mammal species, 35 bird species, three reptile species, and three amphibian species were recorded. Again, control plots had more species than experimental plots. Several rodent species common on control plots were never recorded on reclaimed plots, likely due to the lack of developed shrubs on the latter. Reclaimed plots saw 63 percent fewer number of bird species than controlled plots. Overall, there was no significant relationship between plant and animal species.
Implications: Restoring a semi-arid shrub steppe post-mining requires an extended timeframe. The role of animal species in reclamation requires more research and documentation. Future reclamation legislation should address high walls and permanent ponds on reclaimed sites as habitat and include animal presence and densities in reclamation assessments.
Topics: Mining, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Practices

Partlow, K.A., Schuman, G.E., Olson, R.A., and Belden, S.E., 2004, Effects of wildlife utilization on Wyoming big sagebrush growth and survival on reclaimed mine lands, *in* Barnhisel, R.I., ed., 21st Annual Meetings of the American Society of Mining and Reclamation, and 25th West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, W. Va., April 18–24, 2004, Proceedings: American Society Mining and Reclamation, p. 1434–1437.

DOI: https://doi.org/10.21000/JASMR04011434
Background: Wyoming state law requires that Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) be reestablished on surface coal-mined lands if the species was a component of the pre-mining plant community, and the post-mine land use designation includes wildlife habitat. Despite previous research, reestablishment of sagebrush is complicated, possibly due to excessive wildlife utilization and seed quality. Understanding how wildlife impact sagebrush on reclaimed land is crucial for reestablishment of this vital species.
Objectives: The authors quantified the effect of wildlife on Wyoming big sagebrush growth and survival on reclaimed mine lands.
Methods: A portion of previously reclaimed mine land that had undergone a Wyoming big sagebrush establishment study initiated in 1990 was the location for the current study. A 90 × 30 × 3.1-meter (m) wildlife enclosure of woven wire mesh was erected and extended horizontally to exclude small rodents. In July 2001, the exclosure was placed around half of each of the original treatment plots. Plants were assessed in June and September 2001, and April and September 2002. Sagebrush density was assessed along previously established 1 square meter (m^2) quadrats and 24 m^2 belt transects. Twenty-seven plants within and outside of each sampling plot were measured to assess cumulative growth, survival, and wildlife utilization.
Location: North Antelope Coal Mine near Gillette in northeastern Wyoming, USA
Findings: Wyoming big sagebrush density was significantly higher inside the enclosure in 2002 (but did not differ in 2001). Twenty-four marked plants died outside the exclosure due to wildlife utilization compared to only eight plants within the exclosure. All plants outside the exclosure were browsed. Sagebrush inside the exclosure had longer mean leader length (38–48 millimeters [mm]) compared to outside the exclosure (16–18 mm). The original study grass treatments had little effect from 2001–2002 but plots with higher grass seeding rates had higher sagebrush survival and lower winter wildlife utilization from 1991–2002.
Implications: Excessive wildlife utilization, primarily by rabbits, was documented and negatively impacted Wyoming big sagebrush growth and survival on a reclaimed surface coal mine. This research supports previous claims and is highly useful for land managers in Wyoming. Exclosure fencing, erected to exclude small rodents as well as larger mammals, is crucial for successful sagebrush reestablishment in such areas.
Topics: Mining, Vegetation Recovery Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Paschke, M.W., DeLeo, C., and Redente, E.F., 2000, Revegetation of roadcut slopes in Mesa Verde National Park, U.S.A.: Restoration Ecology, v. 8, no. 3, p. 276–282.

DOI: https://doi.org/10.1046/j.1526-100x.2000.80039.x
Background: Road construction, for energy development or other purposes, disturbs vegetation, especially along steep roadside slopes. In Mesa Verde National Park, revegetation of roadcut slopes was necessary for both aesthetic and bank stability purposes. However, the underlying rock formations in the park complicated revegetation efforts and required multiple methods for ensuring revegetation success.
Objectives: The authors evaluated the effectiveness of using plant species indigenous to Mesa Verde and common techniques to revegetate steep roadcut slopes.
Methods: Test plots were established in three roadcut sites along the park entrance. Test plots were arranged in a randomized complete block design with three replicates of six treatments. Treatments included five cultural methods: (1) Biosol organic fertilizer, (2) excelsior mulch erosion control made of aspen shavings in plastic netting, (3) a combination of Biosol and excelsior mulch, (4) polyacrylamide (PAM) polymer water-absorbing compound, and (5) soil pitting, plus a no-treatment control. All plots were hand broadcast with a seed mix of indigenous grasses, forbs, and shrub seeds collected from the Park, and

planted using containerized transplants of native grasses, forbs, and shrubs. Transplants were monitored for survival and percent species cover was sampled in randomly placed 20 × 50-centimeter (cm) quadrats within each plot. First- and fourth-year study results were reported.
Location: Mesa Verde National Park in southwest Colorado, USA
Findings: At sites 1 and 3, the Biosol-mulch combination yielded higher percent cover than the control, and at site 1 the Biosol only treatment also yield higher percent cover than the control. At sites 1 and 3, the Biosol treatment benefited perennial grasses the most. At site 2, none of the treatments significantly affected percent species cover, cover was greatest overall at this site. Transplant survival of some species mirrored germination results. Indigenous species with the highest transplant survival rates across plots were *Aster glaucodes* (blue leaf aster), *Artemisia ludoviciana* (Louisiana sage), and *Elymus trachycaulus* (slender wheatgrass).
Implications: Aspect is an important factor to consider when revegetating roadcut slopes. In this study, the north-facing slope had the highest overall revegetation followed by the south-west-facing slope, possibly due to the amount of solar radiation. Nutrients and water availability are other important factors for successful revegetation. Rhizomatous growth forms were successful at establishing and, if applicable to their site, should be considered by land managers when revegetating steep roadcut slopes.
Topics: Road, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices

Pilkington, L.H., and Redente, E.F., 2006, Evaluation of reclamation success of Williams Production RMT Company natural gas well pad sites near Parachute, Colorado: Williams Production RMT Company, prepared by Colorado State University, 95 p.

Link (non-DOI): https://www.researchgate.net/publication/268293745_EVALUATION_OF_RECLAMATION_SUCCESS_ON_WILLIAMS_PRODUCTION_RMT_COMPANY_NATURAL_GAS_WELL_PAD_SITES_NEAR_PARACHUTE_COLORADO_Prepared_by
Background: The western United States possess great ecosystem diversity and large aggregations of natural resources. To reclaim disturbed native communities for wildlife habitat and recreational opportunities, successful reclamation practices need to be identified. Various reclamation techniques have been used at natural gas well pads for Williams Production RMT Company, providing an opportunity to assess reclamation practices across a variety of plant communities.
Objectives: The authors quantified the success of different reclamation techniques at previously reclaimed well pads across six plant communities by characterizing vegetation and soil, assessing effectiveness of seed mixtures, and comparing soil treatments to identify reclamation best practices for this region.
Methods: The authors queried a company database to obtain records for reclaimed well pads. Fifty-five well pads (reclaimed three to eight years prior) were identified, which had records on treatments, including soil ripping technique, seed mixture origin, seeding method, fertilization practice, mulch used, time since seeding, aspect, and plant community type. The authors monitored three control sites for each of six native plant communities represented by the well pads (juniper, greasewood, sagebrush, desert shrub, mixed mountain shrub-oak, and agricultural land). They collected vegetation data using the point-intercept method on three randomly selected 50 meter (m) transects at each reclaimed well pad and control site. They collected soils at well pads and control sites for physical and chemical analysis. They compiled current field data and historical reclamation data in an Access database. The authors based restoration success on percent vegetation cover of seeded species as measured in 2005.
Location: Grand Valley, Parachute, and Rulison fields in the Piceance Basin, between the towns of Parachute and Rifle in Garfield County, Colorado, USA
Findings: Reclamation success varied by reclamation treatment and environmental factors. Seed mixture and species composition critically influenced reclamation success. Presence of noxious weeds, namely cheatgrass, hindered native colonization and seeded species success. The most successful seed mixtures were: Sharrard Park Mix with crested wheatgrass, Unocal Mix plus Bureau of Land Management (BLM) Juniper Sagebrush Mix (together), Unocal Mix with crested wheatgrass, Parachute Field Mix #1, BLM Desert Salt Shrub Mix with crested wheatgrass, BLM PA Mix with crested wheatgrass, Dryland Pasture Mix, Sharrard Park Mix and Savage Mix together, and BLM Parachute Creek Mix. Crested wheatgrass, when included in the seed mix, was always the dominant species. Crested wheatgrass, fourwing saltbush, intermediate wheatgrass, and western wheatgrass had the most successful seedling establishment. Regarding plant community reclamation potential, Juniper was moderately challenging, greasewood was the most difficult, big sagebrush was difficult, desert shrub was less difficult, and the mixed mountain shrub-oak was the easiest to establish. The agricultural land plant communities had the highest percentage of non-native, non-noxious species and had considerable seeded species success (18 percent cover).

Implications: Seed mixture composition and specific species selection for seed mixes greatly influence reclamation success. Different vegetation communities have varying levels of reclamation potential.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Plass, W.T., 1974, Revegetating surface-mined land: Mining Congress Journal, v. 60, no.4, p. 53–59.

Link (non-DOI): https://www.osti.gov/biblio/6572572
Background: Following the eruption of the environmental revolution in 1971, mining and reclamation practices found themselves under higher scrutiny to set more rigorous guidelines to increase environmental protection. Improved revegetation practices on coal fields in the Midwest and Appalachian regions provide templates for the development of similar practices in the western United States.
Objectives: The author reviewed advances in site evaluation, site preparation, and revegetation techniques employed in the eastern and midwestern United States and highlighted their national and (or) regional applications.
Methods: The author reviewed literature on site evaluation (that is, physical characteristics, chemical variation, and classification system of mine spoils), site preparation (that is, reshaping, fertilization, and additional soil amendments), and revegetation techniques (that is, species selection, genetics, species compatibility, and seeding timing). They briefly highlighted example projects and committees formed to monitor and development environmentally conscious methods.
Location: This is a review article and does not involve a specific field site location
Findings: The physical and chemical properties of soil impact reclamation methods, specifically in regard to overburden and spoil. Determining mine spoil pH can help determine appropriate revegetation species. When native topsoil is not adequate for reshaping and revegetation, fertilizer and other amendments (such as lime or fly ash) can be used. Reseeding species should be carefully selected based on site characteristics, post-mine land use designation, native and nonnative preferences, genetics, and compatibility. Seeding time is important for maximizing germination success, though timing varies regionally. A variety of additional treatments (for example, mulch, soil stabilizers, waste sludge, compost) can aid in revegetation success and their application depends on site-specific conditions.
Implications: This article is a useful summary of environmentally conscious revegetation techniques for land managers to review or reference when designing reclamation plans.
Topics: Mining, Reclamation Practices, Reclamation Monitoring

Polster, D., 2009, Natural processes—The application of natural systems for the reclamation of drastically disturbed sites, *in* Proceedings of the 33rd Annual British Columbia Mine Reclamation Symposium, Cranbrook, British Columbia, September 14–17, 2009, Proceedings: The British Columbia Technical and Research Committee on Reclamation, 8 p.

DOI: https://doi.org/10.14288/1.0042560
Background: Natural processes have the capacity to assist in mine reclamation. For example, erosion is a common issue in reclamation of steep slopes. Understanding the nutrient and environmental conditions needed by pioneering plants, and recreating them through reclamation, could lead to more effective revegetation and reduced erosion. There are a number of natural processes that could be utilized to improve reclamation outcomes.
Objectives: The author discussed several natural processes that can serve as solutions to common mine reclamation problems.
Methods: The author discussed the need to identify filters or constraints to recovery of disturbed lands to tailor reclamation protocol accordingly. They identified various natural recovery solutions and discussed how to implement them through reclamation management.
Location: This is a review article and does not involve a specific field site location
Findings: Steep slopes can be addressed through pocket planting establishment in collected organic matter. Rapid erosion can be controlled by evergreen ground cover, scattered woody debris, and creating rough loose soil surfaces that can also address limited micro-sites. Soil compaction can be mitigated by freeze-thaw cycle weathering. Low nutrient content and lacking seed sources can be increased by planning nitrogen (N)-fixing pioneer plants that widely disperse seeds. Adverse chemical composition can be altered by isolating materials from the surrounding environment or diluting toxic materials.

Implications: Several natural processes can be utilized in reclamation of disturbed mine lands to avoid problems that arise with non-natural solutions.
Topics: Mining, Reclamation Practices, Reclamation Standards, GrayLit

Powell, K.B., Vincent, R.B., Depuit, E.J., Smith, J.L., and Parady, F.E., 1990, Role of irrigation and fertilization in revegetation of cold desert mined lands: Journal of Range Management, v. 43, no. 5, p. 449–455.

Link (non-DOI): https://www.jstor.org/stable/3899011
Background: Water and nutrient-poor soils are leading limiting factors in reclaiming mine lands in the semiarid and arid western United States. When fertilization alone is used during reclamation, plant response is limited, possibly due to the lack of water. Including irrigation with fertilization during reclamation could improve overall revegetation outcomes.
Objectives: The authors evaluated the short-term (first 4 years post-reclamation) effects of different irrigation rates on revegetation and fertilization efficacy on cold desert mined lands.
Methods: Study plots were established on a 1.4-hectare (ha) mine site following spoil grading, ripping, and application of subsoil and topsoil. The site was drill-seeded with 11 cool-season perennial grasses, three forbs, and five shrubs. Treatments applied included a no irrigation control, three first-year sprinkler irrigation rates, five seasonal schedules of irrigation, and various fertilizer rates in 20 specific combinations within 12.2 square meter (m^2) subplots replicated three times (60 total subplots). Canopy cover was measured by growth form and species, and density and aboveground biomass was determined by growth form from 1984 to 1987. Pre- and post-treatment soil samples were collected from depths of 0–15 centimeters (cm), 15–41 cm, and 41–76 cm and analyzed for chemical and nutrient characteristics. Data were analyzed using analysis of variance (ANOVA).
Location: Jim Bridger surface coal mine (elevation 2,070–2,163 meters [m]; 194 millimeters [mm] mean annual precipitation), 45 kilometers (km) northeast of Rock Springs in southwestern Wyoming, USA
Findings: Irrigation was helpful but not essential for establishing plant communities, specifically accelerating overall revegetation and enhancing shrubs and perennial forbs, and any benefits were temporary. Several irrigation regimes decreased dominant perennial grass productivity. The optimum treatment at the study site for enhancing shrub and forb growth was three months of spring-early summer irrigation at 10 cm/month. Initial fertilization had no effect on plant community establishment and irrigation did not encourage fertilizer uptake by plants.
Implications: Fertilizer may not be a useful or cost-effective method for revegetating semiarid and arid cold deserts; however, land and reclamation managers should conduct site-specific trials. Irrigation rates should also be carefully tested as site-specific conditions may influence irrigation efficacy and suitable rates for producing the desired revegetation outcomes.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Prasser, N.P., and Hild, A.L., 2016, Competitive interactions between an exotic, *Halogeton glomeratus*, and 10 North American native species: Native Plant Journal, v. 17, no. 3, p. 244–254.

DOI: https://doi.org/10.3368/npj.17.3.244
Background: Energy development disrupts plant communities and often introduces invasive species. In Wyoming, halogeton (*Halogeton glomeratus*) is a common invader on disturbed sagebrush and desert shrublands undergoing such disturbances. Halogeton management in restoration seedings has often included exotic perennial grasses even though exotic species are not ideal for reestablishing native plant communities. Native plant competitors with exotics such as halogen are needed to assist revegetation efforts to reestablish native plant communities.
Objectives: The authors sought to identify native species that are competitive with halogen by comparing root:shoot allocation patterns and survival of seedlings of ten native species in the presence of halogen. They hypothesized that native annuals would perform better in the presence of halogen than native perennials.
Methods: Greenhouse studies were conducted using modified replacement-series experiments with seedlings native to the Wyoming Basin (five forbs, four perennial grasses, and one shrub). Species were seeded with and without halogeton competition. Treatments included ten conspecific competitors (four individuals in monoculture/pot) and 11 intraspecific competitions (2 halogeton individuals and 2 native competitors) in five experimental blocks (105 pots in total). After germination, seedlings were transplanted into treatment soils from a disturbed site in the Laramie Basin. Seedlings were

monitored for height, leaf number, and mortality biweekly from June to October. Plants were harvested to obtain above- and below-ground biomass at 14 weeks (or earlier if plants were early mortalities) and to record leaf area using LiCor 3100 leaf area meter. Biomass was averaged across individuals within each pot. Data were analyzed using analysis of variance (ANOVA) and *t*-tests.
Location: Greenhouse experiment in Laramie, Wyoming, USA
Findings: Leaf number, height, and biomass increased across all individual seedlings during the course of the study, as would be anticipated. Halogeton above-ground growth was reduced in the presence of two annuals (annual sunflower, *Helianthus annuus* and Rocky Mountain beeplant, *Cleome serrulata*). Annual sunflower grew taller in the presence of halogeton than when grown alone. The perennial grass alkali sacaton (*Sporobolus airoides*) had greater root growth in the presence of halogeton than in monocultures. As seedlings, hoary tansyaster (*Machaeranthera canescens*) and the shrub fringed sage (*Artemisia frigida*) were not competitive with Halogeton. Halogen seedling growth (aboveground biomass as a percent of pot total) depended upon the native competitor and was reduced by annual sunflower, Rocky Mountain beeplant, blanketflower (*Gaillardia* sp.), curlycup gumweed (*Grindelia squarrosa*) and the perennial grass alkali sacaton more than in other competitor treatments. Additionally, Halogeton seedling survival was <30 percent when grown with annual sunflower, sand dropseed (*Sporobolus cryptandrus*), and blanket flower.
Implications: Native seedlings increased halogeton mortality and fast-growing species reduced the biomass of surviving halogeton seedlings in the greenhouse. Field studies will be an informative next step in determining native species most competitive with halogeton in the long term. While rapid investment in aboveground mass was important for native seedlings to compete with halogeton, perennial species may still serve as competitors over longer periods of time. Reclamation seeding mixes that include fast-growing annuals may be more successful at limiting halogeton seedlings and reestablishing native plant communities.
Topics: Mining, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Pratt, A.C., and Beck, J.L., 2019, Greater sage-grouse response to bentonite mining: The Journal of Wildlife Management, v. 83, no. 4, p. 866–878.

DOI: https://doi.org/10.1002/jwmg.21644
Background: Bentonite surface mining disturbance in the Bighorn Basin in Montana and Wyoming is increasing, leading to a loss of sagebrush habitat. This habitat loss impacts species like the greater sage-grouse (*Centrocercus urophasianus*), though to what extent sage-grouse are affected is largely unknown. Understanding the impacts of mining during the breeding and wintering seasons will inform mitigative strategies for lessening the negative impacts of bentonite surface mining on sage-grouse populations.
Objectives: The authors assessed the effects of bentonite surface mining and reclamation on sage-grouse nesting, brooding, adult breeding, and adult wintering survival and habitat selection.
Methods: From 2011–2015, female sage-grouse were captured during spring, summer, and winter. Individuals were aged and marked with very high frequency radio-transmitters or Global Positioning System (GPS) transmitters, used to track birds April through August. Nests of breeding females were monitored. Variables related to habitat-specific mortality risk and resources selection were determined using principal component analysis. Occupied and random locations were compared to assess bentonite mining on different life stages. Mixed-effects Cox proportional hazards regressions and Akaike information criterion (AIC) were used to analyze data.
Location: Three sites in the Bighorn Basin in northcentral Wyoming and southcentral Montana, USA
Findings: More adult female sage-grouse were exposed to bentonite mining disturbance during over-wintering (69 percent) than any other life stage. Sage-grouse avoided mining disturbance, both active and reclaimed sites, when selecting nest, adult breeding, and adulting winter habitat. Mining disturbance was not associated with nest failure but was associated with adult female mortality; females exposed to mining disturbance within 1,600 meters (m) were 19 times more likely to die.
Implications: Bentonite mining negatively impacts sage-grouse habitat selection and demographic rates, with the highest amount of exposure to mine disturbance during winter. Reclaimed mines were also avoided, suggesting that reclamation to pre-mine conditions is difficult and does not meet sage-grouse habitat requirements. A conservation strategy can include avoiding sagebrush habitat when selecting bentonite mining locations, placing emphasis on conserving, and restoring winter habitat for sage-grouse in disturbed areas.
Topics: Mining, Wildlife/Habitat Data, Reclamation Standards

Prodgers, R.A., 1984, Collection and analysis of baseline vegetation data: Minerals and the Environment, v. 6, p. 101–104.

DOI: https://doi.org/10.1007/BF02043988
Background: To properly evaluate and compare vegetation metrics pre-mining and post-reclamation, a baseline vegetation inventory is necessary. One major concern is identifying vegetational units by which data are summarized and compared. Types defined by growth-forms or physiognomic types allow before-and-after comparisons, whereas species composition does not.
Objectives: The author discussed problems associated with baseline vegetation data collection for monitoring reclamation and possible solutions.
Methods: Identified problem areas of baseline vegetation data collection, focusing on researcher bias, vegetation classification, mensuration, sample adequacy, mapping, and data analysis. Suggested possible solutions and avenues for improvement.
Location: This is a methods article and does not have a specific field site location
Findings: Special care should be taken to reduce researcher bias with thorough documentation and an objective mindset. Meaningful vegetation types from classification are critical to utilize. Several vegetation measurements, especially those pertaining to biomass or production, should be collected to ensure a full assessment is made; measurements must not only do justice to pre-mine plant communities, but also apply to later revegetation assessment. Vegetation mapping should be detailed; types may be combined later for postmining comparison. Pre-mine vegetation data should be collected over time as vegetation communities change, especially productivity. Data analysis is a major component of assessing baseline data, so methods should be carefully vetted to ensure accurate representation of the vegetation community.
Implications: Land managers and researchers should carefully design vegetation monitoring protocols (for both baseline and post-reclamation data collection) to ensure they accurately reflect the state of vegetation communities, both pre-mining and post-reclamation.
Topics: Mining, Reclamation Monitoring

Prodgers, R.A., 2003, Lessons of steep-slope revegetation from the Golden Sunlight Mine, Montana, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 992–1004.

DOI: https://doi.org/10.21000/JASMR03010992
Background: Revegetation of 50 percent (2H:1V) slopes is difficult but not impossible, as seen at the Golden Sunlight Mine in southwestern Montana. Successful revegetation of steep slopes depends on a number of factors, including site conditions, materials used, weather, and aspect, some of which cannot be controlled during the reclamation process. Due to these factors, successful revegetation of steep slopes is variable and extremely site-specific, but the success of Golden Sunlight Mine can serve as a useful case study for future reclamation efforts in similar conditions.
Objectives: The author reviewed and discussed reclamation practices and materials used at the Golden Sunlight Mine as an example of successful steep slope revegetation.
Methods: The author provided an overview of the advantages and disadvantages of steep slope reclamation. They discussed the steep slope reclamation conditions and practices used at the Golden Sunlight Mine, including revegetation practices, and the potential effects of climate and aspect on steep slope revegetation at the mine. To monitor revegetation, they sampled canopy cover in 0.5 square meter (m^2) frames systematically located along 100-meter (m) long transects in revegetation of various age. Canopy cover was estimated to the nearest percent and calculated Shannon index using natural logs. Canopy cover in reclaimed area was compared to native reference vegetation.
Location: Golden Sunlight Mine in southwestern Montana, USA
Findings: Practices associated with successful revegetation of steep slopes at the Golden Sunlight Mine include the application of 0.6 m thick erosion-resistant cover soils containing 30–50 percent rock fragment content and texture conducive for plant growth, installing dozer basins immediately after grading, and sloping benches every vertical 60 m or closer. Alfalfa and grasses like wheatgrass (*Agropyron cristatum*) and sheep fescue (*Festuca ovina*), both prominent in the earliest revegetation, were effective, but more recent work using predominantly native grasses and alfalfa were equally good. Drill-seeding was

more effective than broadcasting seed. Ten-years post-reclamation, west-facing slopes maintained adequate vegetation, but south-facing slopes were vegetated below that of compared reference slopes. Long-term precipitation patterns played a key role in revegetation success, especially on south-facing slopes.
Implications: Steep slope revegetation is difficult but can be successful following the methods used at the Golden Sunlight Mine (when applicable). Proper implementation is critical. Land managers should assess site-specific conditions when deciding on reclamation protocols for steep slopes. Precipitation is an important factor for revegetation in semi-arid climates and can determine the fate of each effort.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, GrayLit

Prodgers, R.A., 2003, Meaningful measurement of revegetation diversity, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 1005–1015.

DOI: https://doi.org/10.21000/JASMR03011005
Background: An important metric of mine land reclamation is revegetation of a diverse community of plant species. However, defining diversity is not universal and can vary with post-reclamation land use goals. In Montana, coal reclamation defines diversity by tightly defined growth-forms (for example, native perennial warm-season graminoids among many others). Diversity measures typically include number of species with a measure of relative abundance, but this definition ignores the obvious fact that species are not equally important in community function. Understanding what plant diversity means is important for assessing reclamation success and post-mine land use viability.
Objectives: The author discussed alternative methods for evaluating the importance and function of plant diversity following mine reclamation revegetation.
Methods: The author reviewed literature on and discussed the restrictions of evaluating diversity based on species, the meaning of diversity depending on land use post-reclamation, and how to measure diversity and at what scale.
Location: This is a methods-review paper and does not involve a specific study site location
Findings: The term "species" itself is difficult to define, complicating its use in evaluating post-reclamation plant species diversity. If wildlife habitat is the post-reclamation land use, understanding the year-round habitat needs of the species of concern is a more important metric than simply plant species diversity. If livestock grazing is the post-reclamation land use, native plant species diversity may not be as desirable as a productive monoculture of introduced species. Diversity can be measured at the structural cover and landscape levels.
Implications: Diversity is a highly variable term when applied to revegetation following mine reclamation, and there is no fundamental unit of diversity. The species as fundamental unit of taxonomy is usually used despite its limitations. Land managers should consider post-reclamation land use and scale when determining how to define and measure plant diversity meaningfully.
Topics: Mining, Reclamation Theory, Reclamation Monitoring, Reclamation Standards, GrayLit

Prodgers, R.A., 2013, Case study—Fitness more than diversity guides vegetational recovery: Journal of the American Society of Mining and Reclamation, v. 2, no. 2, p. 113–141.

DOI: https://doi.org/10.21000/JASMR13020113
Background: Revegetation following reclamation efforts on disturbed lands often encourages diversity, however, in some cases a single species may serve as a linchpin for successful revegetation to occur. Three case studies illustrate the importance of single species, the 'Rosana' cultivar of western wheatgrass (*Pascopyrum smithii*) and the naturalized redtop (*Agrostis stolonifera*), in reclamation efforts on a coal mine, a superfund site contaminated by heavy metals, and a historical sulfur dioxide (SO_2) fumigation and heavy metal deposition site in Montana, USA.
Objectives: The author reviewed and discussed case studies where a single species played a major role in successful reclamation revegetation efforts.

Methods: The author reviewed revegetation efforts for each case study site and included personal expertise in explaining revegetation effort outcomes.
Location: Decker Coal Mine, Clark Fork River Operable Unit, and smelter-polluted lands near Anaconda, all in Montana, USA
Findings: At Montana's Decker Coal Mine with a continental climate and about 30 centimeters (cm) of annual precipitation, ineffective seeding practices resulted in a cheatgrass (*Bromus tectorum*) monoculture that stagnated for years. Then a single rhizomatous wheatgrass, 'Rosana' western wheatgrass, alone converted cheatgrass fields to successful if simple revegetation with very few weeds. Whether its initial presence came from seeding or possibly from direct-haul cover soil is unknown (the 'Rosana' cultivar originated in an adjacent county). At the Clark Fork River Superfund site, western wheatgrass of local origin was observed to form a sparse monoculture on 24 acres of heavy-metal-contaminated soil (about 2,000 parts per million [ppm] copper and other heavy metals) further stressed by historical overgrazing. It is a good revegetation candidate at some important site types in Montana. On a much vaster scale, the naturalized, unseeded rhizomatous grass redtop (*A. stolonifera*) has come to occupy thousands of acres of smelter-contaminated soils around Anaconda, MT, including some previously coniferous forest. One superbly adapted species is better than a variety of also-rans. Rhizomatous spread can play an important role in vegetating stressful sites, whether weed-dominated or polluted.
Implications: Revegetation efforts require appropriate seeding techniques and reduced grazing, among other factors. Focusing on biological diversity in seed mixes is important, however, successful revegetation can result from a single dominating well adapted species. Land managers should consider site specific conditions when planning revegetation. Long term monitoring is also important for assessing revegetation success and trends in species presence.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, Reclamation Monitoring

Rafferty, D.L., and Young, J.A., 2002, Cheatgrass competition and establishment of desert needlegrass seedlings: Journal of Rangeland Management, v. 55, no. 1, p. 70–72.

Link (non-DOI): https://www.jstor.org/stable/4003265
Background: Cheatgrass (*Bromus tectorum*) is a fierce nonnative competitor of native species establishment following revegetation of disturbed areas in the Great Basin. Often, reclamation is not attempted in areas too dry for native species like desert wheatgrass (*Agropyron desertorum*), even though project contractors in such areas are still required to attempt revegetation. Right-of-ways (ROWs) along mining exploration roads can serve as corridors for nonnative species if native species do not reestablish. Desert needlegrass (*Achnatherum speciosum*) is a bunchgrass native to the driest areas of the Great Basin and may be a candidate species for use in revegetation efforts in ROW and other disturbed areas.
Objectives: The authors evaluated the effects of different cheatgrass densities on the establishment and growth of desert needlegrass seedlings.
Methods: Soil, cheatgrass seed, and desert needlegrass seed were collected from a pipeline ROW for greenhouse experiment. A completely randomized experimental design was used with four replicates per treatment. Seedlings were planted in 95 × 30 cm cylinders filled with ROW soil. Number of seeds needed for cheatgrass densities (100, 75, 50, 25, and 0 percent as control) was estimated by surveying ROW for plants per unit of area; seeds were overplanted, and seedlings were thinned to result in desired density. Desert needlegrass seedlings were thinned to one per cylinder. Soil was saturated and surface soil was kept moist until emergence then watering was ceased until the seventh week. Height of desert needlegrass shoots were measured weekly for 12 weeks. Data were analyzed using one-way analysis of variance (ANOVA) with cylinder nested within density by week.
Location: Natural gas transmission pipeline ROW at the base of the Dog Skin Mountains north of Reno, Nevada (39°51′ N.,119°48′ W.), USA, and a greenhouse
Findings: The effect of cheatgrass competition on desert needlegrass shoot height became significant five weeks after planting. Once cheatgrass roots were sufficiently established, it out-competed desert needlegrass for moisture. Desert needlegrass shoot height was two to four times higher in the control compared to pots with any cheatgrass densities.
Implications: Near complete eradication of cheatgrass is necessary to ensure native species like desert needlegrass reestablish after reclamation. Despite desert needlegrass adaptation to extremely dry conditions, cheatgrass is too competitive for this native species to survive, even at low cheatgrass densities.
Topics: Pipeline, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Ramsey, T.R., Buchanan, B.A., and Owens, M.P., 2006, Surface mine reclamation, northern New Mexico—First year response of fall and spring seeding, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 127–128.

DOI: https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2006-Billings/0127-Ramsey.pdf
Background: Surface mine reclamation in northern New Mexico generally occurs in either spring (April–May) or fall (September–October). However, during fall 2004, weather conditions delayed seeding on 300 acres; as a result, only 130 acres were seeded in fall 2004, 12 acres in spring 2005, and the remaining acres seeded in fall 2005. Studying seedling establishment following fall and spring seeding events can help determine the most productive seeding time of year.
Objectives: The authors documented and compared seedling establishment in fall 2004 and spring 2005 on 142 acres of surface mine reclamation land.
Methods: One hundred and thirty acres of surface mine land was seeded in fall 2004 with a seed mixture containing grasses, forbs, and shrubs. Twelve acres of surface mine land was seeded in spring 2005 with the same seed mixture. In September 2005, the point intercept method was used to measure vegetation cover by life form at 60 points along 10 randomly placed 30-meter (m) transections in both the fall and spring seeded areas. Ten randomly placed 2 × 30 m belt transects were used in both the fall and spring seeded areas to measure shrub species density.
Location: Surface mine located 18 miles north of Farmington, New Mexico, USA
Findings: Perennial grass and forb cover was 30 percent in the fall seeded area compared to 1.7 percent in the spring seeded area. Four-wing saltbush density was higher in the fall seeded area (9,467 shrubs per hectare [shrubs/ha]) compared to the spring seeded area (650 shrubs/ha).
Implications: This study suggests that fall seeding is more successful and associated with higher seedling emergence of perennial cover and shrubs.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Rana, S., Stahl, P.D., Ingram, L.J, and Wick, A.F., 2007, Soil microbial community composition in reclaimed soil under different vegetation in Wyoming minelands, *in* Barnhisel, R.I., ed., American Society of Mining and Reclamation 24th Annual National Conference, Gillette, Wyo., June 2–7, 2007 Proceedings: American Society of Mining and Reclamation, p. 653–661.

DOI: https://doi.org/10.21000/JASMR07010653
Background: Mine land reclamation success is assessed by aboveground components that can be visually evaluated, however, belowground soil characteristics and processes are essential for ecosystem function and greatly influence reclamation success. Despite their importance, little is known about the impact of reclamation on soil conditions and microbial communities.
Objectives: The authors evaluated soil microbial community recovery under different plant communities on reclaimed surface coal mines.
Methods: Three reclaimed surface coal mines of differing ages and plant communities were selected, each with a unique status: 14 years post-reclamation dominated by cool season grasses, 5 years post-reclamation dominated by sagebrush and warm season grasses, and 10 years post-reclamation dominated by warm season grasses. For each mine site, a comparative native undisturbed site was identified. Soil was sampled at 0–5 centimeters (cm), 5–10 cm, and 10–15 cm depth intervals at four points along randomly-placed 45 meter (m) transects. Soil phospholipid-derived fatty acid (PLFA) was extracted using a modified Bligh-Dyer method. PLFA signatures were used to quantify microbial groups. Data were analyzed using analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA).
Location: Belle Ayer (44°05.696′ N., 105°25.520′ W.), Dave Johnston (43°00.547′ N., 105°43.339′ W.), and Jacobs Ranch (43°43.433′N., 105°14.470′ W.) surface coal mines in the Powder River Basin in northeastern Wyoming, USA

Findings: Microbial biomass differed among plant communities with PLFA increasing from warm season grasses to sagebrush to cool season grasses, possibly because the latter had the greatest time since reclamation. Microbial soil communities also differed across plant communities. Relative proportions of fungi, arbuscular mycorrhiza fungi (AMF) and bacteria were higher in the sagebrush community.
Implications: Microbial soil communities under sagebrush communities recovered more than those under warm and cool season grass communities, suggesting sagebrush (where applicable) may be a better choice for reclamation seed mixes to ensure full ecosystem response. However, research comparing different vegetation the same age since reclamation is needed.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Redente, E.F., and DePuit, E.J., 1988, Reclamation of drastically disturbed rangelands, chap. 22 *of* Tueller, P.T., ed., Vegetation science applications for rangeland analysis and management, Handbook of vegetation science: Dordrecht, Kluwer Academic Publishers, v. 14, p. 559–584.

DOI: https://doi.org/10.1007/978-94-009-3085-8_22
Background: Understanding successional ecology is paramount for reestablishing native vegetation following largescale ecosystem disruption, such as mining. Clements defined the steps of succession in 1916 as migration, ecesis (establishment), reaction, competition, and stabilization. Succession is an essential aspect of mine land reclamation, and all successional stages must be incorporated into reclamation revegetation methods.
Objectives: The authors' objective was to discuss the successional process defined by Clements (1916, at https://doi.org/10.5962/bhl.title.56234) as it pertains to reclaimed mine lands.
Methods: The authors introduced mining disturbance and reclamation as examples of the initial condition (nudation) precluding ecological succession. They reviewed Clements' (1916) steps of ecological succession: migration, ecesis (establishment), reaction, competition, and stabilization, specifically as they relate to, and can be manipulated by, the process of reclamation. They emphasized the need to reference vegetation sciences as a guiding principle for reclamation.
Location: This is a review article and does not involve a specific field site location
Findings: The steps of ecological succession described by Clements (1916) can be replicated and accelerated through reclamation. However, the steps of competition, reaction, and stabilization as they occur on disturbed mine lands need further research to fully understand and accelerate through reclamation.
Implications: This review article is a useful resource for land managers interested in learning the ecological science behind succession and how to integrate the successional process into their reclamation methods.
Topics: Mining, Vegetation Recovery Data, Reclamation Theory, Reclamation Practices

Redente, E.F., and Hargis, N.E., 1985, Evaluation of soil thickness and manipulation of soil and spoil for reclaiming mined land in northwest Colorado: Reclamation and Revegetation Research, v. 4, p. 17–29.

Link (non-DOI): https://www.osti.gov/etdeweb/biblio/6410063
Background: In reclamation of surface coal mines, the optimal soil replacement thickness depends on spoil characteristics (for example, concentration of soluble salts) and the annual precipitation of the site, among other factors. Previous studies suggest that a thin layer of soil yields higher forage than spoil alone. Mechanical and fertilizer treatments have been applied to soil, but little is known on their impact on the soil-spoil interface. Understanding how soil thickness and mechanical treatments interact may improve future reclamation and revegetation efforts.
Objectives: The authors' objective was to evaluate the effects of soil replacement thickness and mechanical treatment (ripping, disking, or fertilizing) of the soil and spoil on a mix of seeded range plant species.
Methods: Test plots were created on a portion of an active surface coal mine which was backfilled in 1979 and re-contoured in 1980. Two types of treatments were applied: soil thickness (15, 30, 45, and 60 centimeter [cm] depths) and soil mechanical manipulations (combinations of disking and ripping). Following treatment application, the soil was seeded with a mixture of cool-season grasses, forbs, and shrubs, and straw mulch was applied after seeding. Soil characteristics were measured pre- and post-treatment. Plant density, canopy cover, and aboveground biomass of vegetation were sampled 2- and 3-years post-treatment. Root biomass was estimated 3-years post-treatment.

Location: Surface coal mine in the Wyoming Basin ecoregion (operated by Trapper Mining Inc.) in Moffat County, Colorado, 11 kilometers southwest of Craig, Colorado, USA
Findings: Seeded grass biomass was greatest on the thickest soil layer (60 cm), while seeded forb and shrub biomass was greatest on the thinnest layer (15 cm). The biomass of volunteer species (mostly weedy annuals) was lowest on the 15 cm soil layer. Overall biomass and cover of the 3 seeded plant functional types plus volunteer species was highest on the 60 cm layer. There was more root biomass in the soil layer compared to the spoil, and the depth of the topsoil did not affect root penetration into the spoil layer. There were no significant interactions of soil thickness and soil manipulation. The seeded species showed no direct response to the soil manipulations, however annual weedy species were greatest on the ripped soil-spoil to 30 cm below soil-spoil interface treatment level, which resulted in lower seeded biomass.
Implications: Seeded range species responded more to soil thickness than soil manipulations. With effective weed control, a thicker soil layer should yield the greatest plant biomass. Though, a thicker topsoil layer may not lead to greater root biomass in the spoil layer, which is important for late growing season water. Rough contours created by ripping may promote weed invasion.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Ringer, L.N., 2016, Altering water and nitrogen availability after roadside disturbance to favor native plant species: Fort Collins, Colo., Colorado State University, master’s thesis, 101 p.

Link (non-DOI): https://mountainscholar.org/bitstream/handle/10217/178815/Ringer_colostate_0053N_13845.pdf
Background: Reestablishing native species after disturbance, such as road construction, can be difficult due to increased invasion by non-native species. Altering nutrient and water availability and soil structure are possible methods for managing which species successfully establish and germinate. Conducting field and greenhouse experiments provide multiple opportunities to alter these factors and determine the most successful combinations for desired plant community establishment.
Objectives: The author assessed which combinations of water and nitrogen (N) availability and soil amendments would reduce weedy annual species establishment on disturbed roadsides and in greenhouse experiments.
Methods: In 2013, six southeast facing roadside slopes were selected and treatments were applied, including compost, mulch, polymer alone, and all possible pairwise combinations of the amendments, and a no-treatment control (seven total treatments). The treatment areas were hydroseeded with a seed mix of ten perennial grasses and forbs plus a tackifier. Measurements on reclaimed areas included plant density, cover, mineral nutrients, soil moisture, total carbon (C):N, soil temperature, and rainfall during the 2014–2015 growing seasons. In 2014, a greenhouse study was conducted with native and non-native grasses analogue to what was hydroseeded on road segments. In the greenhouse experiment, grass root and shoot biomass, plant height, seedling density, and soil moisture were measured nine weeks after planting. Data were analyzed using a repeated measures analysis of variance (ANOVA).
Location: Rocky Mountain National Park in northcentral Colorado, USA, and a greenhouse
Findings: Amendment treatments did not significantly alter the C:N ratio, though the ratio was lowest with the mulch+compost treatment. The mulch treatment reduced non-native density to two plants per square meter (plants/m^2) while the compost+polymer treatment had up to 12 non-native plants/m^2. For the greenhouse experiment, N was more limiting than water for plant establishment and growth. The mulch treatment increased native species growth compared to non-native species, but also decreased germination and biomass across all species.
Implications: Increased soil moisture and decreased soil N favored native perennial species establishment and growth. Land managers with the goal of reestablishing a native perennial plant community for post-mine land use could consider manipulating water and N availability with amendment and irrigation methods.
Topics: Road, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices, GrayLit

Rivas, G., Moore, A., Dholoo, E., Mitchell, P., 2010, Alien invasive species—Risk and management perspectives for the oil and gas industry, *in* Society of Petroleum Engineers International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Rio de Janeiro, Brazil, April 12–14, 2010, Proceedings: Society of Petroleum Engineers, no. SPE 127132.

DOI: https://doi.org/10.2118/127132-MS
Background: While colonization of new species to an area is a natural process, human activities have increased introductions of new species at a rate and spread that are not typically observed in nature. If a non-native species establishes itself due to human introduction and threatens local biodiversity it is considered an alien invasive species (AIS). Oil and gas development can directly or indirectly introduce AIS to new areas. Preventing introduction and establishment is likely the best course of action.
Objectives: This study focuses on preparing guidelines for prevention and minimizing onshore and offshore AIS invasion.
Methods: The authors conducted a literature search related to AIS and oil and gas development. They developed a risk assessment process to identify direct and indirect sources of AIS. They analyzed different elements of the oil and gas industry including exploration, field development, production, transportation, and onshore versus offshore activities to identify potential sources of AIS introduction.
Location: This is a methods article and does not involve a specific field site location
Findings: A set of preparatory activities are recommended to reduce AIS introduction including incorporating AIS awareness throughout a project, setting up an AIS team early in a project to limit introduction, collecting data on existing AIS at new sites, and preparing for potential AIS introduction due to infrastructure or vehicular activity. Managers should also prepare an environmental impact and risk assessment that outlines the possible sources of AIS before a project commences. This extends to logistical considerations and knowledge of vulnerable environments.
Implication: Planning and logistical foresight can greatly reduce the likelihood that AIS are introduced during development of infrastructure and extraction of oil and gas. Currently, the knowledge set and guidelines to assess risk of introduction of non-native species to an area is incomplete. Baseline data for invasive species are unknown and only a few countries have formalized guidelines for reducing AIS. This article provides other specific guidelines for all stages of oil and gas development and eradication procedures if AIS invasion occurs.
Topics: Well Pad, Exotic Plant Data, Reclamation Practices, GrayLit

Rosner, L., Harrington, J.T., Dreesen, D.R., and Murray, L., 2001, Influence of provenance on *Ribes cereum* and *Symphoricarpos oreophilu*s seed germination in New Mexico seed sources *in* Barnhisel, R.I., Buchanan, B.A., Peterson, D., and Pfeil, J.J., coordinators, Land reclamation, a different approach—18th Annual National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mex., June 3–7, 2001, Proceedings: American Society of Mining and Reclamation, p. 31–38.

DOI: https://doi.org/10.21000/JASMR01010031
Background: Using native species that are specially adapted to local environmental conditions for reclamation is gaining interest in New Mexico. At the Molycorp Mine in Questa, New Mexico, mountain snowberry (*Symphoricarpos oreophilus*) and wax currant (*Ribes cereum*) are candidate species for reclamation revegetation because they prefer full sunlight, can grow in a range of soil conditions, and are already present in disturbed sites at the mine. Propagating snowberry and wax currant seedlings for transplantation could speed the rate of revegetation; however, little is known about growing these species in a nursery.
Objectives: The authors evaluated propagation techniques of Mountain snowberry and wax currant seedlings collected from local provenances for successful transplantation onto disturbed mine lands in New Mexico.
Methods: Snowberry and wax current seeds were collected from eight local provenances in New Mexico from August through October 1997. Seeds were cleaned and separated by species for two experiments on the influence of provenance on germination: (1) examining the effects of acid scarification and moist after-ripening on snowberry seeds, and (2) examining the effects of

stratification duration on wax current seeds. For the snowberry experiment, a factorial combination design was used to apply nine treatment combinations that crossed acid scarification (exposure to concentrated sulfuric acid for 0, 30, or 60 minutes) with moist after-ripening (placed in a polybag with moistened peat moss at room temperature for 0, 21, or 42 days) on four replicate sets of 100-seeds from seven seed sources. Following treatment, seeds were moist stratified in a walk-in cooler for 168 days. For the wax current experiment, four stratification treatments were tested on eight seed sources. Sets of 100 seeds were placed on moistened filter paper in a petri dish that was sealed in a polybag and left in a walk-in cooler 0, 60, 90, or 120 days. Germination data were analyzed using analysis of variance (ANOVA).
Location: This is a lab experiment and does not involve a specific field site location, though seeds were collected from eight locations in New Mexico, USA
Findings: Acid scarification improved snowberry seed germination for all provenances when averaged across all after-ripening treatments and vice versa. Across all provenances, the highest snowberry seed germination rates were observed with a combination of a 30-minute acid scarification treatment followed by a 21- or 42-day after-ripening treatment. Stratification improved wax current seed germination for seven of the eight provenances, though results varied greatly by site; the southern-most provenance did not experience improved germination.
Implications: This study illustrates successful propagation techniques for Mountain snowberry and marginally successful propagation techniques for wax currant. For successful revegetation, seed provenance is an important factor that land managers should consider as it may interact with propagation methods.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices, GrayLit

Rottler, C.M., Burke, I.C., Palmquist, K.A., Bradford, J.B., and Lauenroth, W.K., 2018, Current reclamation practices do not speed up succession or plant community recovery in big sagebrush ecosystems in Wyoming: Restoration Ecology, v. 26, no. 1, p. 114–123.

DOI: https://doi.org/10.1111/rec.12543
Background: Up to 25 percent of western North American shrub steppe ecosystems are expected to be affected by energy development in the future. Since a main objective of reclamation is returning the site to a late-successional plant community, many well pads are seeded with late-successional seed mixes in the hope of bypassing early-succession states. The success of this practice at oil and gas sites is poorly understood.
Objectives: The overall objective was to understand the effect of reclamation on succession at reclaimed and un-reclaimed sites. Specifically, the authors wanted to determine plant community and seed bank differences between oil and gas well pads that were either reclaimed or un-reclaimed and adjacent undisturbed sites. Additionally, they wanted to assess if reclamation increased the rate of recovery to later successional stages relative to natural succession.
Methods: Nineteen sites (nine reclaimed well pads and ten un-reclaimed well pads) were chosen, each with a paired control (undisturbed) site. Nine sites represented reclaimed well pads, which were reclaimed after 1983 (monitored 7–31 years after they were abandoned), and ten sites represented non-reclaimed well pads (monitored 32–66 years after they were abandoned). The reason that well pad status (reclaimed or not) was associated with two differently aged groups of wells was that Wyoming state mandates for reclamation were enacted and enforced starting in 1983. Well pads spanned land ownerships, reclamation goals, and management contexts, and neither specific reclamation practices nor seed mixes used on reclaimed wells were available. Plant communities were sampled to species within 30 quadrats and along two transects within each site. Canopy area of shrubs was determined along the transects. Three sets of soil cores were collected to determine seed bank characteristics. Soil was collected for texture analysis at each soil core location in the interspace, under shrub canopies, and on mounds formed by bunchgrass.
Location: South Baxter Basin (41.28° N., 109.36° W.) south of Rock Springs, Wyoming, USA
Findings: Reclaimed sites showed higher recovery of early-succession species (forbs, including seeded and unseeded non-native species, and grasses, among which crested wheatgrass (*Agropyron cristatum*) was a primary contributor. The reclaimed sites were no different than non-reclaimed sites for late successional species like big sagebrush and perennial forbs. The main drivers of late succession recovery were soil texture and time since well abandonment. More grass and shrub seeds emerged from soil samples taken on non-reclaimed pads, and more annual forbs emerged from soil samples taken on reclaimed pads. Forb and grass species and percent silt were positively correlated. There was no correlation between time since abandonment and plant community characteristics.

Implications: Both reclaimed and non-reclaimed sites recovered similarly for late successional species, indicating that current reclamation practices may not significantly impact recovery time to late successional stages, although these results must be considered in the context that all reclaimed sites were younger than non-reclaimed sites, and that reclamation seed mixes containing crested wheatgrass may complicate establishment of late successional species such as sagebrush due to competitive interactions. Even though the reclamation occurring on well pads in this study did not return communities to undisturbed late successional states, forb and grass cover, resulting from reclamation practices, promoted soil retention and may act as nurse plants.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Theory, Reclamation Practices

Said, K.O, Onifade, M., Githiria, J.M., Abdulsalam, J., Bodunrin, M.O., Genc, B., Johnson, O., and Akande, J.M., 2020, On the application of drones—A progress report in mining operations: International Journal of Mining, Reclamation and Environment, v. 35, no. 4, p. 235–267.

DOI: https://doi.org/10.1080/17480930.2020.1804653
Background: Advances in drone technology have improved mine operations and reclamation efforts by providing real-time data that allow for assessing hazards as they occur and provide timely reclamation progress updates to land managers and other stakeholders. To understand how drones have aided, and can continue to aid, mining operations and reclamation, a history of drone technology is useful information.
Objectives: The authors summarized the history of drone technology and present future applications of drones to further assist the mining industry.
Methods: The authors introduced drone technology and current applications to the mining industry. They reviewed the invention and evolution of the drone concept. They discussed drone classification systems and parameters and classified drones by operational efficiency, safety, and economic value. They reviewed common sensor types embedded in drones and the data each sensor collects.
Location: This is a review and does not involve a specific field site location
Findings: Drones can be classified by their aerodynamics, mean take-off weight, operational altitude, autonomy, and the type of sensor used. Embedded sensor options include thermal infrared, spectral imagery, digital, and lidar cameras and gas sensors. In the 20th century, drones were used for ecological monitoring and conservation, mail delivery, space monitoring, search and rescue operations, marine monitoring, infrastructure and building inspection, landslide monitoring, stockpile volume measuring, traffic control, heritage site restoration, city design, and post incident assessment. In mining specifically, drones are used for mapping surface and underground mines for modeling, assessing land damage and ecological monitoring, temperature monitoring with thermal camera sensors, air quality monitoring, slope stability monitoring, reclamation and ecological restoration assessment, inaccessible area image capturing, fragmentation analysis, tailings storage facility monitoring, and abandoned mine management. Future research could include integrating multiple data sources, improving sensors and flight platforms, increasing real-time large data collection, improving drone suitability for underground mine management, and improving drone resistance to harsh mining environments.
Implications: Drones are incredibly useful tools for mine operation and reclamation. Though the mining industry has yet to fully adopt drone technology, land and reclamation managers may find drones a cost-effective and efficient tool.
Topics: Mining, Reclamation Monitoring

Sauer, R.H., 1975, Vacuumed soil as a seed source for revegetating strip mine spoils: Mining Congress Journal, v. 61, no. 9, p. 16–19.

Link (non-DOI): https://www.osti.gov/biblio/7366770
Background: Reclamation of strip mine coal fields in the semiarid western United States is complicated by harsh soil and climate conditions. Grazing is the post-mine land use in much of the region, so plants must not only establish under difficult conditions but also withstand long-term livestock grazing and wildlife use. Native species are best adapted for these demands, but collecting native seeds is a problem because individuals often do not produce enough seeds to harvest. One proposed solution is to vacuum up seeds from surrounding areas for reclamation use.

Objectives: The author evaluated a seed vacuum for obtaining native seed for reclamation purposes in the semiarid western United States.
Methods: The author used a portable, gas-powered vacuum with a hose and small mesh net for catching seed and soil. Soil was collected using the vacuum from near the highwall of a mine under two conditions: disturbing the soil before vacuuming or leaving the soil undisturbed. Samples were separated into soil and litter. Twenty samples each of soil and litter collection types were placed in petri dishes and all viable seeds within the seeds were counted. The petri dishes were moistened to allow germination and the number of emerged seedlings was recorded. Dishes were then allowed to dry (to kill all seedlings) and after 57 days, were watered again for germination rates of additional seeds.
Location: Big Sky mine operated by Peabody Coal Co. in eastern Montana, USA
Findings: On average, soil samples contained 7,036 seeds per square meter (seeds/m^2) while litter samples contained only 803 seeds/m^2. Soil samples peaked at an 8 percent seedling germination rate while litter samples peaked at a 5 percent germination rate. After the drought, one individual and 50 individuals germinated in the litter and soil samples, respectfully. Species were not identified, soil samples contained seedlings of forb/broadleaf (10 percent), small grass (86 percent), and large grass (4 percent) species while litter samples contained no forbs, small grass (63 percent), and large grass (37 percent) species.
Implications: Soil and litter have sufficient viable native species seeds that can be collected via a soil vacuum for reclamation of strip mine coal fields in the western United States. Soil and litter contain different species seeds/seedlings and should be collected based on site-specific conditions and reclamation goals. However, a scaled-up soil vacuum method/device would be needed to ensure and increase collection efficiency.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices

Schafer, W.M., 1979, Cover soil management in western surface-mine reclamation, *in* De Vore, R.W., and Carpenter, S.B., eds., National Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Ky., December 4–7, 1979, Proceedings: Lexington, Ky., University of Kentucky, p. 305–310.

Link (non-DOI): https://www.osti.gov/biblio/5270875
Background: Research has shown that cover soil (topsoil or overburden) aids revegetation on reclaimed mine land. The Surface Mining Control and Reclamation Act of 1977 (SMCRA) set forth requirements regarding cover soil management. A conceptual framework can aid in selecting the appropriate type of cover-soil for various site conditions.
Objectives: The author reviewed a conceptual framework for cover soil management and address problems land managers may encounter.
Methods: The author defined “cover soil” as used in the article for clarity. They discussed a conceptual framework for managing cover soil that included inventory, analysis, selection, stripping, stockpiling, application, amendment, maintenance, and evaluation. They suggested guidelines for and highlighted potential problems in selecting appropriate cover-soil.
Location: This is a review of methods and does not involve a field site location, but it does discuss methods used at Western Energy (now Westmoreland) mines in Colstrip, Montana; Amax’s (now Eagle) Belle Ayr Mine in Gillette, Wyoming; Glenrock Mine in Glenrock, Wyoming, Glenharold Mine in Stanton, North Dakota, and Decker Mine (near Sheridan, Wyoming) in Montana, USA
Findings: A soil survey must be conducted prior to cover-soil application. Mine spoil physical and chemical analysis, and post-mine land use, will inform appropriate cover-soil characteristics. Replacing topsoil immediately after the stripping operation, when possible. Contrasting texture can complicate cover-soil application. Amendments can improve cover-soil quality and nutrient content. Supplemental maintenance (for example, irrigation, erosion control, fertilization) is necessary for long-term cover-soil quality. Evaluating revegetation and reclamation success is needed to ensure cover-soil application was successful.
Implications: Land managers can use this helpful framework for cover-soil related decision making.
Topics: Mining, Reclamation Practices, Decision Support Tools, GrayLit

Schaid, T.A., Uresk, D.W., Tucker, W.L., and Linder, R.L., 1983, Effects of surface mining on the vesper sparrow in the Northern Great Plains: Journal of Range Management, v. 36, no. 4, p. 500–503.

DOI: https://doi.org/10.2307/3897953
Background: Surface mining is common in the Northern Great Plains of the United States. This disturbance threatens wildlife in the area, though little is known about the effects of mining on avian species. The vesper sparrow (*Pooecetes gramineus*) is a common breeding bird in the Northern Great Plains whose habitat is affected by bentonite mining.
Objectives: The authors compared vesper sparrow densities on unmined native grass-sagebrush habitat, reclaimed mine areas, and un-reclaimed mine areas.
Methods: The study area was divided into three habitat treatments: (1) unmined grass-sagebrush habitat, (2) reclaimed bentonite spoils, and (3) un-reclaimed bentonite spoils, and 92, 200 square meter (m^2) study plots were across all treatments. Vegetation was sampled at all 92 plots in within five randomly located 0.04-hectare (ha) circles using methods described by Wiens (1969, at https://doi.org/10.2307/40166677). Bird counts were conducted along 92, 200 m^2 transects which bisected the plots, from May through July in 1977 and 1978 from 0600 to 0900 hours. Mean vesper sparrow density was calculated per transect per year. Data were analyzed with orthogonal *t*-tests and stepwise forward multiple regression analysis.
Location: An area parallel to U.S. Highway 212 and the Belle Fourche River that extended northwest from Belle Fourche, South Dakota, to Colony, Wyoming, USA
Findings: Grass-sagebrush plots and reclaimed plots had higher occurrences of all species compared to the un-reclaimed plots, including grasses, forbs, and Wyoming big sagebrush. Mean vesper sparrow densities in both study years were significantly higher on the unmined grass-sagebrush than on all mine spoils. All opportunistically found vesper sparrow nests were located under big sagebrush, and none were found on the mine spoil plots. Forbs and grasses were also likely important for vesper sparrow presence.
Implications: Unmined grass-sagebrush habitat had significantly higher vesper sparrow densities, suggesting that surface mining (even when reclaimed) alters vesper sparrow habitat and behavior. Because transplantation of big sagebrush is not economical, land managers should prioritize protecting as much big sagebrush as possible on surface mine lands to ensure post-mining habitat is suitable for vesper sparrow populations.
Topics: Mining, Wildlife/Habitat Data, Reclamation Practices

Scherer, G., and Everett, R., 1998, Using soil island plantings as dispersal vectors in large area copper tailings reforestation, *in* Throgmorton, D., Nawrot, J., Mead, J., Galetovic, J., and Joseph, W., eds., Mining—Gateway to the future, 15th Annual National Meeting of the American Society for Surface Mining and Reclamation, St. Louis, Mo., May 17–21, 1998, Proceedings: American Society for Surface Mining and Reclamation, p. 78–84.

Link (non-DOI): https://www.asrs.us/wp-content/uploads/2021/09/0078-Scherer.pdf
Background: Reclamation of the abandoned Holden copper mine tailings is important due to high scenic and recreational value. The tailings caused airborne dust pollution, had high erosion, and had acidic soil. Initial reclamation involved covering the tailings with gravel. However, previous studies found that gravel was nutrient poor and suggested covering the tailings with small soil islands to assist with revegetation and species dispersal.
Objectives: The authors assessed the success of soil islands as a technique for revegetating and dispersing plant species at the Holden copper mine tailings.
Methods: In 1990–1991, 20 soil islands were constructed from lime-rock, local forest topsoil, gravel, pieces of logs, tree fall, branches, and forest litter. A randomized block design was used to evaluate conifer, alder, and grass species establishment, growth, and dispersal. Seedlings of four conifer species and alder were planted in 1992 on eight soil islands, crossed with four amendment treatments (using two replicates each): (1) compost mixture, (2) compost+lime, (3) compost+fertilizer, and (4) control (no amendment). Height of seedlings were measured and analyzed using analysis of variance (ANOVA). Eight native grass species were seeded with four treatments (using six replicates each): (1) fertilizer, (2) simulated “C load” straw, (3)

fertilizer+straw, and (4) control (no treatment). The same grass species were broadcast seeded on soil island surfaces upwind of treatment blocks. Broadcast seeds were also raked into tailings downwind of the treatment blocks. Individuals of each species were counted in treatment blocks, soil islands, and tailings. Data were analyzed using Kruskal-Wallis methods.
Location: Holden Mine tailings in the central Cascade Mountains of Washington State, USA
Findings: All conifer and alder species established on the soil islands, though not all seedlings survived the treatments; the highest tree survival was on the compost and compost+lime treatments. Alder was the most successful tree species overall. Only four grass species established enough to measure. Mountain brome was the species most adapted to the site. Plots with fertilizer only and straw only had significantly higher establishment than the other two treatments. Grass seedlings were detected up to 11 meters (m) from the soil island seed source.
Implications: Soil islands can serve as revegetation sites for copper mine tailings, and tailings themselves (if covered with gravel) can assist in species dispersal. This method may be more suited for grass species, though alder may also respond positively. Amendment, such as fertilizer or straw depending on species, further aids in successful revegetation.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Schladweiler, B.K., 2009, Comparison of reclamation of coal mines under the Surface Mining Control and Reclamation Act of 1977 and oil and gas sites in Wyoming, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, p. 1196–1206.

DOI: https://doi.org/10.21000/JASMR09011196
Background: Since the enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) technical knowledge of reclamation best practices has grown. However, disturbance characteristics, reclamation practices, and the governing agencies for coal versus oil and gas development are distinct and carry their own complications and short comings. For example, oil and gas versus coal mining have different physical effects on the landscape. Oil and gas disturbance is typically linear due to pipeline construction. Proximity to native vegetation at oil and gas sites promotes reclamation. Reclamation from coal mining is often more challenging because a greater volume of material is moved in a block or given area. While coal mining typically alters the landscape more than oil and gas development, oil and gas disturbance can be larger due to the length of pipelines.
Objectives: This paper serves as an overview of the differences between mining and oil/gas development and reclamation practices in Wyoming. The author covers physical, regulatory, reclamation, and development differences between these types of resource extraction.
Methods: This review summarized the history of mining and regulatory development beginning in the 1930s. Specific data from various agencies in Wyoming were used to quantify the total disturbance by industry in Wyoming. Specific regulations for coal mine reclamation versus oil and gas were taken from the SMRCA and the Wyoming Department of Environmental Quality Land Quality Division (WDEQ-LQD).
Location: Wyoming, USA
Findings: While the US Department of Interior through the SMCRA is supposed to regulate and enforce reclamation, some state agencies, such as the WDEQ-LQD, can also control reclamation at the local level. Under SMCRA and rules from the state of Wyoming, disturbed lands should be reclaimed to a state similar to the surrounding vegetation that also returns or enhances resources for wildlife and aquatic habitat. Many regulations of SMCRA were developed based on the impact of eastern mines to the landscape and did not alter requirements for the west. Coal mines have highly structured bond requirements. Companies must provide bonds to ensure reclamation after completion of mining operations. Bond requirements for oil and gas are dependent upon land ownership and associated governing agency.
Implications: Defining reclamation success even after 30 years of work is still a challenge. Flexibility in definitions of reclamation success and reclamation requirements should be considered for coal versus oil/gas mines due to their unique landscape impacts. Companies are highly incentivized to complete reclamation because state agencies may block future development, investors may consider them a liability, and public awareness may tarnish the company's reputation. The number of regulatory agencies involved in reclamation enforcement makes reclamation for oil and gas companies less straightforward than coal mining operations.
Topics: Mining, Well Pad, Reclamation Policy, Reclamation Standards, GrayLit

Schladweiler, B.K. and Adams, C.L., 2010, Comparison of three vegetation sampling methods on oil and gas sites in southwestern Wyoming, *in* Barnhisel, R.I., ed., 2010 Joint Mining Conference, Pittsburgh, Penn., June 4–10, 2010, Proceedings: The American Society of Mining and Reclamation, p. 993–1004.

DOI: https://doi.org/10.21000/JASMR10010993
Background: Monitoring reclamation outcomes is important for adaptive management and informing reclamation practices. There are many types of monitoring methods that quantify vegetation recovery on oil and gas pads. To produce consistent and time efficient results, however, it is essential to compare these methods in the field.
Objectives: This study looked at three different types of monitoring to quantify which one provided consistent and replicable data while also being sensitive to diversity of lifeforms.
Methods: Vegetation was sampled at 30 reclaimed oil and gas sites using the Bureau of Land Management (BLM) Rawlins Field Office Point Method (RFOP), Point-Line Intercept Transect Method (PLIT), and a Modified Daubenmire Line Transect Method (MDLT). Total vegetation cover, litter cover, rock cover, total cover (total vegetation plus litter plus rock), lifeform cover, the number of each lifeform were collected. Additionally, the amount of time it took to collect and process the data for each measurement type was assessed. Data were analyzed using a multi-response permutation procedure and cluster analysis.
Location: Sweetwater County near Wamsutter, Wyoming, USA
Findings: The multi-response permutation procedure results illustrated that the PLIT method produced results that were significantly different than the RFOP and the MDLT methods for total cover, bare ground, and litter (at p=0.01 and p=0.10), although the three methods were not significantly different at $p \leq 0.10$. This method also produced consistent total cover values and took the least amount of time to implement.
Implications: The point-line intercept transect method should be the preferred method for assessing vegetation post reclamation. The efficiency and consistency of this method can lead to cost savings for companies and consistency in reporting between sites and observers.
Topics: Well Pad, Vegetation Recovery Data, Reclamation Monitoring, GrayLit

Schladweiler, B.K. and Gardner, D.M., 2011, Determining reclamation potential for steep oil and gas sites in the Powder River Basin, Wyoming *in* Barnhisel, R.I. ed., Reclamation—Sciences leading to success, 28th Annual Meeting of the American Society of Mining and Reclamation, Bismarck, N.D., June 11–16, 2011, Proceedings: American Society of Mining and Reclamation, p. 552–566.

DOI: https://doi.org/10.21000/JASMR11010552
Background: Determining reclamation potential at future oil and gas sites by conducting pre-disturbance assessments could reduce costs associated with reclamation and increase the success of reclamation efforts. Assessing the success of low potential sites with steep terrain can inform reclamation practices.
Objectives: This study (1) examined the reclamation potential of sites proposed for oil and gas drilling by assessing existing vegetation and soil characteristics, and (2) assessed the success of previous reclamation on steep terrain sites.
Methods: In 2010, vegetation and soil properties were measured at potential oil and gas locations. Vegetation data collected included: dominant plant species, canopy cover estimate, and associated species. Soil data included: soil depth, physical or soil limiting factors, soil texture, and soil series. These data were compiled into a reclamation potential matrix as a function of erosion potential. Additionally, vegetation characteristics were measured using the point-line intercept transect method at a steep terrain site that was reclaimed 15 years prior to this study.
Location: Northeastern portion of the Powder River Basin west of Gillette, Wyoming, USA
Findings: Reference sites had higher total vegetation cover, mean total ground cover and mean litter/rock cover than the reclaimed site. The authors produced a reclamation potential matrix that describes what slopes, aspects, soil texture and other factors may influence reclamation success. For example: steep, south facing, and sandy sites have low reclamation potential. Alternatively, relatively flat, north and east facing sites with loam soil texture have high reclamation potential. Vegetation at the previously reclaimed site was not significantly different than adjacent reference sites.
Implications: Sites with steep terrain that are characterized as having a low reclamation potential can be successfully reclaimed. One way to increase the potential success on steep terrain is by including erosion control measures.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices, GrayLit

Schladweiler, B.K., Vance, G.F, and Haroian, R., 2003, Evaluation of topsoil depth effects on various plant parameters within a reclaimed area in northeastern Wyoming, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: The American Society of Mining and Reclamation, p. 1086–1098.

DOI: https://doi.org/10.21000/JASMR03011086
Background: Reclamation efforts often focus on increasing vegetative cover and plant production to pre-disturbance levels at the risk of reducing diversity. Additionally, topsoil replacement depths may reduce diversity of plant communities. Understanding how soil depth affects plant diversity can improve plant diversity at reclamation sites.
Objectives: The authors' objectives were to investigate how topsoil depth affects soil characteristics, plant cover, production and diversity following reclamation at coal mines.
Methods: Experimental topsoil treatments of 15, 30 and 56 centimeters (cm) were used at each site and compared to two reference sites were in Upland Grass and Breaks Grass communities. For three consecutive growing seasons, soil and vegetation data were gathered. Vegetation metrics included: vegetation cover, total cover, average number of species, total number of species, and, in only the third growing season, plant production. Soil was collected along transects at 15 cm depth increments relative to where the topsoil met the backfill. Soil samples were analyzed for pH, electrical conductivity (EC), and sodium adsorption ratio (SAR). Shannon-Weiner diversity indices were used to compare diversity between sites.
Location: Powder River Coal Company's (PRCC) North Antelope/Rochelle Coal Mine Complex in Wyoming, USA
Findings: Soil pH and EC were higher in the top 30 cm depths of reclaimed soils than the reference sites. SAR was also higher at reclaimed sites at deeper depths. Reference sites had higher vegetation cover, total cover, and number of species, but did not have higher production than reclaimed sites. Vegetation characteristics did not differ by treatment. Diversity, based on Shannon-Weiner index, varied across sites for all three measurement years. In the second growing season the 30 cm topsoil treatment supported higher plant diversity than the 56 cm topsoil treatment.
Implications: Using native reference sites to monitor success of reclamation is challenging due to the variation in local vegetation structure at undisturbed sites. A shallow depth of 30 cm should be considered for topsoil replacement during reclamation to increase site stability and diversity; 15 cm topsoil depths may be too shallow to reduce rill erosion.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Schuman, G.E., Mortenson, M.C., and Vicklund, L.E., 2012, Effects of Wyoming big sagebrush seeding rate and grass competition on long-term density and canopy volume of big sagebrush and wildlife habitat: Journal of the American Society of Mining and Reclamation, v. 1, no. 1, p. 44–55.

DOI: https://doi.org/10.21000/JASMR12010044
Background: Restoring big sagebrush following disturbance from mining is challenging, but essential for maintaining healthy ecosystems for wildlife such as sage grouse and antelope. Agencies have established that plant density of 1.5 plants per square meter (plants/m^2), shrub height of 18–26.6 centimeters (cm), and 5.5 percent shrub cover is essential for sage grouse habitat, whereas antelope require taller shrub height of 22 to 46 cm and from 5 to 30 percent shrub cover. An examination of seeding rates may illuminate best practices for restoration. In many cases high seeding rates may increase competition and result in poor sagebrush establishment.
Objectives: The authors determined the short- and long-term effects of grass and sagebrush seeding rate on big sagebrush establishment, determined suitability of recovery for sage grouse and antelope, and provided recommendations for future restoration.
Methods: A 56 cm layer of topsoil was spread, seeded with barley, and subsequently mowed to serve as a stubble mulch for the seeding experiment. Big sagebrush seeds were broadcast seeded at three seeding rates (1, 2, and 4 kilograms of pure live seed per hectare [kg PLS/ha]). Grass seeds were drill seeded at seven seeding rates (0, 2, 4, 6, 8, 10, 14 kg PLS/ha). Sagebrush plant

density was measured in 1999 and 2000, and big sagebrush canopy volume and density were measured in 2001, 2002, and 2004. In 2010 these measurements were repeated to evaluate the long-term effects of seeding rates. Additionally, seedling survival and percent cover of Wyoming big sagebrush were quantified.
Location: Belle Ayr West mine south of Gillette, Wyoming, USA
Findings: Grass seeding rates did not statistically affect sagebrush density, even though the highest seeding rate reduced sagebrush density by 50 percent compared to the 0 kg PLS/ha grass seeding rate. However, the highest grass seeding rate did have the highest canopy volume measures for sagebrush in 2010, suggesting a trade-off between sagebrush density and volume. Higher sagebrush seeding rates increased sagebrush plant density. By 2010, average sagebrush canopy volume was 15× greater than in 2004. Additionally, shrub density, cover, and height had recovered to levels desired for critical wildlife habitat.
Implication: Future restoration efforts in Wyoming that target increases to big sagebrush plant communities for wildlife habitat should use lower levels of grass seeding rates and higher big sagebrush seeding rates. Grass seeding rates should fall between 6 and 8 kg PLS/ha and Wyoming big sagebrush seeding rates should be 2 to 4 kg PLS/ha. These seeding rates can lead to stable plant communities for wildlife use, soil stability, and a seed bank for future germination.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices

Schuman, G.E., Vicklund, L.E., and Belden, S.E., 2001, Establishing Wyoming big sagebrush on mined lands in Wyoming, *in* Barnhisel, R.I., Buchanan, B.A., Peterson, D., and Pfeil, J.J., coordinators, Land reclamation, a different approach—18th Annual National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mex., June 3–7, 2001, Proceedings: American Society Mining and Reclamation, p. 39–47.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2001/0039-Schuman.pdf
Background: In the 1970s through 1990s, regulatory and environmental agencies invested considerable research into understanding the ecology, physiology, and reestablishment of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) on disturbed mines in the Great Plains and Great Basin of the western United States. Specific research topics included seed physiology, germination, dormancy, and viability; seedbed ecology; and culture methods for establishment. Wyoming big sagebrush is a critical shrub species in the western United States and successful reestablishment on post-mine disturbance is required for long-term ecosystem function and health.
Objectives: The authors reviewed literature on reestablishing Wyoming big sagebrush on disturbed mine lands in the western United States and compared seeding method and costs to make informed reclamation recommendations.
Methods: The authors discussed considerations regarding sagebrush seed size, harvesting, processing, and germination. They reviewed the literature on the effect of seedbed characteristics on sagebrush establishment, and the literature on additional considerations including transplanting nursery grown seedlings, the use of “seed production plots” or “facilitation bed,” direct seeding methods, and associated costs based on method and seed availability.
Location: This is a literature review and does not involve a specific field site location
Findings: A literature reviewed showed that Wyoming big sagebrush density decreased as grass seeding rate increased and some researchers suggested overseeding sagebrush as a buffer. Direct seeding was more cost effective than transplanting nursery grown seedlings, even at increased seed costs. In 1996, the Wyoming Department of Environmental Quality declared a reestablished shrub density requirement of 1 shrub per square meter (shrub/m^2) on 20 percent on coal mine lands.
Implications: Research into Wyoming big sagebrush has improved scientific understanding of the species and provided important recommendations for successful sagebrush reestablishment. Further research could focus on direct seeding and higher quality seed production.
Topics: Mining, Target Plant Recovery Data, Reclamation Practices, GrayLit

Scoles-Sciulla, S.J., and DeFalco, L.A., 2009, Seed reserves diluted during surface soil reclamation in eastern Mojave Desert: Arid Land Research and Management, v. 23, no. 1, p. 1–13.

DOI: https://doi.org/10.1080/15324980802598698

Background: In desert ecosystems seed reserves and nutrient cycling occurs in the upper portion of soils. Since these seedbanks are easily disturbed and precipitation is highly variable, revegetation of disturbed landscapes can take centuries. Soil reclamation after a disturbance typically involves collection and storage of surface soil pre-disturbance and respreading it during reclamation. However, the suitability of these techniques in arid regions are largely untested. Stockpiling soil can injure and bury seeds as well as alter soil structural and hydrologic function.
Objectives: The authors evaluated if and when seed reserves decreased during reclamation by testing how seed germination was affected after mechanical collection, stockpiling, and reapplying after disturbance.
Methods: Soil was collected during road construction with a bulldozer and stored nearby throughout the summer months. Temperature loggers were deployed in stockpiles at 20, 50, and 70-centimeter (cm) depths and at the soil surface in undisturbed areas. Soil cores were collected at undisturbed sites, in stockpiled soils at depths matching the temperature loggers, and after soil reapplication at a 5–20 cm depth interval. Soil was analyzed for bulk density and gravimetric soil water content. In a greenhouse, field soil was put in pots and several treatments were applied, including various watering applications and chemical additions (ammonium nitrate and gibberellic acid). Seedlings were counted and identified upon emergence. Perennial plant establishment, cover, and density were measured at reclaimed sites with ages varying from 0.5 to 7 years.
Location: Lakeshore Scenic Drive in the Boulder Beach District of Lake Mead National Recreation area (36°05′ N., 114°50′ W.), northeast of Boulder City, Nevada
Findings: The undisturbed soil on average had a germinable seed density of 752 per square meter (m^2) and reapplied surface soil had 97/m^2. Seed reserves within the stockpiled soil declined 86 percent compared to the original germinable seed, with the greatest reduction in seed density (79 percent) occurring during soil collection; there was negligible loss during the 4-month soil storage and soil replacement steps. Within the stockpiled topsoil, germinable seeds were more likely to be found at greater proportions at the 20 cm depth, followed by the 70 cm depth, then the 50 cm depth, although these results were derived from samples with low over all germination, among which over 50 percent had no germination. Low overall seed number prevented statistical tests of the influence of abiotic conditions on germinable seeds, although stockpiled soil was on average 5.7 °C cooler and had 12 times more soil moisture than undisturbed soils. Less than 1 percent perennial plant cover was apparent at sites 7 years after stockpiled soil was reapplied (compared to 5 percent average in undisturbed control areas), and no cover was observed from 0.5 to 5 years after respreading. Outplanting of creosote bush on reclaimed sites increased percent ground cover and density at one site.
Implications: Mechanical collection of soil dilutes seed reserves by mixing seed with lower soil layers. Soil collection for ecosystems with shallow seed banks by itself is not sufficient for restoring native vegetation after disturbance. Collecting surface soils by double stripping for soil collection may reduce soil mixing and increase the abundance of germinable seeds after respreading. Seed reserves in stockpiled soils may suffer from cool and moist conditions that increase fungal activity and false germination. Reclamation in desert ecosystems should also include reseeding and spreading of litter and plant material from the collection area.
Topics: Road, Vegetation Recovery Data, Soil Data, Reclamation Practices

Semborski, C.A., and Oakley, D.C., 2006, Des Bee Dove Mine complex a challenge in the reclamation of a pre-SMRCA site, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society Mining and Reclamation, p. 625–652.

DOI: https://doi.org/10.21000/JASMR06010625
Background: The Des-Bee-Dove Mine complex, located in southeastern Utah, was in operation from the late 1890s through the late 1990s. It was developed before the Surface Mining and Control Act of 1977 with no consideration for future reclamation. Under the Utah Division of Oil Gas, and Mining, a reclamation plan was developed that included using existing on-site soil resources to reestablish the land's original contours and stabilize and protect reclaimed slopes with a diverse vegetation population.
Objectives: The authors reviewed and assessed the planning process and outcomes of reclamation at the Des-Bee-Dove Mine complex in southeastern Utah.

Methods: The mining and acquisition history of the Des-Bee-Dove mine was briefly reviewed, and the environmental conditions of the mine pre-reclamation were described. Reclamation preparation methods were discussed, as well as revisions to the reclamation plan, trench examinations, and Phase 1 and 2 of reclamation, which involved incorporation of weed-free hay by pocking in a random pattern, broadcast seeding, and hydromulching with wood fiber and tackifier. Reclamation success to date was summarized.
Location: Des-Bee-Dove Mine complex in Emery County approximately 13 kilometers north of Orangeville in southeastern Utah, USA
Findings: Roughly 215,000 cubic meters (m^3) of on-site spoil and soil were used for recontouring. Roughly 270 kilograms (kg) of native seed and 3,500 bare root and containerized plants were planted. The authors noted “rich and diverse” vegetation and stable soils in Phase 1 reclamation areas 4 years following installation. Three years after reclamation was completed, native perennial grasses and woody plants began outnumbering nonnative annuals; the overall revegetation provided slope stabilization. The site received state approval for Phase III Bond Release in August 2014.
Implications: This case study provides an example of reclamation planning, revising, and implementing for land managers with similar site characteristics. It is also an example of successful reclamation efforts.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, GrayLit

Sewell, H.J., and Carr, S., 2009, Restoring sagebrush habitat in the Pinedale Anticline natural gas field in Wyoming, *in* The Society of Petroleum Engineers Americas E&P Environmental & Safety Conference, San Antonio, Tex., March 23–25, 2009, Proceedings: Society of Petroleum Engineers, 13 p.

DOI: https://doi.org/10.2118/120980-MS
Background: The Pinedale Anticline natural-gas field is located in a sagebrush-dominated steppe that provides critical habitat for large ungulate populations and greater sage-grouse. Over 90 percent of the land is under jurisdiction of the Bureau of Land Management (BLM) and past reclamation has focused on site stabilization using a grass-dominated seed mix. However, this seed mix is based on criteria for grazing range management and does not meet requirements for sagebrush steppe restoration. Developing a new seed mix and addressing poor topsoil conditions and limited precipitation are necessary to ensure successful reclamation and long-term ecosystem function in the region.
Objectives: Researchers developed and tested a “habitat” seed mix of mostly native shrubs, forbs, and grasses to restore the surrounding sagebrush steppe vegetation community and reduce surface environmental impacts of the natural gas development. They used two drilling techniques and several treatment variables, including overseeding, fencing, and soil amendments.
Methods: In 2004, 14 locations were seeded with a “habitat” seed mix using hydroseeding, drill seeding, or overseeding protocols. Several sites received soil amendments and fencing to restrict grazing. Locations were reseeded where necessary in 2008 to supplement weak plant germination presumably due to drought conditions occurring from fall 2005 to spring 2006. Locations were monitored every spring/summer season from 2005 to 2008 using vegetation line and belt transects. In 2008, on-site/off-site vegetation transect pairs were monitored on all locations seeded in 2004 and 2006.
Location: Pinedale Anticline field, Upper Green River basin, southwestern Wyoming, USA
Findings: Sagebrush stands were successfully established on all primary seeded locations from 2004, potentially due to high rainfall, except at one drill-seeded location. While drill seeding and hydroseeding in 2004 were both successful in establishing sagebrush stands, hydroseeding was unsuccessful in 2005 under drought conditions. Additionally, grass and forb production lagged on hydroseeded sites compared to drill-seeded sites. A lesser-grazed, partially fenced site had more shrubs than a nearby grazed, unfenced location. Weed populations were reduced in topsoil stockpiles by seeding those stockpiles in the first season following construction. Effects of soil amendments was difficult to quantify, though application did reduce high levels of sodium, sulfur, and soluble salts and increase general levels of organic matter.
Implications: The timing of precipitation events is important for successful reclamation. The “habitat” seed mix can successfully establish native sagebrush, shrubs, some forbs, and grass species of the sagebrush steppe ecosystem. Drill seeding delivers seeds more consistently and may be more successful under drought conditions. Temporary fencing on reclaimed areas to allow seedlings to establish and delay grazing pressures is necessary. Soil amendments are believed to improve soil stability and may be useful in sites with difficult soils; however, this study did not yield quantitative evidence for these techniques.
Topics: Well Pad, Vegetation Recovery Data, Soil Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Shackelford, N., Miller, B.P., and Erickson, T.E., 2017, Restoration of open-cut mining in semi-arid systems–A synthesis of long-term monitoring data and implications for management: Land Degradation & Development, v. 29, no. 4, p. 994–1004.

DOI: https://doi.org/10.1002/ldr.2746
Background: Detailed monitoring following mine reclamation (restoration) is necessary for evaluating program success. However, monitoring can be complex, and data can be difficult to synthesize over long periods of time. While the Society of Ecological Restoration has nine attributes of "recovered ecosystems," most restoration monitoring programs assess only a handful of these attributes. Long-term datasets allow for assessing relatively consistent restoration approaches over time.
Objectives: The authors evaluated 10 years of monitoring data to assess restoration performance over time and techniques that may shape such performance into the future.
Methods: Restoration and monitoring data were collected by BHP Billiton Iron Ore on six mining operations were acquired; these included 272 transects on >99 sites using the Ecosystem Function Analysis method 2004–2010, and 90 transects on >84 sites using the revised Rehabilitation Development Monitoring method 2011–2013. Overall community composition relative to reference sites were assessed using nine univariate response variables (total vegetation cover, total vegetation density, perennial grass cover, perennial grass tussocks/hummocks density, woody species cover, woody species density, native species richness, compositional dissimilarity from reference sites, and non-native species cover) and three explanatory variable sets (site descriptors, restoration techniques, and weather).
Location: Mining operations in the semi-arid Pilbara region of northern Western Australia
Findings: Overall restoration performance was highly variable. Woody density and cover were most similar between restored and reference site; restored sites often had higher values of both variables, though this was not reflective of pre-mine conditions. Perennial grass hummock density and cover were generally lower on restored sites and significant changes were made to improve regeneration of these species (for example, *Triodia* spp.). Species richness was generally higher on restored compared to reference sites. Older restoration sites had increased cover and density of all vegetation types compared to newer restoration sites. Reference and restoration sites had more similar composition on low-impact mining sites, when rainfall in the first year of restoration was higher, and with no seeding treatments.
Implications: Restoration outcomes varied with site-specific conditions and environmental conditions. Gathering long-term data on mine restoration is necessary despite the challenges. Early year restoration success can be improved by considering germination and recruitment limitations, variable environmental conditions, and mining impacts.
Topics: Mining, Vegetation Recovery Data, Reclamation Practices, Reclamation Monitoring

Sheoran, V., Sheoran, A.S., and Poonia, P., 2010, Soil reclamation of abandoned mine land by revegetation—A review: International Journal of Soil, Sediment and Water, v. 3, no. 2, 20 p.

Link (non-DOI): https://scholarworks.umass.edu/intljssw/vol3/iss2/13
Background: Successful reclamation of disturbed mine lands requires restoring or reestablishing soil conditions, microbial communities, and plant communities. Managing topsoil is necessary for revegetating disturbed lands. Often, amendments (for example, fertilizer, compost, biosolids, wood) are added to topsoil to increase nutrient content and cycling. Soil mycorrhizae are an additional key component of soil health, revegetation, and long-term reclamation success. After disturbance, restoring the land's biological productivity is paramount for reestablishing a functioning ecosystem for future land use goals.
Objectives: The authors reviewed literature on the factors necessary for successful revegetation of reclaimed mines.
Methods: The authors reviewed soil properties (physical, biological, and chemical) necessary for plant growth, how to manage mine spoil and topsoil for plant and soil productivity, the importance of revegetating disturbed mine lands, and how to assess reclamation effectiveness.
Location: This is a review paper and does not involve a specific field site location
Findings: Reestablishing appropriate soil conditions (for example, nitrogen [N] and carbon [C] content) is required for soil health and revegetation. Soil microbial communities should be reestablished to assist with nutrient cycling. Initial revegetation should focus on promoting self-sustaining future growth. Reclamation assessments should include both above- and belowground biomass surveys.
Implications: The review is a useful tool for land managers interested in reclaiming mine lands and provides an overview of necessary considerations and management techniques.
Topics: Mining, Soil Data, Reclamation Theory, Reclamation Practices

Shrestha, G., Stahl, P.D., and Ingram, L., 2005, Influence of reclamation management practices on soil bulk density and infiltration rates on surface coal mine lands in Wyoming, *in* Barnhisel, R.I., ed., 22nd Annual Meeting of the American Society of Mining and Reclamation, Breckenridge, Colo., June 19–23, 2005, Proceedings: American Society of Mining and Reclamation, p. 1042–1056.

DOI: https://doi.org/10.21000/JASMR05011042
Background: Surface mining affects several natural processes, including soil bulk density (BD), a measure of soil compaction, and saturated infiltration rate (K_s), a measure of the amount of water entering the root zone and exiting as runoff. To reestablish sustainable and pre-mine processes, a variety of land reclamation methods are used including surface mulching, grazing management, topsoil management, and seeding. Understanding the impact of variations within these methods on BD and K_s can elucidate which may be most effective for successful reclamation.
Objectives: The authors (1) examined the effects of various reclamation methods (direct hauling versus stockpiling topsoil, hay versus stubble mulching, grazing versus no grazing, and grass versus shrub seeding) on BD and infiltration rate, (2) compared the effects of these methods on reclamation efforts, and (3) compared BD and K_s between reclaimed sites with these methods and undisturbed sites.
Methods: Four pairs of reclamation methods were tested: direct hauling versus stockpiling topsoil, hay versus stubble mulching, grazing versus no grazing, and grass versus shrub seeding and compared adjacent undisturbed sites. For each treatment at each mine, soil was sampled along three randomly placed 100 meter (m) transects (two replicate samples were collected at 40 m intervals. For BD measurements, soil was collected in columns at depth intervals of 0–5 centimeters (cm), 5–15 cm, and 15–30 cm. K_s was also measured at all replicate points. BD was calculated using gravimetric method. Data were analyzed using general linear models and Tukey's post-hoc analysis. Treatments were compared within mine sites but not across them.
Location: Reclaimed areas of the following surface coal mine sites: Belle Ayre (BA), Jacob's Ranch (JR), and Dave Johnson (DJ) in the Powder River Basin; Jim Bridger (JB) in the Green River Basin; and Seminoe (Sem) in the Hanna Basin, all in Wyoming, USA
Findings: BD differed by treatment within each mine, with significant differences found at JB, DJ, and Sem. No significant differences were found at BA. Interactions between depth and treatment yielded significant differences at JR. For all sites except BA, K_s differed significantly between reclaimed and undisturbed sites, though not always between compared management methods. In general, BD was low across all samples indicating relatively uncompacted soils. BD and K_s were inversely related, though for undisturbed sites, BD was lower compared to reclaimed sites, but K_s was not always greater.
Implications: Different reclamation methods had varied effects on soil characteristics, with an overall positive impact on soil BD and K_s. K_s specifically can be improved using stubble mulching and seeding.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Simmers, S.M., and Galatowitsch, S.M., 2010, Factors affecting revegetation of oil field access roads in semiarid grassland: Restoration Ecology, v. 18, no. S1, p. 27–39.

DOI: https://doi.org/10.1111/j.1526-100X.2010.00716.x
Background: Roads associated with oil and gas development can leave lasting impacts to the vegetation community, including higher amounts of invasive species, bare ground, and lower diversity. The methods used to revegetate roads can impact the ability of the road to recover to be more like the surrounding vegetation.
Objectives: The authors analyzed the vegetation community on a number of reclaimed roads by comparing the roads with the nearby vegetation community and explored patterns in the restoration area over time.
Methods: Fifty-eight roads that had been revegetated between 1983–2001 were assessed for this study. A number of transects (depending on the length of the road) were installed perpendicular to the roads. Within quadrats going out from the center of the roads, species were identified, and vegetation cover classes were recorded. Each road was visited once, taking two summer growing seasons to collect all the data. Data were analyzed using nonmetric multidimensional scaling.
Location: U.S. Department of Agriculture, Forest Service; Medora and McKenzie management districts (405,000 hectares [ha] between latitudes 46°16′–48°08′ N., and longitudes 102°39′–104°02′ W.) in western North Dakota, USA

Findings: Restored roadways had lower plant richness, more grasses, fewer shrubs and forbs, more abundant invasive and nonnative species, and double the bare ground when compared to the surrounding native plant community. Over time, differences in plant composition within the restored roadways were best explained by changes in seed mixes (trend from seeding nonnatives to seeding more native species), and age of restoration, with older sites having more late-successional species. Three grass species had low success, though commonly used in seed mixes, and several species that were not as common in seed mixes established well when seeded.
Implications: Adequate record-keeping is essential for evaluating restoration outcomes; without such records, secondary evidence and assumptions render evaluation insufficient or impossible. Restoration success reflects organizational capacity and competence. Reclamation practices could be improved by considering abiotic factors and improving seed mixes. Differences in vegetation composition in the small linear disturbances compared to adjacent native prairie suggested that conditions for germination and persistence of native vegetation was poor due to abiotic factors on the roadways. Seed mixes could be improved by eliminating species with poor establishment and including more species with a higher likelihood of persistence. Finally, it will take more than two decades for a roadway to successfully be restored, and this trajectory can be improved with careful site preparation and choice of seeded species.
Topics: Road, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, Reclamation Monitoring, Reclamation Standards

Sindelar, B.W., 1984, Vegetation development on surface mined land in eastern Montana, *in* Dvorak, A.J., Ecological studies of disturbed landscapes—A compendium of the results of five years of research aimed at the restoration of disturbed ecosystems: U.S. Department of Energy, Office of Scientific and Technical Information, DOE/NBM-5009372 (DE85009372), p. 6-1–6.32.

Link (non-DOI): https://www.osti.gov/biblio/5506382
Background: 1n 1975, little was known about reclamation potential following coal surface mining. Many states passed strict acts to require productivity and function be restored to disturbed lands. Several problems are associated with rehabilitation of disturbed arid ecosystems, such as topsoil removal and replacement. However, few studies had been conducted to provide input for reclamation methods. Realizing this lack of basic knowledge, a long-term study was established on strip mines at Colstrip, Montana, to investigate revegetation success in the semiarid environment.
Objectives: The author assessed plant establishment and succession, stability and persistence of plant communities, and the rate of concurrent soil and vegetation development on strip mined land.
Methods: In 1975, permanent exclosures were established on 15 study sites; 13 sites were on mine spoil, one site was on unmined native range, and one was a pipeline construction site. Reclamation sites were seeded in 1969, 1970–1975, and 1977. Naturally vegetated sites were leveled and abandoned in 1928 and 1930. At each site, three 20-meter (m) transects were set up, one with 10, 0.75 square meter (m^2) quadrats that were stereophotographed twice each growing season, one with 40, 20 × 50 m quadrats for ground and canopy cover, and one with 20, 15 square centimeter (cm^2) quadrats for plant density plus 10, 0.5 m^2 quadrats for above-ground biomass. Cover data were collected twice each growing season. Density data were collected biweekly during the growing season. Above-ground biomass was harvested by species twice each growing season. Below-ground biomass was sampled in 1978 with a coring procedure. Soil moisture was sampled at each site at six depths biweekly during the growing season and simultaneously, soil temperature was recorded. Color and infrared low-level aerial photographs were taken at each site.
Location: A coal strip mine in the Northern Great Plains region near Colstrip, Montana, USA
Findings: Weather, spoil-soil characteristics, and reclamation practices were the leading factors that affected plant establishment and initial succession; competitive interaction among species was also important. Spoil higher in clay and silt had more advanced plant communities compared to spoil high in sand due to differing infiltration and percolation rates and water holding capacities. When cover crops were sparse/absent and introduced grasses excluded, the species diversity trended towards a naturally vegetated community of native plants. Shrubs were an important species on the landscape pre-mining, but mostly absent post-reclamation. Generally, succession on reclaimed land trended towards that on native range. Reestablishing life-form (grass, shrub, forb) composition and seasonality were major reclamation challenges.
Implications: Land and reclamation managers of disturbed land in semiarid and arid environments should consider site-specific conditions and reclamation objectives (for example, post-mine land use and revegetation goals) before selecting topsoil handling and revegetation methods. Precipitation will play a major role in reclamation and should be considered in planning.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Smith, P.W., Depuit, E.J., and Richardson, B.Z., 1988, Plant community development on petroleum drill sites in northwestern Wyoming: Journal of Range Management, v. 41, no. 5, p. 372–377.

Link (non-DOI): https://www.jstor.org/stable/3899569
Background: Oil and gas development likely affects soil and plant community regeneration in distinct ecological life zones differently. Understanding the nuances of ecological succession and soil properties can illuminate how plant communities rebound after oil and gas development and inform reclamation practices.
Objectives: The authors (1) evaluated how time since abandonment affected vegetation community dynamics and soil properties in two vegetation types: sagebrush woodland and coniferous forest in Wyoming, and (2) investigated the impacts of seeding and natural regeneration of native species on these abandoned mine sites.
Methods: Mines 3 to 33 years since abandonment were monitored for this project. Data were collected at 40 random points at each site in 1982 using the Daubenmire quadrat method. Measurements included canopy cover, ground cover, soil texture, organic matter, pH, cation exchange capacity, electrical conductivity, bulk density, and mineral composition.
Location: Bridger-Teton National Forest of northwestern Wyoming, USA
Findings: Disturbed soils had higher bulk density, higher pH, and lower organic matter compared to undisturbed areas. Shrub and tree seedling establishment in sagebrush communities occurred more quickly than in the conifer forest. Seeding accelerated the establishment of native vegetation (even when nonnative seeds were used), but at different rates in the two vegetation types. Species composition, regardless of age, differed between disturbed and undisturbed sites.
Implications: Quick recovery of arid ecosystems after disturbance is unrealistic; however, vegetation does become more similar to the surrounding undisturbed landscape over time. Reducing impacts to soil during drilling operations could increase vegetation recovery. Vegetation types and ecological communities will recover at different rates but can be improved by active reclamation techniques, such as seeding.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices, Reclamation Standards

Stahl, P.D., Anderson, J.D., Ingram, L.J., Schuman, G.E., and Mummey, D.L., 2003, Accumulation of organic carbon in reclaimed coal mine soils of Wyoming, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 1206–1215.

DOI: https://doi.org/10.21000/JASMR03011206
Background: One of most detrimental impacts of surface coal mining is the loss of soil organic matter (SOM) and organic carbon (C) when topsoil is striped, stockpiled, then respread during reclamation. These substances are necessary for capturing water and maintaining overall soil quality. Proper management techniques have the potential to enable disturbed soils to sequester soil C and function yet again as a large C sink, but empirical data supporting this are limited.
Objectives: The authors sought to advance existing literature with preliminary research on organic C sequestration and accumulation in soil on reclaimed surface coal mines.
Methods: Soil was collected in 1983, 1997, 2000, 2001, and 2002 from various sites at three reclaimed surface coal mines from depths of 0–30 centimeters (cm). Soil was also collected at undisturbed sites for comparison. Organic C content was determined using the Walkley-Black method and Carlo-Erba C and nitrogen (N) analyzer. Microbial biomass was quantified using the chloroform fumigation extraction method.
Location: Rosebud, Dave Johnston, and North Antelope-Rochelle Complex surface coal mines in the Powder River Basin in northeastern Wyoming, USA
Findings: Over time, organic C content in reclaimed soils surpassed that found in undisturbed soils. However, native soils had higher soil microbial biomass (SMBC) than reclaimed soils.

Implications: This study suggests that reclaimed soil can sequester organic C, in some cases in higher amounts than undisturbed soils. However, SMBC did not recover after reclamation, possibility due to changes in soil structure that reclamation efforts did not address. More research is needed to determine if the observed sequestration of organic C by reclaimed soils is sustainable in the long term.
Topics: Mining, Soil Data, GrayLit

Stahl, P.D., Ingram, L.J., Wick, A.F., and Rana, S., 2006, Relating mineland reclamation to ecosystem restoration, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 695–702.

DOI: https://doi.org/10.21000/JASMR06010695
Background: “Reclamation” and “restoration” have traditionally been defined differently, with reclamation meaning to reconstruct a disturbed site to some level of habitability by organisms present pre-disturbance and restoration meaning to return a disturbed site to the exact condition it was pre-disturbance. Over time these terms have somewhat merged, as the realization that returning a site to the exact previous conditions (restoration as described above) is near impossible. However, the goals of reclamation and restoration still differ. Understanding the characteristics of successfully reclaimed lands as they relate to characteristics of restored ecosystems can improve long-term reclamation success.
Objectives: The authors reviewed 10 years of data on ecosystem recovery on reclaimed surface mines to relate successful reclamation characteristics to those of successfully restored ecosystems.
Methods: The authors discussed mine land reclamation versus ecosystem restoration definitions and goals. They compared attributes of restored ecosystems as stated by the Society for Ecological Restoration International (2004) to 10 years of observed characteristics of reclaimed surface coal mines in Wyoming according to the Wyoming Department of Environmental Quality (WDEQ) Wyoming Coal Rules and Regulations (2005).
Location: This is a review paper and does not involve a specific field site location
Findings: Ten years of research shows that many attributes of restored ecosystems are fulfilled by reclamation efforts and that reclaimed mine lands have the potential to be self-sustaining into the future.
Implications: Reclamation is a form of ecosystem restoration. However, because reclamation assessments focus on plant community characteristics, the impacts of reclamation on other organisms are generally not assessed. This results in an incomplete picture of reclamation success as it pertains to ecosystem restoration, which could be improved if land managers included non-plant organisms in reclamation assessments.
Topics: Mining, Reclamation Policy, Reclamation Theory, Reclamation Standards, GrayLit

Stahl, P.D., Perryman, B.L., Sharmasarkar, S., and Munn, L.C., 2002, Topsoil stockpiling versus exposure to traffic—A case study on in situ uranium wellfields: Restoration Ecology, v. 10, no. 1, p. 129–137.

DOI: https://doi.org/10.1046/j.1526-100X.2002.10114.x
Background: Managing soil subjected to disturbance like surfacing mining is critical for successful revegetation and land reclamation. Removing topsoil and stockpiling until the disturbance is complete or leaving topsoil exposed to the disturbance are two methods often employed in reclamation, both of which may have negative consequences. Topsoil removal and storage can result in loss of vegetation, destruction of soil structure, habitat loss, and other serious detrimental effects on soil physical chemical and biotic properties; leaving soil in situ during mining can result in compaction due to vehicular activity, causing reduced pore space, increased bulk density, and altered hydraulic properties. For in situ uranium mining, topsoil management generally involves removing about 15 percent of topsoil in disturbed areas leaving the rest exposed to vehicle traffic, which can destroy vegetation. Topsoil management strategies should be evaluated for any negative impacts they may have.
Objectives: The authors evaluated which of two methods, removing all topsoil and stockpiling until surface mining disturbance is complete or leaving soil on site allowing exposure to mining disturbance, resulted in less-negative impacts on soil and vegetation.

Methods: Soil samples were collected from uranium mining well pad sites on fine-textured soil where topsoil was either: (1) removed, stockpiled, replaced, and seeded, (2) left in place during mining and then seeded, (3) stockpiled but not replaced, or (4) removed subjecting subsoil to mining disturbance. In addition, samples were collected from nearby undisturbed areas. Soil properties were compared among samples, including pH, bulk density, organic matter content, electrical conductivity (EC), available phosphorous (P), total nitrogen (N), available nitrate, arbuscular spore content, and microbial biomass carbon (C). Water infiltration rate was measured using cylinder-type infiltrometers. Percent herbaceous vegetation cover and aboveground biomass were measured at Highland Uranium site (Irigaray Ranch was not seeded). Soil data were analyzed using single factor analysis of variance (ANOVA) and post-hoc analysis; vegetation data were analyzed using paired *t*-tests.
Location: Highland Uranium Project (44°00′ N., 106°15′ W.) near Glenrock, Wyoming, and the Irigaray Ranch Uranium Mine (43°00′ N., 105°45′ W.) near Pumpkin Buttes, Wyoming, USA
Findings: Removing, stockpiling, and replacing topsoil more negatively impacted soil properties (particularly soil biota and total N), than leaving topsoil exposed to in situ uranium mining activity. There was no evidence that vehicle traffic on in situ uranium well pads led to soil compaction. Soil microorganisms and vegetation recovered more quickly on in situ soil than on removed and respread topsoil.
Implications: While removing and stockpiling soil is a common and useful practice in the mining industry, it can have negative consequences to soil and vegetation that should be considered before implementing this approach.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Stahl, P.D., Wick, A.F., Dangi, S., Regula, V., Ingram, L.J., and Mummey, D.L., 2009, Ecosystem recovery on reclaimed surface minelands, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, v. 3, p. 1371–1393.

DOI: https://doi.org/10.21000/JASMR09011371
Background: Mine reclamation ultimately aims to restore disturbed lands for long term function and sustainability. However, reclamation assessments focus heavily on plant communities and largely ignore other organisms. While more recent research has explored soil microbial community response to reclamation, the scientific tools exist for directly assessing multiple characteristics (that is, various organisms) of ecosystem structure and function after reclamation.
Objectives: The authors compared the ecological structure and processes of differently aged, reclaimed mine lands to undisturbed reference sites to assess reclamation recovery.
Methods: Two chronosequences of reclaimed surface coal mines were established, though this paper is limited to one chronosequence which included: (1) a topsoil stockpile 10–18 months old, (2) two reclaimed sites dominated by cool season grasses (14–15 and 26–27 years old), and (3) an undisturbed site. Soil samples were collected from depth intervals of 0–5 centimeters (cm) and 5–15 cm at five evenly spaced points along three, randomly-placed 45 meter (m) transects at each site. Five soil samples were collected for bulk density using a double-cylinder hammer driven core sampler. Aboveground biomass was assessed in five 1 square meter (m^2) plots and plant cover was recorded at 100 points along a 50 m transection within each plot. Soil samples were analyzed for physical properties and nutrient content. Water stable aggregate size distribution was determined using the wet sieving protocol, corrected for sand, and analyzed for carbon (C) and nitrogen (N) content. Particulate organic matter analysis was then performed. Soil microbial community structure was determined using the phospholipid fatty acid (PLFA) methodology. Arthropod and nematode communities were also assessed.
Location: Dave Johnston (43°03′ N., 105°82′ W.) and Belle Ayer (44°10′ N., 105°27′ W.) surface coal mines in the Powder River Basin in northeastern Wyoming, USA
Findings: Plant community composition differed across time due to succession with the greatest diversity at the undisturbed site. Soil N and C were reduced up to 70 percent but increased over time. Macroaggregate proportions peaked at 14 years post-reclamation. Microbial communities differed over time but peaked around 14 years post-reclamation. Arthropod and nematode communities recovered over time though differed with soil depth.
Implications: This study suggests that multiple ecosystem components (soil structure and plant, soil microbe, arthropod, and nematode communities) do recover over time following reclamation of surface coal mines. However, more studies that assess biodiversity post-reclamation are needed.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, Reclamation Standards, GrayLit

Stahl, P.D., Wick, A.F., Ganjegunte, G., Norton, U., and Ingram, L.J., 2009, Redevelopment of soil carbon pools on reclaimed surface mine lands, *in* 26th Annual Meeting of the American Society of Mining and Reclamation and 11th Billings Land Reclamation Symposium, Billings, Mont., May 30–June 5, 2009, Proceedings: American Society of Mining and Reclamation, v. 3, p. 1348–1370.

DOI: https://doi.org/10.21000/JASMR09011348
Background: Soil organic matter (SOM) represents the majority of carbon (C) found in soils and contributes greatly to soil physical, chemical, and biological characteristics. Surface mining disturbs soil and leads to a degradation and loss of SOM and associated functions. Reclamation can restore SOM and improve soil condition through the reestablishment of soil C pools.
Objectives: The authors assessed soil C pool recovery on reclaimed surface coal mines and identified the mechanisms that protect reestablished soil C pools.
Methods: Two chronosequences were established on reclaimed surface coal mines: (1) at the shrub-dominated Dave Johnston Mine, with reclamation areas <1, 5, 10, and 16 years old, plus an undisturbed control site, and (2) at the cool season grass-dominated Belle Ayr Mine, with a <1 year old topsoil stockpile, and reclamation areas that were 14 and 26 years old, both of which had topsoil replacement and similar perennial grass seed mixes. Soil was collected from interval depths of 0–5 centimeters (cm), 5–15, and 15–30 cm at four evenly spaced points along three randomly placed 45 meter (m) transects at each site. Samples were composited by transect for SOM analysis. Five soil samples were collected for bulk density using a double-cylinder hammer driven core sampler. Soil physical properties and nutrient content were also assessed. Soil lignin was determined from subsamples of all three depths. Soil aggregate size distribution was determined using the wet sieving protocol and analyzed for C and nitrogen (N) content. Finally, C availability for microbial mineralization was quantified.
Location: Dave Johnston (43°03′ N., 105°82′ W.) and Belle Ayer (44°10′ N., 105°27′ W.) surface coal mines in the Powder River Basin in northeastern Wyoming, USA
Findings: Lignin in SOM and soil aggregate associated C in both chronosequence reclaimed sites were greater or equal to undisturbed sites. Potentially mineralizable C concentrations in reclaimed soils were comparable to undisturbed soils after 5–6 years.
Implications: Lignin and soil aggregates are important for building up soil C pools on reclaimed surface coal mines. Recovery of soil C pools is influenced by plant community type; land managers should consider which plant community would best fit their site characteristics and foster soil health.
Topics: Mining, Soil Data, Reclamation Practices, Reclamation Standards, GrayLit

Strager, M.P., Hentz, A.M.K., Kinder, P., and Grushecky, S., 2020, Using unmanned aerial vehicles to model surface runoff during well pad development: Journal of the American Society of Mining and Reclamation, v. 9, no. 1, p. 51–69.

DOI: https://doi.org/10.21000/JASMR20010051
Background: Unmanned aerial vehicles (UAVs), or drones, have great potential for monitoring the effects of oil and gas well pad construction on environmental processes through their ability to quickly capture permanently recorded data of landscape features. UAV technology has benefited oil and gas development in several ways and could further assist with identifying possible future hydrological and runoff issues by recording real time well pad construction and resulting landscape alteration.
Objectives: The authors used UAV-collected imagery to identify key locations for controlling total suspended solid runoff from the construction of oil and gas well pads.
Methods: An unconventional oil and gas site was selected which relied on natural pressure of wells and pumping or compression operations for extraction. UAV imagery was collected with 80 percent overlap between images using a DJI Phantom 4 Pro with a red-green-blue (RGB) camera from ~80 meters (m) above ground. Eight targets were used for georeferencing. Agisoft Photoscan was used to align images and create a density point cloud, orthophoto, and digital elevation model. 3D structures were estimated from 2D image sequences, and a digital surface model was created using structure from motion UAV processing technology. A hydrologically corrected elevation surface was produced using the surface model in an ArcGIS model. Impervious surfaces were classified and loading rates were assigned to the classes following methods adapted from previous studies. The digital elevation model and hydrological grid outputs were used to estimate water quality and total suspended solids across the landscape.

Location: An unconventional oil and gas site ~40 kilometers west of Morgantown in Monongalia County (39.6216° N., -80.2786° W.), West Virginia, USA
Findings: Three locations were identified as focus areas for managing runoff based on flow patterns and total dissolved solids calculations. Placing sediment control devices at these locations would help mitigate harmful downstream impacts of well pad runoff and the estimated 35 milligrams per liter (mg/L) total dissolved solids load.
Implications: UAV technology is a valuable tool that can provide important real time information on the impacts of oil and gas well pad construction to the surrounding landscape. Land managers and the energy industry should consider the use of UAVs to help mitigate negative ecological impacts of oil and gas extraction and guide reclamation plans.
Topics: Well Pad, Hydrology Data, Reclamation Monitoring, GrayLit

Sylvain, Z.A., Branson, D.H., Rand, T.A., West, N.M., and Espeland, E.K., 2019, Decoupled recovery of ecological communities after reclamation: PeerJ, v. 7, article e7038.

DOI: https://doi.org/10.7717/peerj.7038
Background: Fully restoring ecological communities on land disturbed for energy development is necessary for long-term ecosystem function and land management. However, oil and gas land reclamation efforts often focus on plant species while ignoring other organisms, like soil nematodes. Examining reclamation results with a multi-trophic approach provides a more complete evaluation of reclamation success and post-oil and gas disturbance condition.
Objectives: The authors assessed reclamation outcomes on oil and gas fields with a multi-trophic approach to determine if reclamation successfully restored soil, plant, and nematode communities to pre-disturbance condition.
Methods: Fourteen reclaimed oil and gas well sites (“reclaims”) were selected with time since reclamation ranging from 2 to 33 years. Three 100 meter (m) transects were established on all reclaims and similar transects were established on undisturbed sites 50 m and 150 m away from reclaim edges. Vegetation was sampled: species were identified, categorized as native or exotic and invasive or ruderal, and cover was measured in 5 percent increments. Soil was also sampled at 15 points on either side of transects by randomly placing a 20 × 50 centimeters (cm) Daubenmire frame up to 7.5 m away; subsamples were combined for two bulk samples per transect. Soil nematode samples were collected from 10 soil cores combined for bulk sample per plot within 50 × 20 m plots centered along transects. Nematodes were extracted using the Baermann funnel method. Nematode density, soil characteristics, and plant cover data were averaged for one value per transect. Data were analyzed by mixed model analysis of variance (ANOVA), regression testing, nonmetric multi-dimensional scaling ordinations, and a Structure Equation Model.
Location: Little Missouri National Grassland (between latitudes 47.404°–47.743° N., and longitudes 103.394°–104.041° W.) in western North Dakota, USA
Findings: Total plant richness was lower on reclaims compared to undisturbed sites due to lower native species richness on reclaims. Native species cover was also lower on reclaims. Reclaims had higher exotic species richness, which increased with time. Plant communities on reclaims and undisturbed sites were significantly different. Electrical conductivity, salts, calcium (Ca), sodium (Na), and pH were all significantly higher, and percent silt significantly lower, on reclaims. Nematodes increased with soil pH and soil organic matter and decreased with increasing bare ground, and community trophic structure did not appear to differ between reclaims and undisturbed sites, though total nematode abundance was lower on reclaims. Few significant relationships existed between abiotic factors and biotic communities.
Implications: Reclamation of oil and gas wells failed to restore pre-disturbance plant communities and soil characteristics, even after 33 years since reclamation. Nematode communities seemed to have been restored in trophic structure but not in total abundance, potentially due to the prevalence of bare ground on reclaimed areas, although this study did not capture possible species-level changes. Using diverse seed mixes and incorporating soil amendments can result in more successful reclamation to pre-disturbance conditions.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices

Tannant, D., and Smith, K., 2018, Evaluation of a low-cost drone for monitoring restoration of well pads: BC Oil and Gas Research and Innovation Society, prepared by University of British Columbia, School of Engineering, 59 p.

Link (non-DOI): https://www.bcogris.ca/files/projects/pre/hs-2018-01-uav-land-disturbance-reclamation-final-tannant-ubco.pdf

Background: Small low-cost drones can autonomously capture aerial imagery, which could be used to monitor reclamation of well pads. Products from the aerial images may better capture reclamation success and enable well operators to receive a Certificate of Restoration. To receive this certificate well operators must meet criteria in five categories: geotechnical stability, land use or facilities affecting reclamation, vegetation growth, slope and drainage, and soil replacement and quality.
Objectives: The authors assessed if small low-cost drones can adequately capture reclamation progress on well pads based on the British Columbia Oil and Gas Commission criteria for successful reclamation.
Methods: Five well pads were selected on three clustered sites approximately 8 kilometers (km) west of Hudson's Hope. A fourth site, with three well pads, was located 7.4 km northwest of Hudson's Hope, and a fifth site, with one well pad, was located at Universal Transverse Mercator (UTM) zone 10, 6250275 N., 551306 E. In most cases, a Phantom 4 Pro drone (approximately $2,100) was programmed to fly a grid pattern under autonomous control with PixCapture software. Drones were flown at 50 meters (m) for 5–15 minutes to acquire aerial imagery at each of the five sites. Flights captured 1,000 points per square meter (points/m^2). Pix4d (version four) software was used to perform Structure-from-Motion photographic analysis to produce 3D point clouds, digital surface models, contour maps, and geo-referenced orthophotos. The data that could be quantified using the aerial images which applied to assessing the reclamation objectives required for certification were assessed.
Location: Nine well pads at five sites on crown land near Hudson's Hope, British Columbia, Canada
Findings: Imagery from drones captured the distribution and coverage of vegetation. 3D topographic models enabled detection of small changes to topography. Slopes, slumping, subsidence, and tension cracks are apparent in the drone imagery. In wooded areas aerial imagery detected adjacent sources of disturbance hidden by tree cover that may not be detected from a ground level assessment. The drones captured dramatic vegetation change at four well pads flown in July and September 2017. Programmed drone flights gave operators time to walk the well pads and record observations at a ground-level.
Implications: Drone imagery provides a more detailed assessment of reclamation success than the standard site inspection. Therefore, drone-photography and ground inspections should be conducted simultaneously. Well operators should use drone imagery to archive their well pads restoration efforts to achieve a Certificate of Restoration. Drones are especially beneficial for inaccessible sites. Flying drones immediately after reclamation activities can improve the reliability of bare-earth topography models.
Topics: Well Pad, Vegetation Recovery Data, Erosion Data, Reclamation Monitoring, GrayLit

Toy, T.J., 1989, An assessment of surface-mine reclamation based upon sheetwash erosion rates at the Glenrock Coal Company, Glenrock, Wyoming: Earth Surface Processes and Landforms, v. 14, no. 4, p. 298–302.

DOI: https://doi.org/10.1002/esp.3290140405
Background: Erosion control is a major goal of mine reclamation. However, there is little research documenting soil erosion on mined lands in the United States. Comparing sheetwash erosion rates on reclaimed and natural hillslopes provides a basis for understanding the effects of erosion on seed, fertilizer, and topsoil used during reclamation.
Objectives: The author compared sheetwash erosion rates on natural and reclaimed hillslopes.
Methods: Ten reclaimed and eight natural hillslopes were selected based on their soil properties, hillslope aspect, land use, grading method, and the seed mix used. Half of both slope types were east facing and the other half west-facing. Sheetwash erosion was measured using the Linear Erosion/Elevation Measuring Instrument from March 1981–June 1985.
Location: Dave Johnson Mine operated by Glenrock Coal Company in east-central Wyoming, USA
Findings: Over the study period, the natural hillslopes experienced a net -2.7 millimeters (mm) of sheetwash erosion while the reclaimed hillslopes experienced a net -4.1 mm of sheetwash erosion. Erosion rates varied within and between hillslope type (natural or reclaimed) depending on elements (curvilinear unities including convexities and concavities) and segments (straight units) within the hillslope profiles. Concave elements had notably different erosion rates between natural and reclaimed hillslopes. All hillslopes experienced annual cycles of positive and negative changes in surface elevation due to frost-heave and surface erosion.
Implications: Reclaimed hillslopes may erode slightly more over time than natural hillslopes though the difference may not be significant. The difference should decrease through time as the revegetation matures. Additionally, erosion rates are affected by underlying landscape geomorphological features. Reclamation practices that reduce erosion as much as possible can support successful revegetation.
Topics: Mining, Erosion Data, Reclamation Practices

Udy, S., 2019, Assessing amendment treatments for sodic soil reclamation in arid land environments: Logan, Utah, Utah State University, master's thesis, 130 p.

DOI: https://doi.org/10.26076/2dda-cc66
Background: The Uintah Basin in northeast Utah has a long history of natural resource extraction, including oil and gas operations that begin in the 1940s. Soil in the basin is shallow and saline-sodic, which greatly complicates well pad reclamation. Improving soil quality with amendment could increase native revegetation and reclamation success; testing and comparing various amendments in the lab could led to more informed choices for field studies. Saline-sodic soils form surface crusts (due to clay aggregate breakdown and dispersion). Methods for analyzing surface crusts are limited and antiquated, though technological advances have allowed for new methods. Assessing the accuracy of newer methods could make surface crust analysis more accessible to land managers with limited computer software knowledge and access.
Objectives: The author (1) evaluated the effectiveness of soil amendments (gypsum, biochar, sulfuric acid, and activated carbon [C]) at reducing soil sodicity, and (2) compared novel methods of surface crust analysis to their respective original method to determine new method accuracy.
Methods: The author collected two saline-sodic test soil substrates from a Pariette Wetland pond (Desilt sediment) and five active oil pads with an exchangeable sodium percentage >15 percent that represented soils found throughout the Uintah Basin (conglomerate). They characterized the chemical, physical, and structural properties of test soils. They applied eight amendment treatments (gypsum, sulfuric acid, biochar, activated C, and several combinations) and a control for a total of 18 treatments; each combination had three replicates. They analyzed percent dispersion, hydraulic conductivity, surface crusts and density, infiltration flux, and clay mineralogy and compared across treatments using generalized linear modeling. They analyzed surface crust using (a) ImageJ crust bulk density and clod density methods and (b) linear extensibility percent and modified linear extensibility percent methods; they compared methods within each pairing with a correlation coefficient (r).
Location: Analyses were performed in a lab with soil collected from the Uintah Basin in northeast Utah, USA
Findings: Gypsum formed within soil pores, increasing crust bulk density and infiltration. Biochar and activated C had little impact on soil parameters and sodicity. Sulfuric acid significantly improved several soil parameters (that is, saturated hydraulic conductivity, infiltration flux, and crust bulk density); compared to the control, the sulfuric acid treatment had increased pore space and aggregation. Crust bulk density methods were strongly correlated for Desilt soil (r=0.81) but not for the Conglomerate soil (r=0.32). Linear extensibility percent methods were moderately to strongly correlated for Desilt and Conglomerate soils.
Implications: In the Uintah Basin, and regions with similar soil conditions, sulfuric acid is the only tested substance recommended for use as a soil amendment. However, field trials should be conducted to incorporate environmental variables and test seed germination with sulfuric acid application. ImageJ crust bulk density method was not accurate due to shrink-swell properties of the soil and the modified linear extensibility percent method was accurate but not as efficient as the original method, clod density.
Topics: Well Pad, Soil Data, Reclamation Practices, GrayLit

Um, J.-S., and Wright, R., 2000, Effect of angular field of view of a video sensor on the image content in a strip target—The example of revegetation monitoring of a pipeline route: International Journal of Remote Sensing, v. 21, no. 4, p. 723–734.

DOI: https://doi.org/10.1080/01431161.2020.12088651
Background: Traditional area-based sensors, like aerial photography, are ill-suited for monitoring long, linear corridors (for example, gas lines, utility roads) due to a wide cover angle which often includes excessive information and can confuse classification of imagery content.
Objectives: The authors investigated whether video sensing, with a narrow-coverage-angle, can obtain acceptable imagery of revegetation monitoring along a pipeline compared to the current standard of aerial photography.
Methods: The visibility of ground features pertinent to monitoring revegetation recovery on pipeline right-of-ways (ROWs) were evaluated using video imagery and aerial photography simultaneously from the same altitude and under the same illumination conditions. Video imagery was acquired with an S-VHS camera at various coverage angles and focal lengths at two altitudes (300 meters [m] and 600 m) and the video imagery was used to determine the optimal ground coverage for monitoring the pipeline corridor. Video imagery was compared with vertical aerial photography acquired using Zenza Bronica medium format (55 square millimeters [mm^2]) camera. The consistency of airborne video was evaluated by investigating the feature content in an image from different landscape widths.
Location: Experimental site at Carnwath Moss moorland, part of Shell's North West Ethylene Pipeline in the United Kingdom

Findings: Video imagery was able to isolate major ground-cover types of a narrow pipeline ROW with good spatial precision due to its narrow angle of coverage. The aerial photography, with a wide angle of coverage, contained redundant data and did not have the necessary pixel size. The video sensor at a 64 m swath provided imagery that could be classified into six categories. Narrower swath video did not meaningfully improve ground-cover detail required for monitoring purposes. The level of feature detail in an image was not a function of the coverage angle.
Implications: Airborne videography should be considered for strip target monitoring in general as it is more cost-effective than aerial photography and adequately captures ground level detail. Ultimately, the appropriate coverage angle depends on the information desired about the ground scene and the spatial structure of the scene itself.
Topics: Pipeline, Vegetation Recovery Data, Reclamation Monitoring

U.S. Environmental Protection Agency [EPA], 2007, The use of soil amendments for remediation, revitalization, and reuse: EPA, Office of Superfund Remediation and Technology Innovation, EPA 542-R-07-013, 57 p.

Link (non-DOI): https://www.epa.gov/biosolids/use-soil-amendments-remediation-revitalization-and-reuse
Background: Disturbed and contaminated landscapes can benefit from cost-effective remediation, revitalization, or reclamation methods. Soil amendment application is one such method that can increase cleanup success and long-term results.
Objectives: The authors provided regulators, consultants, site owners, and other stakeholders with information on soil amendments for remediation, revitalization, and reuse of disturbed and contaminated landscapes.
Methods: The authors introduced the need for soil amendment and importance of soil conditions for vegetation growth and health. They described various problems that can be addressed with soil amendments. They discussed types of sites where soil amendments can be used (like natural resource extraction operations) and the possible contaminants, problems, and solutions. They detailed the types of soil amendments, suitable application situations, costs, benefits, and challenges. They suggested logistical considerations to consider with soil amendment application and possible revegetation planning. They reviewed the regulatory requirements for using soil amendments. They summarized the environmental, health, economic, and other advantages of using soil amendments. They described the U.S. EPA's web-based tool to help land managers select technical performance measures to verify soil amendment effectiveness.
Location: This is a methods-review and does not involve a specific field site location
Findings: Soil residual materials and byproducts such as municipal biosolids, animal manures and litters, sugar beet lime, wood and fly ash, log yard waste, neutralizing lime products, composted biosolids, agricultural byproducts, and traditional agricultural fertilizers can reduce toxicity and bio/phytoavailability of contaminants, neutralize pH, reduce excess salts (salinity and sodicity), and increase micronutrients like zinc and manganese. Amendment transportation and storage should be strategically planned to reduce costs. Regulations like the Resource Conservation and Recovery Act ensure amendments are not harmful waste products, though care should be taken when blending amendments.
Implications: Soil amendments are cost effective in situ methods for reclamation of disturbed lands. This article provides tables for determining which types of amendments are appropriate for what conditions at different types of sites. Ultimately, the type of soil amendment and application rate depend on site-specific conditions, post-disturbance land use, reclamation goals, and funding availability.
Topics: Well Pad, Reclamation Practices, Reclamation Monitoring, Decision Support Tools, GrayLit

Vance, G.F., and Spackman, L.K., 1999, Is it topsoil or overburden? Case study of a small mine in Wyoming, *in* Bengson, S.A., and Bland, D.M., eds., Mining and reclamation for the next millennium, 16th Annual National Meeting of the American Society for Surface Mining and Reclamation, Scottsdale, Ariz., August 13–19, 1999, Proceedings: American Society of Mining and Reclamation, p. 209–224.

DOI: https://dx.doi.org/10.21000/JASMR99010209
Background: Regulating the use of topsoil as overburden by a Wyoming gravel-mining operation was discussed in the Wyoming Supreme Court due to its importance in governing future reclamation efforts. Separating topsoil from overburden is important to ensure surface mine operators use only the highest quality material in reclamation efforts.

Objectives: The authors wanted to assess the chemical and physical properties of topsoil, subsoil, and native soil at the gravel mine in question, and determine quality of soil types for cool- and warm-season grass growth.
Methods: Soil samples were collected from topsoil and subsoil stockpiles and from natural areas with a bucket auger. Soil samples were analyzed for chemical and physical properties. Greenhouse experiments were conducted using topsoil, subsoil, and natural area soils to grow cool- and warm-season grass species to assess soil quality.
Location: Small, privately owned gravel mine east of Casper, Wyoming, USA
Findings: Chemical, physical, and textural analyses revealed topsoil was well suited and subsoil was marginally suited for use as surface cover in gravel mine reclamation. Native soils outperformed both stockpile samples and were of highest quality. Cool-season grasses outperformed warm-season grasses. Species growth differed among soil samples though; generally speaking, topsoil samples were most productive.
Implications: Wyoming surface mine reclamation protocol should distinguish among topsoil, subsoil, and overburden as each has distinct chemical and physical properties.
Topics: Mining, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Vasek, F.C., Johnson, H.B., and Eslinger, D.H., 1975, Effects of pipeline construction on creosote bush scrub vegetation of the Mojave Desert: Madroño, v. 23, no. 1, 13 p.

Link (non-DOI): https://www.jstor.org/stable/41423976
Background: In the Mojave Desert, revegetation after pipeline construction (which includes trenching, piling, and refilling) is likely affected by the degree of aridity in the disturbed area. However, quantitative estimates of revegetation following pipeline construction in the Mojave Desert are lacking. The dominant plant community in the desert is creosote bush (*Larrea tridentata*) scrub and understanding the effects of pipeline construction on revegetation succession of this plant community is important for reclamation success in the desert.
Objectives: The authors assessed secondary succession of creosote bush scrub revegetation along a pipeline with a 12-year since reclamation reference frame.
Methods: Ten sample areas were selected along a 33.8-kilometer (km) segment of a pipeline right of way. In each sample area, four 50 × 2-meter (m) belt transects were set up in two control plots and two disturbed areas. In 1972, perennial plant and ground cover were measured and calculated for each transect. Species were categorized as long-lived perennials, pioneer shrubs, pioneer perennial herbs, and other perennials and counted. Ground cover across transects within sample areas was compared using Jaccard's coefficient of community similarity and the proposed Community Quality Index (equal to the square root of the product of percent ground cover by long-lived perennials and percent total perennial ground cover).
Location: Southern California Gas Company natural gas pipeline between Newberry and Lucerne Valley, San Bernardino County, California, USA
Findings: Ground cover varied widely among the 10 sample areas, likely due to localized differences in topography, slope, exposure, elevation, substrate, and general climate, and prevented comparison among sample areas. On control transects, *L. tridentata* ground cover ranged from 0 to 94 percent and *Ambrosia dumosa* from 0 to 27 percent. Jaccard's coefficient above 0.7 indicated near identical conditions, but values varied in both comparisons between the control transects and comparisons between the disturbed transects at each sample area. Revegetation quality and success varied greatly among the sample areas, but some experienced significant revegetation for long-lived species.
Implications: Revegetation time depends on a number of ecological and biological factors in the Mojave Desert creosote bush scrub plant community. The plant community is fragile and easily disturbed so extreme care should be taken to reduce disturbance from oil and gas operations. In some cases, revegetation can occur 12 years after reclamation, though this varies widely depending on landscape characteristics, and it is more likely full revegetation will take centuries.
Topics: Pipeline, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Monitoring, Reclamation Practices

Vasquez, E.A., and Sheley, R.L., 2018, Developing diverse, effective, and permanent plant communities on reclaimed surface coal mines—Restoring ecosystem function: Journal of the American Society of Mining and Reclamation, v. 7, no. 1, p. 77–109.

DOI: https://doi.org/10.21000/JASMR18010077
Background: Under the Surface Mining Control and Reclamation Act, permittees must reclaim surface coal mines to recreate their original topography and productivity, implying the recreation of services such as grazing, wildlife habitat, and cultural sites. To ensure that reclaimed mines will successfully sustain these ecosystem services, the metrics used to assess reclamation must go beyond evaluation of plant community composition and structure to consider whether the processes necessary to maintain ecosystem function have also been re-established, such as hydrologic function, soil and site stability, and biotic integrity. Overall, the most successful reclamation strategies will be process-oriented, integrate self-repair mechanisms, and will consider the interactions between the reclaimed mine site and the larger landscape context.
Objectives: The authors discussed the ecological processes driving ecosystem function, methods for reestablishing ecological processes, and the implications of integrating ecologically based management principles into reclamation procedures.
Methods: The authors reviewed current research and principles behind ecological processes affecting the reconstruction of ecosystem function, including landform integrity, hydrological processes, soil and site stability, and integrity of soil biology (soil organic matter, nutrient availability, and soil microbes). They reviewed difficulties of growing plants in a variety of challenging soil conditions and presented possible solutions for restoring ecosystem function, such as assisted plant community succession and considerations for creating seed mixes. They outlined how principles from Ecologically-based Invasive Plant Management can also be used to inform reclamation practices. They also assess how the traditionally short time frames associated with implementing reclamation action and conducting site monitoring can impact the success of the reclaimed landscape.
Location: This is a review article and does not involve a specific field site location
Findings: Geomorphic reclamation approaches can help reestablish pre-mine hydrological functions. Water infiltration into the soil is a limiting factor in seedling reestablishment but can be improved by amending the soil and preventing soil crust development. Soil erosion and runoff control are necessary to ensure long-term site stability and revegetation, as are soil organic matter, nutrient content, and microbes. Topsoil handling practices can be carefully selected to retain soil nutrients and microbial activity, and to limit spread of exotic species propagules. Sourcing local plant materials that are adapted to site conditions and applying seed mixtures with site-appropriate functional groups can improve ecosystem function restoration. Monitoring programs used to evaluate reclamation outcomes can integrate indicators of the status of ecological processes such as soil stability, plant spatial distribution, and plant community vigor.
Implications: Reclamation practices can be more successful when they are site-specific, tailored to the desired post-mine land use, and focus on restoring ecosystem processes to enable to creation and maintenance of desired ecosystem functions. Using metrics which allow for monitoring of ecological processes, rather than those which only monitor species-specific responses to reclamation, can aid in evaluating whether the post-reclamation landscape will be sustainable and capable of providing the desired long-term services.
Topics: Mining, Reclamation Theory, Reclamation Practices, Reclamation Standards

Vicklund, L.E., Schuman, G.E., and Mortenson, M.C., 2011, Effects of Wyoming big sagebrush seeding rate and grass competition on long-term density and canopy volume of big sagebrush and wildlife habitat, *in* Barnhisel, R.I. ed., Reclamation—Sciences leading to success, 28th Annual Meeting of the American Society of Mining and Reclamation, Bismarck, N.D., June 11–16, 2011, Proceedings: American Society Mining and Reclamation, p. 678–689.

DOI: https://dx.doi.org/10.21000/JASMR11010678
Background: Successful establishment of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) after mine disturbance is necessary for maintaining a functioning healthy ecosystem in much of the western United States. Standard reclamation practice includes seeding a mixture of grass, forbs, and shrubs; however, research has shown that grass competition can limit sagebrush establishment. The Wyoming Department of Environmental Quality (WDEQ) has mandated a minimum

shrub density of one shrub per square meter (m^2) on 20 percent of reclaimed coal mine lands when the post-mine land use includes wildlife habitat. Competition from grasses can negatively impact big sagebrush establishment but minimizing grass seeding rates could increase sagebrush density.
Objectives: The authors determined the effect of various grass and Wyoming big sagebrush seeding rates on big sagebrush seedling establishment.
Methods: A split-plot randomized complete block experimental design with three sagebrush seeding rates (1, 2, and 4 kilograms of pure live seed per hectare [kg PLS/ha]) and seven grass seeding rates (0, 2, 4, 6, 8, 10, and 14 kg PLS/ha) was established. Rates were randomly assigned to 6.5 × 27-meter (m) plots within each of four 27 × 45.5 m replicate blocks. Grasses (*Pascopyrum smithii* western wheatgrass, *Elymus lanceolatus* thickspike wheatgrass, and *Elymus trachycaulus* slender wheatgrass) were drill seeded. Treatment plots were divided into three 6 × 9 m subplots and randomly broadcast seeded with the sagebrush rates. Multiple 1 m^2 quadrats were established to assess sagebrush density (measured 1999–2002, 2004, 2010) and canopy volume (measured 2001, 2002, 2004, 2010). Sagebrush seedling survival was monitored and percent cover for each quadrat was determined.
Location: Belle Ayre coal mine (44°17′ N., 105°30′ W.) in the Powder River Basin near Gillette, Wyoming, USA
Findings: This article compared 2004 to 2010 for long-term survival and growth. Although the higher grass seeding rates tended to have lower sagebrush densities and the highest seeding rate (14 kg PLS/ha) was associated sagebrush density (50 percent of that where no grass was seeded), the analysis did not find that grass seeding rates was a significant predictor of sagebrush density. Mean sagebrush density exceeded the mandated 1 shrub/m^2 in both 2004 (3 shrubs/m^2) and 2010 (2.2 shrubs/m^2). Sagebrush seeding rate was positively correlated with sagebrush density. In 2004, sagebrush canopy volume (cubic centimeter [cm^3]) was negatively correlated with grass seeding rate, though the relationship was reversed in 2010. Sagebrush canopy volume (cm^3/m^2) was variable within both years of measurement, although increased tenfold on average from 2004 to 2010. Canopy was highest in the 0 and 4 kg PLS/ha rates in 2004 and highest in the 14 kg PLS/ha rate in 2010, which may be associated with the noted lowest sagebrush density at that seeding rate. Across all treatments, average sagebrush height, cover, and density was reestablished to what other research has considered adequate or good habitat levels for antelope and sage grouse. At the higher sagebrush seeding rates (2 and 4 kg PLS/ha), sagebrush densities also exceeded recommended density targets set for general sage grouse use (2.2 shrubs/m^2) and approached targets for nesting (2.9 shrubs/m^2).
Implications: A 13-year research study documents the reestablishment of quality Wyoming big sagebrush habitat. These results, combined with additional studies, suggest that successful practices for meeting and exceeding density, canopy, and height requirements include grass seeding rates of 6–8 kg PLS/ha and Wyoming big sagebrush seeding rates of 2–4 kg PLS/ha.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Wildlife/Habitat Data, Reclamation Practices, GrayLit

Vincent, R.B. and Hoy, R.N., 2003, Assessing the feasibility of developing technical standards to evaluate revegetation success at coal mines in the Southern Powder River Basin of Wyoming, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society for Mining and Reclamation, p. 1350–1380.

DOI: https://dx.doi.org/10.21000/JASMR03011350
Background: The authors tested a dataset curated by the Wyoming Department of Environmental Quality (WDEQ), Land Quality Division Coal Rules and Regulations. The purpose of the dataset was to use baseline vegetation on a mine site as the reference condition during reclamation, and to develop technical standards for reclamation. This study used the database to answer several questions important to reclamation efforts.
Objectives: This study analyzed vegetation and climate data for a number of mines in a region to investigate if mine sites were similar enough to influence standards for reclamation for the region.
Methods: This study used data for five mines, each mine was sampled three different years over 12 years between 1978 and 1999. The authors chose two broadly distributed plant communities (mixed-grass prairie and big sagebrush shrubland) to compare vegetation cover and presence of desired species (not invasive species) within a mine, among mines, and as related to precipitation.
Location: Southern Powder River Basin in the northeast corner of Wyoming, USA

Findings: Datasets for the individual mines were significantly different and most of the data violated assumptions of normality. Sampling methods (point-intercept and quadrat) gave statistically significant results for cover data. Herbaceous species production was correlated with precipitation at the small area of an individual mine, but correlation among mine sites in the entire basin was confounded by other factors, such as sampling method.
Implications: The results of this study show that making standards for the entire Southern Powder River Basin could be difficult, but the data could support standards for individual mine sites if the standards were based on conservative measures of vegetation estimates.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Monitoring, Reclamation Standards, GrayLit

Waaland, M.E., and Allen, E.B., 1987, Relationships between VA mycorrhizal fungi and plant cover following surface mining in Wyoming: Journal of Rangeland Management, v. 40, no. 3, p. 271–276.

Link (non-DOI): https://www.jstor.org/stable/3899096
Background: Naturally occurring vesicular-arbuscular mycorrhiza (VAM) fungi are important for soil function and health. However, surface mining disturbance in arid western states negatively impacts VAM fungi and can eliminate localized populations. It is possible that VAM abundance contributes to succession rates in mined lands, but more research is needed.
Objectives: The authors examined relationships of VAM spore density and root infection and plant cover among reclaimed mine sites (1–6 years old), orphan (no reclamation) mine sites (10–31 years), and native undisturbed sites.
Methods: Several reclaimed sites representative of different soil substrates and ages (but on similar topography) were sampled at the Kemmerer Coal Mine: four sites were reclaimed with topsoil, three sites were reclaimed with spoil, four sites were reclaimed with orphan spoil, and one site was a native undisturbed area. At each site, plant cover was estimated within eight 1 × 1.5-meter (m) quadrats placed along five 20 m transects. Soil samples were taken from the center of each quadrat to measure eight soil variables (nitrogen [N], phosphorous [P], pH, bulk density, organic matter, and percent sand, silt, and clay). Root samples were also collected within quadrats, from the abundant shrub species (*Atriplex canescens, Chrysothamnus nauseosus, Artemisia tridentata,* and *Artemisia arbuscula*) and from two grass species (*Agropyron smithii* and *A. dasystachyum*), for mycorrhizal spore analyses. Roots were stained with trypan blue to assess percent VAM infection, and spores were extracted from remaining soil samples using sucrose flotation method to calculate spore density. Data were analyzed with stepwise regressions.
Location: Kemmerer Coal Mine in southwest Wyoming, USA
Findings: Soil nutrient variables differed by site with no apparent relationship to time on reclaimed or orphan sites. Plant species presence differed among sites; annuals decreased with time in reclaimed spoil, but no trends were apparent for reclaimed topsoil or orphan sites. Percent cover of perennial grasses increased over time on reclaimed sites while shrub cover increased over time on east facing aspects at all sites. Total percent cover was higher on east versus west facing aspects. Percent VAM root infection was lower on younger (reclaimed) compared to older (orphan and native) sites. VAM spore density was lower in spoil than topsoil.
Implications: VAM fungi recolonized naturally within the first year after revegetation, originating from adjacent native vegetation. While percent root infection tended to be highest in native soil, plants in all previously mined substrates and ages became mycorrhizal. The density of VAM spores, which is an indication of soil inoculum density, was related more to soil type than time, and may also be related to plant species as some early successional colonizing species do not form mycorrhizal relationships. The study shows the importance of using topsoil to promote inoculum density.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices

Wagner, A., Buchanan. B., Owens, M., and Redente, E., 2006, Second year transplant survival on constructed test plots, Questa Mine, Questa, New Mexico, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society Mining and Reclamation, p. 652–655.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2006-Billings/0656-Wagner.pdf
Background: In 2003, Molycorp, Inc. established a test program at the Questa Mine in New Mexico to determine the best methods for revegetation of the mine's rock piles. The test program involved plots with various slopes, cover soil depth, amendments, seeding methods, and seedling transplantation.
Objectives: The authors summarized second year results of a revegetation test program on the Questa Mine in New Mexico.
Methods: In 2003, plots were constructed which represented three slope classes: (1) 2:1 slopes, (2) 3:1 slopes, and (3) flat slopes. Treatments were applied within each plot, including: (a) no cover soil, (b) 30 centimeters (cm) of cover soil, and (c) 90 cm of cover soil. Cover soil was mixed with an amendment treatment that depended on the slope: flat slopes received either no amendment (control), a mycorrhizal inoculant/forest soil treatment (1,120 kilograms per hectare [kg/ha]), or a fertilizer (67 kg phosphorus pentoxide/ha) treatment; sloped plots received either no amendment (control) or a mycorrhizal treatment/forest soil treatment (1,120 kg/ha). All plots were mulched. Flat plots were drill seeded and hydroseeded; sloped plots were only hydroseeded. Roughly 27,000 tree and shrub seedlings (categorized as nurse species, crop species, or shrub species) were transplanted at two planting rates: 1,510 nurse species trees/ha and 2,115 nurse species trees/ha. Seedling survival was monitored. Seedling survival mean were compared for each test plot and various subplots; second year survival data were presented in this report.
Location: Questa Mine near the Village of Questa in New Mexico, USA
Findings: Overall mean seedling survival was highest on the 2:1 slope test plots (65.6 percent). Across all plots, seedling survival was statistically higher on cover soil treatment plots (regardless of depth) compared to control (no cover treatment) plots and slightly higher on 30 cm depth plots than 90 cm depth plots. Across all plots, mycorrhizal and fertilizer treatments slightly improved survival compared to controls. Survival did not differ between seeding treatments.
Implications: While these data are preliminary, they suggest that 90 cm of cover soil may not provide additional survival benefits and that 30 cm of cover soil may be as beneficial for seedling survival and more cost effective. Mycorrhizal inoculant or fertilizer may increase survival. Seeding method was not a factor in seedling survival and may not be as important a consideration for land mangers (though site conditions should be considered).
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Wagner, A., Owens, M., and Buchanan, B., 2006, Plant community establishment on reclaimed molybdenum tailings, Questa Tailings Facility, Questa, New Mexico, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 656–658.

DOI: https://doi.org/10.21000/JASMR06010656
Background: Reclamation success hinges on long-term monitoring and planning. Final reclamation plans can be informed by assessing plant communities and cover soil on mine tailings at different years since interim reclamation. Based on results, future reclamation plans can be adjusted or modified.
Objectives: The authors assessed existing plant communities and cover soil depth at four tailing basins with different periods of interim reclamation to inform final reclamation plans.

Methods: Locations were identified in four tailings areas representing different reclamation periods (1970, 1980, 1993–1994, and 1998–2004). A 50-meter (m) point-intercept transect was established at each sampling location and used to estimated total and perennial plant cover. Shrub density was estimated using a 2 × 50 m belt transect placed parallel to each cover transect. Cover soil depth was estimated at two random locations along each sampling transect. Sampling occurred in groups of five until sampling adequacy was met (20–50 sampling locations per area).
Location: Four tailing basins at the Questa Tailing Facility near Questa, New Mexico, USA
Findings: Total plant cover (22.9–31.4 percent) and perennial plant cover (22.3–31.2 percent) did not vary much over time and followed similar patterns (lower on the oldest and most recently reclaimed tailings and higher on the intermediate-aged, reclaimed tailings). The number of species per transect was almost identical over time, though there were two fewer species on the most recently reclaimed tailing. Shrub density was six times higher on the oldest (2,302 shrubs/acre) than the most recently reclaimed tailing but highest on the 1993–1994 reclaimed tailing (3,255 shrubs/acre). Statistical analysis indicated cover soil depth had a significant effect on total cover, perennial cover, and shrub density but not number of species per transect.
Implications: This study provides an assessment of reclamation over time and cover soil depth on selected mine tailings, information that can help direct future and final reclamation plans at the site.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Wagner, W.L., Martin, W.C., and Aldon, E.F., 1978, Natural succession on strip-mined lands in northwestern New Mexico: Reclamation Review, v. 1, p. 67–73.

Link (non-DOI): https://www.osti.gov/biblio/5247926
Background: Documenting natural revegetation on previously mined, but untreated lands, is important for understanding how natural vegetation may be altered by mining disturbance. Such studies have occurred in the midwestern and eastern United States, but they are not informative of what may be happening in the southwestern United States due to different ecological and environmental conditions.
Objectives: The authors compared plant species composition and diversity on mined and unmined lands to better understand species colonization rates on mined lands in the southwest.
Methods: Eight mined and three unmined sites varying in age from 13 years to 1 year since reclamation were used in the study. At each site, 516 circular plots were placed along randomly selected transects. Species were identified in each plot and classified for dominance based on visual assessment. An Importance Value was calculated for each species by multiplying the average dominance value by the frequency. Plant species diversity was assessed in relation to topography (predominately on the unmined sites). Importance Values were compared across all sites.
Location: McKinley Coal Mine in northwestern New Mexico, five kilometers east of Windowrock, Arizona, USA
Findings: Overall, species diversity was greater on the unmined sites than all mined sites. Mined sites varied in species diversity with no apparent pattern based on age and seemed to be in early seral stages despite age differences. Mined sites contained mostly introduced annuals compared to unmined sites dominated by native perennials and woody species.
Implications: Reclamation seed mixes should focus on native species that are natural colonizers to help establish a natural successional pattern. For southwestern New Mexico, such species could include *Atriplex canescens*, *Chrysothamnus nauseosus*, *Chrysothamnus greenei*, *Sitanion hystrix*, *Agropyron smithii*, *Atriplex saccaria*, *Atriplex powellii*, and *Atriplex rosea*.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Reclamation Practices

Waller, E.K., Villarreal, M.L., Poitras, T.B, Nauman, T.W., and Duniway, M.C., 2018, Landsat time series analysis of fractional plant cover changes on abandoned energy development sites: International Journal of Applied Earth Observation and Geoinformation, v. 73, p. 407–419.

DOI: https://doi.org/10.1016/j.jag.2018.07.008
Background: Understanding the rate of recovery and long-term landscape alterations resulting from oil and gas pads compared to the pre-disturbed state is important for energy development and land management agencies. Using multi-decadal satellite imagery, 365 abandoned well pads across the Colorado Plateau were tested compared to a nearby undisturbed area. Understanding the relationship between vegetation regrowth and local environmental factors can improve reclamation standards and reduce bare ground on reclaimed well pads.

Objectives: The objectives of the study were to (1) use Landsat data to quantify vegetation recovery at oil and gas pads over time, (2) assess how climate, environmental, and management factors explain variability in recovery, and (3) demonstrate how Landsat imagery of plant cover can be used to monitor land-use development and post-development reclamation.
Methods: Data on well pad locations and abandonment dates were assembled, and pads that could be seen on Google Earth Pro were selected. Satellite data were collected from Landsat 5 from the Google Earth Engine covering 28 years of imagery. A time series model was created from these data showing plant cover over time then a statistical model was created to compare recovery five years post-abandonment using several predictor variables, including biotic and abiotic factors.
Location: Colorado Plateau including parts of Arizona, New Mexico, Colorado, and Utah, USA
Findings: The time series model captured 95 percent of vegetation cover over time. The median cover five years after abandonment was 25.8 percent and approximately one-third of wells had cover 50 percent or greater. Cover values increased over time, however in a non-linear manner. The year of abandonment and annual moisture levels interact to affect the rate of cover change. Presence of invasive species, *Salsola spp.* and cheatgrass, were strong predictors of error in the models. Wetter climate conditions were followed by increases in vegetation cover.
Implications: It is important to understand the non-linear behavior of vegetation cover on the Colorado Plateau and include this information when defining trajectories of recovery. Using satellite imagery can offer a clearer picture of site behavior over time as compared to field office data and reports. It is important to understand noise in these models because it could mean that invasive species are contributing significantly to a metric that might otherwise suggest high recovery rates. Given these considerations, quantifying plant cover using satellite imagery over time can be used to help land managers assess reclamation on oil and gas well pads.
Topics: Well Pad, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Monitoring

Weaver, T. and Aho, K., 2006, Identification of community types of southeast Montana as targets for mine reclamation, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and American Society of Mining and Reclamation, p. 774–802.

DOI: https://dx.doi.org/10.21000/JASMR06010774
Background: Coal mining has disrupted native vegetation in the Fort Union formation in the eastern plains of Montana. Successful revegetation of disturbed mining sites requires land managers to identify and characterize the native vegetation community pre-mining. Understanding and characterizing regional vegetation communities can help facilitate revegetation efforts across a broader region and provides a model than can be applied to unstudied mine sites.
Objectives: The authors (1) identified regional vegetation types, (2) described the composition of each regional type to inform seed mix design, (3) identified species well-suited for reclamation, and (4) identified weedy species that may require additional management.
Methods: At three mine sites, the Daubenmire method was used at different scales at each site to estimate ocular species cover. Vegetation was classified to understand structure at each site. Relevé analysis was used to visualize patterns in vegetation types across the region and to classify pre-disturbance vegetation communities across the three mines. This analysis involved (1) identifying vegetation communities at each site, (2) classifying species based on water requirements, (3) analyzing relationships between plants with similar water requirements, and (4) identifying similarities and differences between communities.
Location: Absaloka, Rosebud, and Spring Creek mine sites in southeastern Montana, USA
Findings: Shortgrass prairie, foothills prairie, sage steppe, pine savanna, slope-tow snowberry, and *Agropyron* old-fields were identified as regional vegetation communities. Ten groups of co-occurring species were discovered and listed based on water availability and shared abiotic conditions. Weedy species were more tolerant of diverse environmental conditions than native plants at the study sites. Non-native species *Agropyron cristatum* and *Medicago sativa* occupied moist sites. Native species *Opuntia fragilis, Cirsium undulatum, Gutierrezia sarothrae, Koeleria cristata,* and *Stipa comata* would likely establish easily on dry reclamation sites. *Carex filifolia, Phlox hoodii, Carex pensylvanica,* and *Bouteloua gracilis* are native species that would be difficult to restore and likely require additional management.
Implications: This research provides useful information on regional vegetation communities and groups of species that co-occur and vary in their reclamation potential in southeastern Montana. Sampling methods and land-use history at mine sites can make collaboration and extrapolation of vegetation structure across a region challenging. Increased sampling is important, especially in riparian and dry sites, to better characterize the vegetation in southeastern Montana.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, Reclamation Monitoring, GrayLit

Webb, R.H., Wilshire, H.G., and Henry, M.A., 1983, Natural recovery of soils and vegetation following human disturbance, chap. 14 *of* Webb, R.H., Wilshire, H.G., eds., Environmental Effects of Off-Road Vehicles: New York, Springer-Verlag, p. 279–302.

DOI: https://doi.org/10.1007/978-1-4612-5454-6_14
Background: Soil and vegetation disturbance from human activities can persist for decades. In arid areas, like the southwestern United States, these disturbances may last several hundred years. "Recovery" of disturbed areas (meaning a return to soil and vegetation conditions comparable to undisturbed conditions) may never occur if a relic soil or vegetation was removed. Recovery time will likely vary by disturbance type and severity and depend on the characteristics of the soil and vegetation communities that were disturbed. Reviewing examples of natural recovery after various disturbances could inform future land management.
Objectives: The authors reviewed literature regarding natural desert soil and vegetation recovery following human disturbance and presented management recommendations.
Methods: The authors discussed research and literature on the process of soil recovery from compaction and secondary plant success in compacted soils. They reviewed five examples of recovery in disturbed desert areas: (1) motorcycle impact on soil and vegetation, (2) abandoned agriculture land, (3) utility corridors, (4) the Wahmonie Townsite, Nevada, and (5) the Skidoo Townsite Death Valley National Monument, California. They outlined management recommendations for these areas.
Location: This is a literature review book chapter and does not involve a specific field study location. However, most of the referenced sites are in the Mojave Desert in California, USA
Findings: In the study of motorcycle impact on soil and vegetation, compaction had lessened on surface (0–3 millimeters [mm]) but not deep (30–60 mm) soil one year after disturbance. Twenty years after abandonment, only one species, *Atriplex polycarpa*, was present on abandoned agriculture land in the western Mojave Desert. Utility corridors (pipelines, powerlines) offer many examples of reclamation revegetation while the disturbed land adjacent is often left to natural recovery, which varies widely based on disturbance severity. In the townsites of Wahmonie, Nevada, and Skidoo in Death Valley National Monument, California, complete recovery is indeterminable due to a lack of data but will likely require decades or centuries more time. Reclamation techniques are required to fully revegetate disturbed arid desert lands as full natural recovery will likely take centuries, if it occurs at all.
Implications: This chapter compiles useful information for land managers seeking to reclaim disturbed land in arid desert environments. The management recommendations may prove useful for selecting revegetation reclamation methods.
Topics: Mining, Pipeline, Vegetation Recovery Data, Soil Data, Reclamation Practices

Wendell, D.L., and Westerman, C.A., 2004, Successful reclamation in dry-land environments—A case study, *in* Barnhisel, R.I., ed., 21st Annual Meetings of the American Society of Mining and Reclamation, and 25th West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, W. Va., April 18–24, 2004, Proceedings: American Society of Mining and Reclamation, p. 1990–2001.

DOI: https://doi.org/10.21000/JASMR04011990
Background: The De-Na-Zin and Gateway coal mines near Farmington, New Mexico, were operated during the 1980s. After closure in 1989, Yampa Mining Co. assumed all reclamation responsibilities for the 314 acres disturbed. De-Na Zin Mine is located in a rolling low dune landscape with fine sandy soils while the Gateway Mine is located in badlands environment. These mines serve as case studies of successful reclamation in the arid southwestern United States.
Objectives: The authors reviewed the reclamation process of two mines in New Mexico as case studies of successful dry-land reclamation.
Methods: During reclamation, open pits were backfilled using spoil and stockpiled topsoil and regraded. The areas were seeded with native grass and shrub species specific to address the post-mine land use goals of grazing and wildlife habitat. At the Gateway Mine, several soil amendments were applied to improve vegetation cover, including combinations of wood chips, nitrogen (N) fertilizer, calcium chloride, gypsum, and phospho-gypsum. Monitoring occurred from 1998–2002, and included measurements of vegetation cover, productivity, species diversity, water quality, and soil chemistry along 30 permanently located transects in treatment and reference (undisturbed) areas. Erosion rates were also assessed at the Gateway Mine.

Location: De-Na-Zin and Gateway coal mines near Farmington in northwestern New Mexico, USA
Findings: At the Gateway Mine, all soil amendment treatments had more vegetation cover compared to untreated areas; the wood chips+calcium chloride+gypsum+fertilizer treatment was the most productive. Mean vegetation cover and productivity (kilograms per hectare [kg/ha]) at both mines was comparable to, or greater than, reference sites. Both mines were approved for Phase II (De-Na-Zin in 1999 and Gateway in 2000) and Phase III (De-Na-Zin in 2003, and Gateway in 2004) bond release based on revegetation success.
Implications: The De-Na-Zin and Gateway coal mines serve as examples of successful dry-land reclamation without irrigation. Land managers in similar arid environments can apply reclamation techniques used at these mines (that is, using native seed, seeding before annual monsoon season, analyzing chemical properties of soil/spoil, and amending soil when needed). Additionally, long-term monitoring is required to ensure successful reclamation and to meet regulatory requirements for bond release.
Topics: Mining, Vegetation Recovery Data, Soil Data, Erosion Data, Reclamation Practices, GrayLit

Wessman, S., 2003, Designing for biodiversity—Data, regulation, and lore, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 1577–1585.

Link (non-DOI): https://www.asrs.us/wp-content/uploads/2021/09/1577-Wessman.pdf
Background: Reclamation of land disturbed by surface mining requires redesigning the landscape to promote self-sustaining biodiversity. Over time, research and observation have informed development of reclamation standards but biodiversity is often not the focus. Considering how these standards were developed, and whether or not they meet mandated and regulatory outcomes, is important for ensuring reclamation success.
Objectives: The author reviewed the information sources that inform landscape design standards and evaluated if such standards produce desired results.
Methods: The author reviewed the four main data tools used by landscape designers and planners: data-based knowledge, lore, regulation, and technology. They detailed the three stages of reconstructing (and reclaiming) disturbed landscapes: design, construction, and maintenance. They suggested guidelines for evaluating if large-scale restoration projects have been successful over time.
Location: This is a methods paper and does not involve a specific field study location
Findings: Landscape designers and planners have ample tools for reconstructing biologically diverse habitats post-disturbance. However, the long-term sustainability and success of reconstruction and reclamation depends on effective design, sound construction, and commitment to appropriate long-term maintenance.
Implications: Surface mine reclamation should focus more on biodiversity goals for sustained function ecosystems. Landscape designers and planners can offer insight on how to reach this goal.
Topics: Mining, Reclamation Theory, Reclamation Monitoring, Reclamation Standards, GrayLit

White, T.A., Grandinetti, C.L., Miller, S.D., Hill, T.B., Mengel, D.L., and Waechter, S.M., 2003, The Bunker Hill hillsides—A case study in the use of adaptive management in early successional restoration on the Nation's largest Superfund site, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 1472–1500.

DOI: https://doi.org/10.21000/JASMR03011472
Background: Reclaiming steep hillsides and reestablishing vegetation can be a challenge due to accessibility, high erosion rates, and increased run off. These conditions can cause additional issues downstream with increased pollution and sedimentation in waterways. The southern hillsides of the Bunker Hill Superfund Site in northern Idaho provide a case study on steep slope revegetation and reclamation methods. Over 400 acres of steeply sloped landscape were denuded impacting six different watersheds. The soil is highly acidic and contaminated with heavy metals, and early revegetation was limited. The reclamation goal is to restore the landscape to coniferous forest.
Objectives: The authors discussed the adaptive management strategies used to reclaim the southern hillsides at the Bunker Hill Superfund Site.
Methods: The Bunker Hill hillside revegetation project was described in context of larger Superfund site reclamation goals. Constraints associated with revegetation and their impacts on reclamation decision making were reviewed. Discussions were provided on: criteria used to develop reclamation design, development of site prescriptions for plant species selection, and protocol and results for soil amelioration, revegetation implementation technology, and monitoring. Site reclamation outcomes and future opportunities were reviewed.
Location: Southern hillsides of the Bunker Hill Superfund Site near Kellogg and Smelterville in northern Idaho, USA
Findings: Lack of site access resulted in aerial applications, and shipping costs were increased to account for the site's remote location. Over 2 million conifer seedlings were previously planted across the site so non-competitive herbaceous species were selected for revegetation. Soil stabilization was a leading design criteria and methods included balancing soil chemistry with liming materials, increasing nutrients with organic and inorganic fertilizer, and tackifier application to stabilize seeds for germination. Three years post-seeding, hydroseeding efforts successfully increased percent vegetation ground cover dominated by early successional herbaceous species; overtime, natural succession toward a conifer forest is expected. Water quality has increased with a decrease in turbidity.
Implications: Reclamation of the Bunker Hill hillsides is an example of successful revegetation methods and monitoring protocol. Long-term monitoring is essential for informed reclamation assessment.
Topics: Mining, Vegetation Recovery Data, Soil Data, Hydrology Data, Reclamation Practices, Reclamation Standards, GrayLit

Whitford, W.G., 1988, Decomposition and nutrient cycling in disturbed arid ecosystems, chap. 7 *of* Allen, E.B., ed., The reconstruction of disturbed arid lands—An ecological approach: New York, Routledge, p. 136–161.

DOI: https://doi.org/10.4324/9780429314216-7
Background: Much of the semiarid and arid land in the United States has been disturbed by human activities, beginning with livestock grazing in the 1700s. All disturbances since, including surface mining, have been imposed on already overgrazed rangelands. Reclamation of surface mined lands requires reestablishing soil processes and microbial communities that are far from their natural, or pre-disturbance, state. One important function of microfauna and microflora is decomposition, though few studies have examined this process on restored surface mining spoils.
Objectives: The author reviewed studies of decomposition process, soil biota, and nitrogen (N) cycling as indicators of reclamation success in restoring soil ecosystems.
Methods: The author briefly reviewed research on general soil processes in arid ecosystems. A series of studies was conducted on reclaimed surface mines to evaluate the effects of restoration methods on soil microflora, microfauna, and overall viability. Specifically, the studies assessed (1) the efficacy of organic amendments in increasing the rate of soil development from raw

spoil material, and (2) soil development on restored areas 1–4 years following similar restoration procedures. Research findings were reported as they pertained to (1) the effects of mulches on soil biota and processes on reclaimed mine spoils; (2) change in soil biota over time on reclaimed mine spoils; (3) soil biota, amendments, decomposition, and N cycling on degraded rangelands; and (4) N availability on rangelands.
Location: McKinley Coal Mine 30 kilometers (km) northwest of Gallup, the New Mexico State University Range and Jornada Experimental Range, 40 km northeast of Las Cruces, and degraded rangeland 20 km south of Cuba, all in New Mexico, USA
Findings: Soil processes such as decomposition and mineralization depend upon intact soil biota; when key groups of organisms were absent these processes faltered, and soil stability decreased. Overlaying stored topsoil and (or) mulch on mine spoils then seeding and irrigating and (or) fertilizing did not promote complete soil biota development; such reclamation practices should be reevaluated. Recalcitrant (slow to decompose) organic amendment application, in some cases, did promote complete soil biota development and higher rates of decomposition and mineralization. Such amendment also provided necessary nutrients (that is, N) for long-term energy.
Implications: Recalcitrant organic soil amendment, such as wood chips and bark, can be applied in semiarid and arid environments to provide nutrients and induce soil biota development, decomposition, and mineralization.
Topics: Mining, Soil Data, Reclamation Practices

Wick, A.F, Merrill, S.D., Toy, T.J., Hendrickson, J., and Liebig, M. A., 2005, The effects of soil depth and other soil characteristics on plant community development in North Dakota, *in* Barnhisel, R.I., ed., 22nd Annual Meeting of the American Society of Mining and Reclamation, Breckenridge, Colo., June 19–23, 2005, Proceedings: American Society of Mining and Reclamation, p. 1233–1243.

DOI: https://doi.org/10.21000/JASMR05011233
Background: Poor spoil material and a semiarid climate complicate successful revegetation of mining sites in North Dakota. Building soil wedges on old mining sites that replace topsoil and subsoil of various types at varying depths, then seeding the wedges, can help determine the best conditions for successful revegetation. Comparing vegetation and soil conditions over time at revegetated soil wedge sites provides a better understanding of the long-term effects of soil replacement on plant communities.
Objectives: The authors examined (1) long-term changes in plant communities in relation to variable soil depths and soil characteristics, and (2) relationships between plant community, variable soil depth and soil properties at previously revegetated soil wedge sites.
Methods: Cattle were cleared from existing experimental soil wedge study locations: Zap Soil Wedge (ZSW) established in 1975 and Stanton Soil Wedge (SSW) established in 1974. A single wedge was established at ZSW, using variable subsoil depths and types plus a uniform 20 centimeters (cm) layer of loam topsoil; the area was seeded with several species in separate subplots distributed throughout wedge, including crested wheatgrass (*Agropyron cristatum*), spring wheat (*Triticum aestivum*) followed by smooth brome (*Bromus inermis),* and alfalfa (*Medicago sativa*). SSW was established on a double wedge with various depths of silt loam subsoil and silt loam topsoil; subplots were seeded with either spring wheat, alfalfa, crested wheatgrass, or a native grass mixture of blue grama (*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*). A stratified random sampling design was used to select sample plots from the toe-, mid-, and shoulder-slope positions of each soil wedge and across vegetation type subplots. Five basal cover readings were taken with a 10-pin point frame and plant diversity was determined using Shannon's Diversity Index at ZSW, but not at SSW due to small sample size. Soil samples were collected from randomly chosen plots at 30 cm depth increments to 120 cm or to the subsoil-spoil contact. Soil data recorded in the field included topsoil and subsoil depths, electrical conductivity (EC) and pH. The hydrometer method was used to determine soil texture. Climate data were obtained from the nearest National Oceanic and Atmospheric Administration (NOAA) station. Data were analyzed using a one-way analysis of variance and multiple correlation analysis.
Location: Zap Soil Wedge at Indianhead Lignite Mine in Zap, North Dakota, and Stanton Soil Wedge at Glenharold Mine in Stanton, North Dakota, USA
Findings: Crested wheatgrass and Russian wildrye production decreased over time at both soil wedges, which was attributed to invasion by weedy plant species and grazing. The production of the native grass mixture and alfalfa also decreased over time at SSW (no data reported for ZSW); decline of seeded species was attributed to invasion by smooth brome at this site. Soil EC decreased, pH increased, and production varied overtime at toe-, mid-, and shoulder-slope positions at both soil wedges. Species diversity differed among vegetation type subplots and subsoil type, indicating multiple interactions among plant communities and soil characteristics.

Implications: Relationships among soil properties and revegetation plant communities can change over time. Using native seed mixes is important for understanding the long-term impacts of replacing topsoil and subsoil, because non-native species affect native species regeneration. Continued research at these sites and others will provide better understanding of the long-term relationships between plant communities and soil properties.
Topics: Mining, Vegetation Recovery Data, Exotic Plant Data, Soil Data, Reclamation Practices, GrayLit

Wick, A.F., Stahl, P.D., Ingram, L.J., Schuman, G.E., and Vance, G.F., 2006, Aggregate size distribution and stability under a cool season grass community chronosequence on reclaimed coal mine lands in Wyoming, *in* Barnhisel, R.I., ed., Reclamation—Supporting future generations, 10th Billings Land Reclamation Symposium, Billings, Montana, June 4–8, 2006, Proceedings: Billings Land Reclamations Symposium and the American Society of Mining and Reclamation, p. 806–815.

DOI: https://dx.doi.org/10.21000/JASMR06010806
Background: While most reclamation success is assessed on aboveground biomass (that is, vegetation), belowground soil processes and characteristics are essential for long-term success of mine reclamation. Soil structural properties, like water stable aggregate size distribution, are important for maintaining organic matter and nutrient cycling, soil stability, and plant communities. However, very little research has explored the impact of reclamation on soil aggregation and structure.
Objectives: The authors assessed soil aggregation develop over time on reclaimed lands and explored the relationships between plant communities and soil structure as an assessment of reclamation success.
Methods: A chronosequence was established using four reclaimed mine sites aged 4 months, 14 years, 26 years, and 29 years after reclamation, plus one undisturbed native site. Reclaimed sites had direct haul topsoil replacement, cool season grass mix seeding, and grazing (in a 3-year rotation). Soil was sampled at 0–5 centimeters (cm), 5–15 cm, and 15–30 cm depth intervals at four points along three randomly oriented 45 m transects. Soil was collected for bulk density using a double-cylinder hammer driven core sampler. Soil texture, soil properties, and water stable aggregate size distribution (corrected for sand) were determined. Vegetation was sampled following appendix A of the Wyoming Department of Environmental Quality standards (WDEQ). Data were analyzed using one-way analysis of variance (ANOVA) and student's *t*-tests.
Location: Five reclaimed mine sites (44°04.613′ N., 105°25.520′ W.; 44°05.696′ N., 105°22.564′ W.; 44°06.333′ N., 105°22.4476′ W.; 44°05.890′ N., 105°22.330′ W.; 44°04.997′ N., 105°26.016′ W.) in Belle Ayr Mine in the Powder River Basin, Wyoming, USA
Findings: Macroaggregations (250–2,000 micrometer [µm]) increased over time, while microaggregations (53–250 µm) decreased. Aside from the 29-year-old site, macroaggregation size fraction increased over time. Both results suggest soil recovery over time. Macroaggregate formation was significantly related to aboveground biomass, though the relationship was weak (R^2=0.457). Macroaggregation formation and recovery was not related to vegetation percent cover or plant diversity.
Implications: This study found that soil aggregation does recover with time since reclamation, suggesting that reclamation practices can successfully restore soil structure. However, soil aggregation was not directly related to plant community characteristics other than aboveground biomass and more research is needed to better understand soil and plant community interactions on reclaimed mine lands.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, Reclamation Standards, GrayLit

Wick, A.F., Stahl, P.D., Ingram, L.J., and Vicklund, L., 2009, Soil aggregation and organic carbon in short-term stockpiles: Soil Use and Management, v. 25, no. 3, p. 311–319.

DOI: https://doi.org/10.1111/j.1475-2743.2009.00227.x
Background: Coal surface mining disturbs soil conditions and topsoil, which is often stockpiled for some time, is typically used during reclamation to replenish nutrients. To understand topsoil quality for reclamation use, research has focused on chemical, physical, and microbial community properties while largely ignoring soil aggregation. Macro- (250–2,000 micrometers [µm])

and microaggregates (53–250 µm) directly impact soil properties, organic matter retention, and microbial communities. However, the incorporation of organic matter into soil aggregates is poorly understood. Understanding how soil aggregates interact with organic matter in stockpiled topsoil is necessary for assessing reclamation soil dynamics and overall success.
Objectives: The authors (1) quantified soil aggregate proportions and organic carbon (C) in the macro- and microaggregate size classes over time in stockpiled soils, (2) quantified and determined the location (light, heavy, and mineral fractions) of new organic matter within each aggregate size class, and (3) observed changes in these properties given a second disturbance.
Methods: A topsoil stockpile (22 hectares [ha], max height 18 meters [m]) was sampled at <1, 1.5, and 3 years following its removal and transfer to a temporary location. An adjacent undisturbed native site was sampled for comparison. Samples were collected from the top 5 centimeters (cm) of soil at four points along each of three randomly oriented 45 m transects, Samples were collected at 5–15 cm and 15–30 cm depth intervals at the native site. Five samples were collected for bulk density at each site using a double-cylinder hammer driven core sampler. Roots from the 1.5-year-old stockpile were collected. Soil properties, aggregate size distribution (correcting for sand across all sites), and density floatation were characterized. Aggregate associated C and isotopes were assessed. Data were analyzed using a one-way analysis of variance (ANOVA) and student's *t*-test.
Location: Belle Ayr surface coal mine in the Powder River Basin in northeastern Wyoming, USA
Findings: General soil properties differed across sites but did not affect aggregate formation in stockpiled soils. Differences in aggregates between the stockpile and native site were likely due to lower clay content at the native site. C content was lower at all stockpile sites compared to the native site. Aggregation stability increased slightly over time since removal in stockpiled soils, but gains were lost when the stockpile was moved.
Implications: Though stockpiling positively influenced aggregation and aggregated associated C concentration, C was concentrated mainly in surface soils and was still lower than that of native soils. More research is needed to understanding organic matter and aggregate dynamics over time.
Topics: Mining, Soil Data, Reclamation Practices

Wick, A.F., Stahl, P.D., Rana, S., and Ingram, L.J., 2007, Recovery of reclaimed soil structure and function in relation to plant community composition, *in* Barnhisel, R.I., ed., American Society of Mining and Reclamation 24th Annual National Conference, Gillette, Wyo., June 2–7, 2007, Proceedings: American Society of Mining and Reclamation, p. 941–957.

DOI: https://dx.doi.org/10.21000/JASMR07010941
Background: Interactions among soil physical and biological characteristics and vegetation characteristics can determine whether reclamation of a disturbed mine site is successful or not. Soil aggregates, an important part of soil structure, and the soil microbial community protect organic matter from breaking down and enable functional nutrient cycling, while plant community composition, root thickness, and nutrient cycling interact with soil properties. Understanding the relationships among soil and vegetation is necessary for long-term reclamation success. Chronosequences (substitution of space for time) can assist in understanding these dynamics.
Objectives: The authors evaluated changes in the relationships among soil aggregation, microbial communities, and plant community biomass across reclaimed sites of different ages.
Methods: Two shrub and cool season grass chronosequences were established using sites that were <1, 5, 10, and 16 years since reclamation, plus an undisturbed site. Samples were collected from the top 5 centimeters (cm) of soil at four points along three randomly oriented 45 meter (m) transects. Five soil samples were collected for bulk density at each site using a double-cylinder hammer driven core sampler. Soil texture was determined using the hydrometer method and water stable aggregate size was determined using the wet sieving protocol. Soil samples were analyzed for physical properties and nutrient levels. Microbial community was characterized using a modified Bligh-Dyer methodology for phospholipid fatty acid (PLFA) extraction followed by gas chromatography for analysis. Vegetation data were collected according to appendix A of the Wyoming Department of Environmental Quality (WDEQ) standards for determining reclamation success. Data were analyzed using a one-way analysis of variance (ANOVA) and student's *t*-test.
Location: Dave Johnston and Belle Ayr Mines in the Powder River Basin, Wyoming, USA
Findings: Soil texture was similar across chronosequences sites, though shrub soils were a sandy loam texture and cool season grass soils were a clay loam texture. Soil organic carbon and nitrogen (N) generally increased at all sites over time, as did total microbial biomass. Plant communities differed across chronosequences at both shrub and grass sites. Relationships between macroaggregates and vegetation characteristics were not significant in shrub sites but were related to vegetation type at grass

sites. Macroaggregation was negatively related to microaggregation and fungi, and positively related to bacteria in the cool season grass community. In the shrub community, microaggregates were negatively related to living fungi, and bacteria were positively correlated with fungi. Both sites showed a negative relationship between fungi and actinomycetes.
Implications: Microbial community biomass was the best indicator of reclamation success (recovery) and may be an important characteristic for land managers and reclamationists to consider monitoring. However, more research is needed to fully understand relationships between soil structure and plant community composition.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices, GrayLit

Williams, H.F.L, Havens, D.L, Banks, K.E., and Wachal, D.J., 2008, Field-based monitoring of sediment runoff from natural gas well sites in Denton County, Texas, USA: Environmental Geology, v. 55, p. 1463–1471.

DOI: https://doi.org/10.1007/s00254-007-1096-9
Background: Construction of well pads can affect sediment loads in a watershed. Sediment loads from oil and gas are not currently monitored or regulated.
Objectives: This study aimed to test observations that sediment loads coming off gas well pads were greater than in undisturbed areas. To test this hypothesis, the author (1) determined the extent of sediment movement off gas well pads, (2) identified conditions that might contribute to sediment movement, and (3) characterized the sediment.
Methods: The author installed weirs and sediment traps to funnel rain run-off and sediments. The weirs collected stormwater samples. They also measured debris lobes (sediments distributed by sheet flows) and erosion channels. The experiment was deployed in February 2005 and removed in May 2005.
Location: Denton County southwest of Denton, Texas, USA
Findings: Sediments from the study sites included silt and clay and averaged 57.1 tons of sediment/year/acre. Characteristics that affected the amount of sediment included the slope of the land where the well pad was placed, the size and intensity of the rain event, and vegetation cover that reduces sediment loads. Well pads contributed more sediment to the watershed than the undisturbed surrounding landscape.
Implications: Erosion and sediment loads coming from oil and gas development might be significant enough to warrant regulation. Erosion can be mitigated by using and maintaining erosion control features near well pads. Future studies should look at sediment loads before, during, and after well pad construction and bond release.
Topics: Well Pad, Erosion Data, Reclamation Monitoring

Winkel, V.K., Medrano, J.C., Stanley, C., and Walo, M.D., 1995, Effects of gravel mulch on emergence of galleta grass seedlings, *in* Roundy, B.A., McArthur, E.D., Hayley, J.S., and Mann, D.K., compilers, Wildland Shrub and Arid Land Restoration Symposium, Las Vegas, Nev., October 19–21, 1993, Proceedings: U.S. Department of Agriculture Forest Service, Intermountain Research Station General Technical Report INT-GTR-315, p. 130–134.

DOI: https://doi.org/10.2737/INT-GTR-315
Background: The Nevada Test Site and Tonopah Test Range have high levels of surface plutonium contamination that requires reclamation. Stabilizing revegetation is necessary but complicated by the arid environment of the Mojave and Great Basin deserts. Plutonium contamination is limited to the top 10 centimeters (cm) of soil and is associated with the <3-millimeter (mm) soil fraction. Separating out >3mm soil fraction (gravel) and applying as a mulch could assist with revegetation efforts.
Objectives: The authors (1) assessed the effects of gravel mulch on seedling emergence and soil water, (2) assessed the effects of irrigation rates on seedling emergence, and (3) determined the optimal depth of gravel mulch for seedling emergence.
Methods: A split plot experimental design was used with two replication blocks. The top 15 cm of gravelly sandy loam soil was collected from Plutonium Valley on the Nevada Test Site, sieved to 3 mm, placed in 24 flats, and seeded with 20 seeds from each of nine desert species. Within these flats, the following treatments were tested: bare seed, buried seed, 2 cm gravel, 4 cm gravel, and one of three irrigation treatments. Daily seedling emergence data were collected. Gravimetric soil water content was measured from non-seeded flats. Data were analyzed using analysis of variance (ANOVA).
Location: Greenhouse at the Nevada Test Site, Nevada, USA

Findings: Galleta grass was the only species with germination rates high enough for analysis. With the one day and every 10 days watering treatments, seedlings emerged and survived from the buried and 2 cm gravel treatments. With the five-day watering interval, seedlings emerged and survived from the bare and 2 cm gravel treatments. Soil water content was affected by interactions among irrigation treatment, gravel treatment, and days.
Implications: Several different watering regimes and soil water conditions resulted in galleta grass seedling emergence and growth under 2–3 cm of gravel. However, this was a greenhouse experiment and in-field conditions could alter results. Field tests are needed to determine the viability of gravel as an overlay on reclaimed soils in arid conditions.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Soil Data, Reclamation Practices, GrayLit

Winkel, V.K., Ostler, W.K., Gabbert, W.D., and Lyon, G.E., 1995, Effects of seedbed preparation, irrigation and water harvesting on seedling emergence at the Nevada test site, *in* Roundy, B.A., McArthur, E.D., Hayley, J.S., and Mann, D.K., compilers, Wildland Shrub and Arid Land Restoration Symposium, Las Vegas, Nev., October 19–21, 1993, Proceedings: U.S. Department of Agriculture Forest Service, Intermountain Research Station General Technical Report INT-GTR-315, p. 135–141.

Link (non-DOI): https://www.fs.usda.gov/rm/pubs_int/int_gtr315/int_gtr315_135_141.pdf
Background: Revegetation of the Nevada Test Site due to plutonium contamination is complicated due to harsh climate conditions (including heat and low precipitation), altered soil viability, and the removal of 5–10 centimeters (cm) of topsoil without replacement. Techniques for harvesting water, modifying soil microtopography to capture precipitation, applying soil amendments, and installing irrigation systems are all methods that could be helpful for site reclamation.
Objectives: The authors assessed the effects of seedbed preparation, irrigation, and water harvesting on native grass, forb, and shrub emergence on reclaimed land in the Mojave/Great Basin Transition Desert.
Methods: A split-split plot experimental design was used with three replicate blocks of 18, 7.5 × 20-meter (m) plots. Whole plots were assigned one of three irrigation treatments, split plots were assigned one of six seedbed/water harvesting treatments, and split-split plots were planted with specific plant species. Prior to treatment application, all blocks were lightly brushed with a road-grader to remove existing vegetation and harrowed in December 1992. Irrigation treatments were randomized within blocks and included: (1) an un-watered control, (2) germination irrigation, or (3) maintenance irrigation. Seedbed/water harvesting treatments were randomized within irrigation and included: (1) an unseeded control, (2) seeded, (3) seeded with 4,500 kilograms per hectare (kg/ha) wheat straw mulch (crimped in with a disk), (4) seeded with crimped straw mulch and imprinted with a Dixon-style imprinter, (5) seeded with crimped straw mulch and pitted with a Lee Pocket-Seeder, and (6) desert strip, in which 10 percent slopes were constructed on the plots with a road grader, sprayed with a water-shedding treatment on the top half of the slope, and seeded with crimped straw mulch on the lower half of the slope. Seeding was done using a drill seeder in Dec. 1992, with a mixture of shrubs (*Atriplex canescens, A. confertifolia, Ericameria nauseosa* ssp. *consimilis*, *Grayia spinosa*), grasses (*Pleuraphis jamesii, Achnatherum hymenoides, Sporobolus airoides*), and the forb *Sphaeralcea ambigua*, at 20 kg/ha pure live seed (PLS). In 1993, densities of all seeded species were counted in 20, 1 square meter (m^2) quadrats per plot and seedbank species (*Amsinckia tessellata*, *Bromus rubens*, *Descurainia sophia*, *Mentzelia obscura*, *Phacelia fremontii*, and *Phlox stansburyi*) were counted in five, 1 m^2 quadrats per plot. Data were analyzed using analysis of variance (ANOVA).
Location: Nevada Test Site in southern Nevada, USA
Findings: Seedling density for all species showed highly significant 2- and 3-factor interactions involving species, irrigation treatments, and seedbed/water harvesting treatments. Across all species, the only species that emerged with no supplemental irrigation were *A. hymenoides, G. spinosa, B. rubens* and *A. tessellata* (seedbank species). Results of the supplemental and maintenance irrigation treatments were similar. Generally, seedbed preparation treatments did not increase germination.
Implications: Various seedbed preparation as well as irrigation treatments did not necessarily increase seedling germination. However, increased monitoring is needed to determine if observed patterns hold true. Reclamation in arid and semi-arid environments may need, at minimum, a maintenance irrigation program but land managers should assess site-specific conditions to determine irrigation needs.
Topics: Mining, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices, GrayLit

Winslow, S.R., Clause, K.J., Hybner, R., and Jacobs, J., 2009, Evaluating seeding techniques and native plant establishment in the Pinedale anticline, Wyoming, *in* Brummer, J.E., ed., High Altitude Revegetation Workshop No. 18, Fort Collins, Colo., March 4–6, 2008, Proceedings: High Altitude Revegetation Workshop Information Series no. 107, p. 49–73.

Link (non-DOI): http://hdl.handle.net/10217/69248
Background: Successful reclamation of oil and gas drill pads requires appropriate seed mixes that include grasses, forbs, and shrubs. Many cultivars of species exist, and scientific testing of these varieties using various seeding techniques can improve reclamation practices.
Objectives: The authors (1) tested cultivars, varieties, and germplasm of native species known to support wildlife habitat, (2) tested seeding methods, mixtures, and rates required to achieve desired diversity, and (3) distributed the results to land managers and others, including listing in the Pinedale Resource Area Cooperative Working Agreement of 2005.
Methods: Experimental plots were established on two oil and gas sites. The Shell site was disturbed in 2002 and the topsoil was stockpiled for 37 months. The Questar site was disturbed in 2005; the area was ripped and reshaped using respread salvaged topsoil. Both sites were seeded in the fall of 2005 with two seed mixes that included a number of grasses, forbs, and shrubs. The Shell seed mix was commercially sourced by the oil and gas operator, and the Bridger seed mix was commercially sourced by the Natural Resources Conservation Service (NRCS) Bridger Plant Materials Center. Cover and density were measured at the sites in July 2006 and September 2007. Additionally, 25 shrub species were drill seeded in replicated single species plots at the Questar site and 72 grass, forb, and shrub species were drill seeded in replicated single species plots at the Shell site.
Location: Shell project area approximately 30 miles (mi) south of Pinedale (N½SW¼ sec. 10, T. 29 N., R. 107 W.) and Questar project area 9.5 mi south of Pinedale (SW¼SW¼sec. 34, T. 33 N., R. 109 W.) in Wyoming, USA
Findings: Several species established quickly and stabilized soils including: *Elymus lanceolatus, Elymus trachycaulus, Leymus cinereus, and Pseudoroegneria spicata.* Despite low establishment of forbs, several species have potential for establishing including *Cleome serrulata, Achillea millefolium, Linum perenne, Penstemon eatonii, Penstemon eriantherus, and Phacelia hastata*. Establishment by shrubs was also low, but these species performed better: *Atriplex aptera, Atriplex canescens, Atriplex falcata* (*A. gardneri*), and two accessions of *Krascheninnikovia lanata*. Broadcast seeding outperformed drill-seeding and hydro-seeding at increasing plant cover. The drill seeded shrubs established poorly.
Implications: Some species establish better than others and should be considered priority for successful restoration of wildlife habitat. Shallow seeding rather than deep seeding may increase success of seeding operations for smaller seed sizes. Other technologies or strategies are needed to increase the success of establishing forbs and shrubs.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Reclamation Practices, GrayLit

Winterhalder, K., 2003, The roles of biotic and abiotic diversity in establishing ecosystem integrity on reclaimed minelands, and strategies for their enhancement, *in* Barnhisel, R.I., ed., Working together for innovative reclamation—Joint Conference of the 9th Billings Land Reclamation Symposium and the 20th Annual Meetings of the American Society of Mining and Reclamation, Billings, Mont., June 3–6, 2003, Proceedings: American Society of Mining and Reclamation, p. 1586–1598.

Link (non-DOI): https://www.asrs.us/Portals/0/Documents/Conference-Proceedings/2003/1586-Winterhalder.pdf
Background: Reestablishing biodiversity on disturbed land requires reclamation, though the exact methods will differ depending on the disturbance. A more "natural" degraded landscape, like a smelter area with intact physical diversity, may need less reclamation intervention than a more homogenous disturbance like a mine tailings deposit. Both environments can be reclaimed for future biodiversity and function, but the site-specific reclamation needs must be addressed.
Objectives: The author compared restoration of biodiversity on a degraded natural landscape (smelter area) with that on a mine tailings deposit.

Methods: The author discussed abiotic diversity on degraded natural landscapes, using a smelter area in Sudbury, Ontario, Canada as an example. They discussed abiotic diversity on mine tailing deposits and methods for directly enhancing biotic diversity.
Location: This is a review paper and does not involve a specific field study location, but used a smelter area in Sudbury, Ontario, Canada as an example.
Findings: Due to existing physical diversity, reclamation of natural degraded landscapes requires less intervention, mainly soil amendment application (like limestone) and seeding. This form of minimal amelioration, combined with interactions among physical and chemical soil properties and timing of amendment application, can restore soil pH enough for plant establishment and growth, which can then contribute to nutrient cycling and plant biodiversity development. Due to more homogenous physical diversity on mine tailings, more intensive reclamation is needed, such as soil amendment and cover soil applied in mosaics or strips and altering site microtopography. Methods for enhancing biotic diversity include seeding with diverse species mixtures, building topsoil islands and native soil plugs, and considering genetic diversity.
Implications: Land managers should consider their site-specific reclamation methods and needs depending on disturbance type and severity. Given climate change, plant species genetics should be considered when reseeding to increase long-term survivability of revegetated species.
Topics: Mining, Vegetation Recovery Data, Reclamation Theory, Reclamation Practices, GrayLit

Wood, M.K., Buchanan, B.A., and Estrada, O.J., 1990, Runoff and erosion from native and reclaimed sites—Large versus small plots, *in* Planning, rehabilitation, and treatment of disturbed lands, Fifth Billings Symposium on Disturbed Land Rehabilitation, Billings, Mont., March 25–30, 1990, Proceedings: Bozeman, Mont., Montana State University, Reclamation Research Unit Publication no. 9003, v. 2, p. 158–162.

Link (non-DOI): https://archive.org/details/fifthbillingssym00bill/page/n1/mode/2up
Background: Runoff and erosion rates can be used as markers of reclamation success. Plot studies with artificial rainfall have been widely used to assess the hydrological and hydraulic characteristics of natural and disturbed land since the 1930s. It is thought that large plots have an advantage over small plots.
Objectives: This study compared runoff and erosion from small and large plots located on a variety of disturbed and native sites.
Methods: Four small plots (1 square meter [m^2]) and two large plots (3 × 10.67 meters [m]) were established on each of eight sites. These sites included four native sites (two undisturbed native sites, two barren badland sites) and four disturbed sites (two 1-year post-reclamation sites, and two 10-year post-reclamation sites). Rainfall was simulated on all plots, although the large plots experienced much less consistency in their application. Runoff was collected and measured by volume every 5 minutes for 30 minutes. A 1-liter (L) sample was used to quantify sediment in the runoff.
Location: Navajo Mine in northwestern New Mexico, USA
Findings: Increased runoff was positively correlated with sediment yield. Mean runoff volume was significantly higher in large plots compared to small plots at p=0.1, but not p=0.05, suggesting the ecological difference is negligible. Rates were not different. Sediment load in the badlands sites was very high. Both 1-year and 10-year reclaimed sites showed improvement over the badlands sites.
Implications: Small plots can be used in shorter timescales with less investment. This allows for more replication, with greater precision.
Topics: Mining, Erosion Data, Hydrology Data, GrayLit

Woosaree, J., and Otfinowski, R., 2017, Importance of species diversity in the revegetation of Alberta's northern fescue prairies: Biodiversity Conservation, v. 27, no. 3, p. 665-680.

DOI: https://doi.org/10.1007/s10531-017-1456-z
Background: Oil and gas disturbance threatens native fescue prairies in the North American northern Great Plains. Historically, restoration of disturbed grasslands has included nonnative species for reseeding. Currently, the need for rapid revegetation, even with native species, threatens species diversity of restored native fescue prairies. A lack of long-term evaluative data on restoration efforts complicates assessing species diversity on restored fescue prairies over time.

Objectives: The authors evaluated long-term revegetation results of previously disturbed well sites to test the hypothesis that increased species-rich seeding mixes improve the structure, diversity, and composition of revegetated fescue prairie plant communities.
Methods: Three previously reclaimed northern fescue prairie study sites surrounded by representative fescue prairie habitat were selected. The experimental design incorporated the following treatments: (1) natural reclamation (disturbed, unseeded), (2) reclamation mix (disturbed, seeded with two species), (3) simple mix (disturbed, seeded with five species), (4) diverse mix (disturbed, seeded with 15 species), and (5) control (undisturbed prairie). All applicable treatments were direct seeded using 20-centimeter (cm) row-spacing at a 1.2–1.9 cm depth and 600 pure live seed per square meter (PLS/m^2). Each study site was divided into four 50 m^2 plots and randomly assigned one of the four treatments (excluding control treatments, which were located adjacent to each prairie site). To assess vegetation, sixteen sampling points were spaced at 2-meter (m) intervals along 60 m transects in treatment plots, and at 4 m intervals along 100 m transects in control plots. Daubenmire quadrats (20 × 50 cm) were placed northeast of sampling points to describe plant community structure and composition. Percent cover at ground level of live vegetation, plant litter, and bare ground was monitored for 10 years following seeding (1997–2000, 2004, 2007–2008). Data were analyzed using linear mixed-effect models with fixed effect of year and seeding treatment and random effects of study site.
Location: Northern Fescue Natural Subregion and Central Parkland Natural Subregion in east-central Alberta, Canada
Findings: Plant community structure differed among treatments but did not change consistently over time. Overall, fescue cover was highest in the control but increased significantly overtime for all treatments. Plant community composition was significantly different among all seeding treatments and the control and remained so through the length of the study. Average species diversity, richness, effective richness, and evenness were not significantly different among treatments and control.
Implications: Restoration of fescue prairies depends on many factors (for example, environmental conditions, historical disturbance, funding). However, even using a low diversity seed mix can overtime produce a structurally rich and comparable plant community. Fescue prairies are fire adapted, and the use of prescribed burns could lead to increased native species presence. Restoration methods of disturbed fescue prairies should consider the measure of success and desire for reestablishing native, undisturbed conditions.
Topics: Well Pad, Vegetation Recovery Data, Target Plant Recovery Data, Exotic Plant Data, Reclamation Practices

Wu, G.-L., Yang, Z., Cui, Z., Liu, Y., Fang, N.-F., and Shi, Z.-H., 2016, Mixed artificial grasslands with more roots improved mine soil infiltration capacity: Journal of Hydrology, v. 535, p. 54–60.

DOI: https://doi.org/10.1016/j.jhydrol.2016.01.059
Background: Mining operations have dramatic impacts on soil properties and soil structure. Due to destruction of soil, plant establishment following reclamation is difficult, especially in arid regions. The capacity for soil to hold water is critical for vegetation maintenance and survival in arid and semi-arid landscapes. Revegetation success following mining disturbances may depend on soil infiltration capacity and water storage.
Objectives: The objectives were to determine the effect of artificial grassland vegetation on soil properties, including soil infiltration capacity. Specifically, the authors wanted to test if the artificial grassland would increase root biomass and improve soil infiltration capacity and rates. Additionally, the authors wanted to identify the main factors influencing soil infiltration.
Methods: At a dump area of the Yongli coal mine, nine types of artificial grasslands were established, based on the most common species used in revegetation, Above- and belowground biomass was harvested and measured. Soil measurements were collected at 10-centimeter (cm) intervals in the top 30 cm, including bulk density, dry mass, total soil porosity, capillary porosity, and soil non-capillary porosity. Soil infiltration rates were measured, and soil infiltration capacity was calculated using an automatic system. Data were analyzed using principal component analysis (PCA) to determine the factors that affect soil infiltration capacity and establish a soil infiltration capacity index.
Location: Yongli coal mine in the Inner Mongolian Autonomous Region on the northern Loess Plateau (39°4′52″ N., 110°16′30″ E.), China
Findings: Artificial grasslands increased the average infiltration rate at several stages defined by length of time exposed to water delivery. The PCA results suggest that soil water content at 20 cm, below-ground root biomass at 10 and 30 cm, capillary porosity at 10 cm and non-capillary porosity at 20 cm affect soil infiltration capacity and were used in the soil infiltration capacity index.

Implication: Artificial grasslands can improve the capacity of soil to hold water due to increased root biomass. Creating a soil infiltration capacity index from different soil properties can improve interpretation of soil properties and identify factors affecting soil infiltration capacity at different sites. Legume-grass and legume-shrub mixes should be used for restoration to improve soil infiltration.
Topics: Mining, Hydrology Data, Soil Data, Reclamation Practices

Yang, Y., Erskine, P.D., Lechner, A.M., Mulligan, D., Zhang, S., and Wang, Z., 2018, Detecting the dynamics of vegetation disturbance and recovery in surface mining area via Landsat imagery and LandTrendr algorithm: Journal of Cleaner Production, v. 178, p. 353–362.

DOI: https://doi.org/10.1016/j.jclepro.2018.01.050
Background: Revegetation is a key component of coal and mineral mine site reclamation. However, capturing the revegetation process is difficult as it varies spatially and temporally and often occurs on a large scale. Traditional field monitoring methods may not adequately capture the complexity and dynamics, and therefore incompletely assess, the revegetation process. Remote sensing techniques, such as Landsat, allow for largescale imagery data collection and, when paired with tailored analysis programs like LandTrendr (Landsat-based detection of Trends in Disturbance and Recovery, available at https://www.fs.usda.gov/research/pnw/products/dataandtools/tools/landtrendr-and-timesync) can provide a more detailed and complete understanding of revegetation and reclamation success.
Objectives: The authors assessed the feasibility of using Landsat and LandTrendr to detect mining disturbance and vegetation recovery of a surface mine.
Methods: Fifty-six Landsat images spanning 1988 to 2015 were acquired; each pixel had a 30 square meter (m^2) spatial resolution. LandTrendr was used to reconstruct spatial-temporal trajectories of vegetation cover. The occurrence of mining disturbance or recovery by year was calculated. Maps were rendered with a gradient of spatial and temporal changes in mining disturbance and recovery. The accuracy of mapped changes in vegetation were validated in ArcGIS 10.3.
Location: Curragh coal mining site (central, north and east Curragh mines) east-central Queensland, Australia
Findings: Accuracy for a given year ranged from 60 to 100 percent; errors in detected land changes could have resulted from non-abrupt disturbance/recovery, non-mining disturbance, or cleared land. A total of 58 percent of disturbed land had recovered from 1990 to 2014.
Implications: Rapid vegetation changes on reclaimed mine land can be accurately monitored and assessed via LandTrendr and freely available Landsat imagery data. However, site-specific landscape characteristics must be used to choose the spectral index to ensure accurate results. Also, other forms of land disturbance (for example, flooding) need to be accounted for to reduce error.
Topics: Mining, Vegetation Recovery Data, Reclamation Monitoring

Yang, Z., Hao, H.M., Wang, D., Chang, X.F., Zhu, Y.J., and Wu, G.L., 2015, Revegetation of artificial grassland improve soil organic and inorganic carbon and water of abandoned mine: Journal of Soil Science and Plant Nutrition, v. 15, no. 3, p. 629–638.

DOI: https://dx.doi.org/10.4067/S0718-95162015005000032
Background: Mining and energy extraction disturbs soil carbon (C), which is essential for ecosystem stability. Reclamation can reestablish plant communities and increase biomass production, which can help restore soil C over time.
Objectives: The authors evaluated the plant community response and changes in soil properties on reclaimed grasslands 5, 10, and 20 years after reclamation.
Methods: Nine restored mine sites were selected, representing three sites in three age categories (5-, 10-, and 20-years post-reclamation); all were dominated by *Stipa capillata* and *Agropyron cristatum*. Field vegetation included aboveground and belowground biomass, canopy cover, and height. Soil bulk density for 1–10 centimeters (cm), 10–20 cm, and 20–30 cm depths was determined in three randomly selected 1 m^2 plots at each mine site. Data were analyzed using analysis of variance (ANOVA).
Location: Heidaigou mining areas in the northern Loess Plateau, Inner Mongolian Autonomous Region, China

Findings: Aboveground and belowground biomass, canopy cover, soil C, and soil water content all increased over time, though biomass peaked at 10 years after reclamation. Soil depth affected soil properties and varied by time since reclamation.
Implications: Reclamation can restore soil and plant community characteristics, though outcomes will vary with time since reclamation.
Topics: Mining, Vegetation Recovery Data, Soil Data, Reclamation Practices

Zhang, Z.F., Bugosh, N., Tesfa, T., McDonald, M.J., and Kretzmann, J.A., 2018, Conceptual model for hydrology-based geomorphic evapotranspiration covers for reclamation of mine land: Journal American Society of Mining and Reclamation, v. 7, no. 2, p. 61–88.

DOI: https://doi.org/10.21000/JASMR18020061
Background: Abandoned surface mine sites are ecologically detrimental to vegetation, soils, bedrock, landscape, hydrology, groundwater, and surface flow patterns. Traditional reclamation methods pay little attention to hydrological function, which can lead to increased erosion and the need for long-term management. Geomorphic grading uses the natural landscape to inform reclamation, but hydrological function can still be drastically different than pre-mining. Surface evapotranspiration soil covers are self-renewing biological systems that use natural processes to protect hydrological function. A geomorphic evapotranspiration soil cover could be laid over mined land after geomorphic grading for a more comprehensive reclamation outcome.
Objectives: The authors wanted to present the concept of GeoFluv, a geomorphic evapotranspiration cover, as a method for reclamation at abandoned surface mine sites and reducing further environmental degradation.
Methods: The authors summarized GeoFluv components, benefits, and design. They described the site, watershed, and geomorphic grading design of the GeoFluv demonstration at Tin Pan mine sit. GeoFluv construction was not included in the scope of this article.
Location: Tin Pan mine site (36°56′30.47″ N., 104°32′16.51″ W.) near Raton, New Mexico, USA
Findings: Geomorphic grading and evapotranspiration cover can be combined to improve the success and end product of reclamation efforts on abandoned surface coal mines. Current demonstration at the Tin Pan mine illustrates the feasibility of GeoFluv cover application on the landscape. GeoFluv results and specific design were not discussed in this article as the project is still in progress.
Implications: GeoFluv is a new and promising method for reclaiming surface mines that better mimics the natural landscape and hydrological function pre-mining.
Topics: Mining, Reclamation Practices

Appendix 1. Species names

Tables for converting biological species scientific names to common names, and vice versa, are provided here. For plant species, nomenclature follows usage by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov). Plants not listed on the USDA site follow nomenclature found on https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/. Animal nomenclature follows usage by the Integrated Taxonomic Information System (https://itis.gov).

Table 1.1. Conversion of common names to scientific names.

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
African liverseed grass	*Urochloa mosambicensis* (Hack.) Dandy
alfalfa	*Medicago sativa* L.
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.
Altai wildrye	*Leymus angustus* (Trin.) Pilg. syn. *Elymus angustus* Trin.
annual sunflower/common sunflower	*Helianthus annuus* L.
autumn olive	*Elaeagnus umbellata* Thunb.
basin big sagebrush	*Artemisia tridentata* Nutt. ssp. *tridentata*
basin wildrye	*Leymus cinereus* (Scribn. & Merr.) Á. Löve
Bengal kino	*Butea monosperma* (Lam.) Taubert
big sagebrush	*Artemisia tridentata* Nutt.
bighorn sheep	*Ovis canadensis* Shaw
bitterbrush/antelope bitterbrush	*Purshia tridentata* (Pursh) DC.
black cutch	*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb. syn. *Acacia catechu* (L.f.) Willd. [excluded]
black henbane	*Hyoscyamus niger* L.
black locust	*Robinia pseudoacacia* L.
black sagebrush	*Artemisia nova* A. Nelson
black-tailed prairie dog	*Cynomys ludovicianus* (Ord)
blue flax	*Linum perenne* L.
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths
blue leaf aster/gray aster	*Eurybia glauca* (Nutt.) G.L. Nesom syn. *Aster glaucodes* S.F. Blake
bluebunch wheatgrass	*Pseudoroegneria spicata* (Pursh) Á. Löve
blunt-nosed leopard lizard	*Gambelia sila* (Stejneger)
bossiaea/broad leaved brown pea	*Bossiaea ornata* (Lindl.) Benth.
bristly fiddleneck	*Amsinckia tessellata* A. Gray
brittle pricklypear	*Opuntia fragilis* (Nutt.) Haw.
broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton & Rusby
brown-headed cowbird	*Molothrus ater* (Boddaert)
buffelgrass	*Pennisetum ciliare* (L.) Link

Table 1.1. Conversion of common names to scientific names.—Continued

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
burningbush	*Kochia scoparia* (L.) A.J. Scott
burrobush	*Ambrosia dumosa* (A. Gray) Payne
California broomsage	*Lepidospartum squamatum* (A. Gray) A. Gray
Canada bluegrass	*Poa compressa* L.
Canada thistle	*Cirsium arvense* (L.) Scop.
Canadian milkvetch	*Astragalus canadensis* L.
cattle saltbush	*Atriplex polycarpa* (Torr.) S. Watson
cheatgrass/downy brome	*Bromus tectorum* L.
coastal Bermudagrass/Bermudagrass	*Cynodon dactylon* (L.) Pers.
cold-desert phlox	*Phlox stansburyi* (Torr.) A. Heller
common barley	*Hordeum vulgare* L.
common yarrow	*Achillea millefolium* L.
corn	*Zea mays* L.
cowpea	*Vigna unguiculata* (L.) Walp.
creosote bush	*Larrea tridentata* (DC.) Coville
crested wheatgrass	*Agropyron cristatum* (L.) Gaertn.
crested wheatgrass	*Agropyron cristatum* (L.) Gaertn. ssp. *pectinatum* (M. Bieb.) Tzvelev syn. *Agropyron pectiniforme* Roem. & Schult.
curlycup gumweed	*Grindelia squarrosa* (Pursh) Dunal
Dahurian lespedeza	*Lespedeza daurica* (Laxm.) Schindl.
Dahurian wild rye	*Elymus dahuricus* Turcz. ex Griseb.
desert globemallow	*Sphaeralcea ambigua* A. Gray
desert needlegrass	*Achnatherum speciosum* (Trin. & Rupr.) Barkworth
desert wheatgrass	*Agropyron desertorum* (Fisch. ex Link) Schult.
dickcissel	*Spiza americana* (J.F. Gmelin)
diffuse knapweed	*Centaurea diffusa* Lam.
Douglas' ragwort	*Senecio flaccidus* Less. var. *douglasii* (DC.) B.L. Turner & T.M. Barkley syn. *Senecio douglasii* DC.
field brome	*Bromus arvensis* L.
firecracker penstemon	*Penstemon eatonii* A. Gray

Table 1.1. Conversion of common names to scientific names.—Continued

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
four-wing saltbush/fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.
four-wing saltbush/fourwing saltbush	*Atriplex canescens* (Pursh) Nutt. var. *angustifolia* (Torr.) S. Watson
four-wing saltbush/fourwing saltbush	*Atriplex canescens* (Pursh) Nutt. var. *canescens* syn. *Atriplex canescens* (Pursh) Nutt. var. *occidentalis* (Torr. & Frém.) S.L. Welsh & Stutz
Fremont's phacelia	*Phacelia fremontii* Torr.
fringed sage/prairie sagewort	*Artemisia frigida* Willd.
fuzzytongue penstemon	*Penstemon eriantherus* Pursh
galleta grass/James' galleta	*Pleuraphis jamesii* Torr. syn. *Hilaria jamesii* (Torr.) Benth.
golden eagle	*Aquila chrysaetos* L.
greater sage-grouse	*Centrocercus urophasianus* (Bonaparte)
Greene's rabbitbrush	*Chrysothamnus greenei* (A. Gray) Greene
grizzly bear	*Ursus arctos* L.
halogeton/saltlover	*Halogeton glomeratus* (M. Bieb.) C.A. Mey.
herb sophia	*Descurainia sophia* (L.) Webb ex Prantl
hoary tansyaster	*Machaeranthera canescens* (Pursh) A. Gray
Hoover's woollystar	*Eriastrum hooveri* (Jeps.) H. Mason
Illinois bundleflower	*Desmanthus illinoensis* (Michx.) MacMill. ex B.L. Rob. & Fernald
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth syn. *Oryzopsis hymenoides* (Roem. & Schult.) Ricker ex Piper
intermediate wheatgrass	*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey syn. *Agropyron intermedium* (Host) P. Beauv. syn. *Agropyron trichophorum* (Link) K. Richt.
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot syn. *Lolium multiflorum* Lam.
jack pine	*Pinus banksiana* Lamb.
Japanese brome	*Bromus arvensis* L.
Kentucky bluegrass	*Poa pratensis* L.
kikuyu/kikuyugrass	*Pennisetum clandestinum* Hochst. ex Chiov.
kleingrass	*Panicum coloratum* L.
lacy phadelia	*Phacelia tanacetifolia* Benth.

Table 1.1. Conversion of common names to scientific names.—Continued

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Common name	Scientific name
Lahontan sagebrush/little sagebrush	*Artemisia arbuscula* Nutt. ssp. *longicaulis* Winward & McArthur
Lewis flax	*Linum lewisii* Pursh
lodgepole pine	*Pinus contorta* Douglas ex Loudon
Lousiana sage/white sagebrush	*Artemisia ludoviciana* Nutt.
low sagebrush/little sagebrush	*Artemisia arbuscula* Nutt. ssp. *arbuscula*
moundscale	*Atriplex* × *aptera* A. Nelson (pro sp.) [*canescens* × *nutallii*]
mountain plover	*Charadrius montanus* J.K. Townsend
mountian snowberry	*Symphoricarpos oreophilus* A. Gray
mustard	*Brassica* L.
needle and thread	*Hesperostipa comata* (Trin. & Rupr.) Barkworth syn. *Stipa comata* Trin. & Rupr.
North African grass	*Ventenata dubia* (Leers) Coss.
northern red oak	*Quercus rubra* L.
northern wheatgrass/thickspike wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould
one-seed juniper/oneseed juniper	*Juniperus monosperma* (Engelm.) Sarg.
Pacific blazingstar	*Mentzelia obscura* H.J. Thomp. & Roberts
Parish's phacelia	*Phacelia parishii* A. Gray
partridge pea	*Chamaecrista fasciculata* (Michx.) Greene var. *fasciculata* syn. *Cassia fasciculata* Michx.
Pennsylvania sedge	*Carex pensylvanica* Lam.
plains rough fescue	*Festuca hallii* (Vasey) Piper
plantain	*Plantago* L.
ponderosa pine	*Pinus ponderosa* Lawson & C. Lawson
pongame oiltree	*Millettia pinnata* (L.) Panigrahi syn. *Pongamia pinnata* (L.) Pierre
Powell's saltweed	*Atriplex powellii* S. Watson
prairie Junegrass	*Koeleria macrantha (Ledeb.) Schult.* syn. *Koeleria cristata* auct. Non Pers. p.p.
prairie sunflower	*Helianthus petiolaris* Nutt.
purple needlegrass	*Nassella pulchra* (Hitchc.) Barkworth syn. *Stipa pulchra* Hitchc.

Table 1.1. Conversion of common names to scientific names.—Continued

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
quaking aspen	*Populus tremuloides* Michx.
rape	*Brassica napus* L.
red brome	*Bromus rubens* L.
red fescue	*Festuca rubra* L.
redtop	*Agrostis gigantea* Roth syn. *Agrostis alba* auct. Non L.
redtop/creeping bentgrass	*Agrostis stolonifera* L.
Rhodes grass	*Chloris gayana* Kunth
rockspirea	*Holodiscus dumosus* (Nutt. ex Hook.) A. Heller
Rocky Mountain beeplant	*Cleome serrulata* Pursh
Rocky Mountain juniper	Juniperus scopulorum Sarg.
rosy twotone beardtongue/pinto beardtongue	*Penstemon bicolor* (Brandegee) Clokey & D.D. Keck ssp. *roseus* Clokey & D.D. Keck
rough fescue	*Festuca campestris* Rydb.
rubber rabbitbrush	*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird syn. *Chrysothamnus nauseosus* (Pall. ex Pursh) Britton
rubber rabbitbrush	*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird ssp. *consimilis* (Greene) G.L. Nesom & Baird syn. *Chrysothamnus nauseosus* (Pall. Ex Pursh) Britton ssp. *consimilis* (Greene) H.M. Hall & Clem.
Rusby's desertmallow	*Sphaeralcea rusbyi* A. Gray ssp. *eremicola* (Jeps.) Kearney
prickly Russian thistle	*Salsola tragus* L. syn. *Salsola kali* L. *ssp. tragus* (L.) Celak
Russian wildrye	*Psathyrostachys juncea* (Fisch.) Nevski
sack saltbush	*Atriplex saccaria* S. Watson
San Joaquin kit fox	*Vulpes macrotis mutica* Merriam
Saskatoon serviceberry/western serviceberry	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.
seaberry	*Hippophae rhamnoides* L.
sericea lespedeza	*Lespedeza cuneata* (Dum. Cours.) G. Don
shadscale saltbush	*Atriplex confertifolia* (Torr. & Frém.) S. Watson
sheep fescue	*Festuca ovina* L.
sickle saltbush	*Atriplex falcata* (M.E. Jones) Standl.
sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
silver sagebrush	*Artemisia cana* Pursh

Table 1.1. Conversion of common names to scientific names.—Continued

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
skunkbush sumac	*Rhus trilobata* Nutt.
slender Russian thistle	*Salsola collina* Pall.
slender wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners
slender wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners ssp. *Trachycaulus* syn. *Agropyron trachycaulum* (Link) Malte ex H.F. Lewis
sliverleaf phacelia	*Phacelia hastata* Douglas ex Lehm
smooth brome	*Bromus inermis* Leyss.
sow-thistle/field sowthistle	*Sonchus arvensis* L.
spike dropseed	*Sporobolus contractus* Hitchc.
spiny phlox	*Phlox hoodii* Richardson
spiny hopsage	*Grayia spinosa* (Hook.) Moq.
spring wheat/common wheat	*Triticum aestivum* L.
squirreltail	*Elymus elymoides* (Raf.) Swezey ssp. *Elymoides* syn. *Sitanion hystrix* (Nutt.) J.G. Sm.
sweetclover	*Melilotus* Mill.
switchgrass	*Panicum virgatum* L.
thickspike wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould
thickspike wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould ssp. *Lanceolatus* syn. *Agropyron dasystachyum* (Hook.) Scribn. & J.G. Sm.
threadleaf sedge	*Carex filifolia* Nutt.
timothy	*Phleum pratense* L.
tumbling saltweed	*Atriplex rosea* L.
Utah juniper	*Juniperus osteosperma* (Torr.) Little
vesper sparrow	*Pooecetes gramineus* (J.F. Gmelin)
vetch/garden vetch	*Vicia sativa* L.
Watson's goosefoot	*Chenopodium watsoni* A. Nelson
wavyleaf thistle	*Cirsium undulatum* (Nutt.) Spreng.
wax currant	*Ribes cereum* Douglas
western wheatgrass	*Pascopyrum smithii* (Rydb.) Á. Löve syn. *Agropyron smithii* (Rydb.) Á. Löve
white clover	*Trifolium repens* L.

Table 1.1. Conversion of common names to scientific names.—Continued

[In the case that a scientific name used in an article has been taxonomically updated, the currently accepted name will be listed first, followed by the historically used synonym (syn.). When applicable, an "/" is used to differentiate between the common name used in an article and the common name listed in the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov). In these instances, the name before the "/" is the common name used in an article and the name after the "/" is the common name listed in the databases.]

Common name	Scientific name
white spruce	*Picea glauca* (Moench) Voss
whitetop	*Cardaria draba* (L.) Desv.
winterfat	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit syn. *Ceratoides lanata* (Pursh) J.T. Howell
Wyoming big sagebrush	*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young
yellow rabbitbrush	*Chrysothamnus viscidiflorus* (Hook.) Nutt. ssp. *viscidiflorus*
yellow twotone beardtongue/pinto beardtongue	*Penstemon bicolor* (Brandegee) Clokey & D.D. Keck ssp. *bicolor*
(no common name listed)	*Rhynchosia sublobata* (Schumach.) Meikle
(no common name listed)	*Stipa capillata* L.
(no common name listed)	*Triodia* R. Br.

Table 1.2. Conversion of scientific names to common names.

[The entries in this list include the currently accepted scientific names for all species mentioned in the articles and any historical scientific names that were directly referenced in the articles. In cases where more than one scientific name is listed for a given species (a historical scientific name and a currently accepted scientific name), all synonyms (syn.) are included for each listing for that species. For each entry, the common name referenced in the articles is listed first, and if different, the currently accepted common name is listed second, within parentheses. Currently accepted common names were derived from the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov).]

Scientific Name	Common Name
Acacia catechu (L.f.) Willd. [excluded] syn. *Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb.	black cutch
Achillea millefolium L.	common yarrow
Achnatherum hymenoides (Roem. & Schult.) Barkworth syn. *Oryzopsis hymenoides* (Roem. & Schult.) Ricker ex Piper	Indian ricegrass
Achnatherum speciosum (Trin. & Rupr.) Barkworth	desert needlegrass
Agropyron cristatum (L.) Gaertn.	crested wheatgrass
Agropyron cristatum (L.) Gaertn. ssp. pectinatum (M. Bieb.) Tzvelev syn. *Agropyron pectiniforme* Roem. & Schult.	crested wheatgrass
Agropyron dasystachyum (Hook.) Scribn. & J.G. Sm. syn. *Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould ssp. *lanceolatus*	thickspike wheatgrass
Agropyron desertorum (Fisch. ex Link) Schult.	desert wheatgrass
Agropyron intermedium (Host) P. Beauv. syn. *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey syn. *Agropyron trichophorum* (Link) K. Richt.	Intermediate wheatgrass
Agropyron pectiniforme Roem. & Schult. syn. *Agropyron cristatum* (L.) Gaertn. ssp. *pectinatum* (M. Bieb.) Tzvelev	crested wheatgrass
Agropyron smithii (Rydb.) Á. Löve syn. *Pascopyrum smithii* (Rydb.) Á. Löve	western wheatgrass
Agropyron trachycaulum (Link) Malte ex H.F. Lewis syn. *Elymus trachycaulus* (Link) Gould ex Shinners ssp. *trachycaulus*	slender wheatgrass
Agropyron trichophorum (Link) K. Richt. syn. *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey syn. *Agropyron intermedium* (Host) P. Beauv.	intermediate wheatgrass
Agrostis alba auct. Non L. syn. *Agrostis gigantea* Roth	redtop
Agrostis gigantea Roth syn. *Agrostis alba* auct. Non L.	redtop
Agrostis stolonifera L.	creeping bentgrass
Ambrosia dumosa (A. Gray) Payne	burrobush
Amelanchier alnifolia (Nutt.) Nutt. Ex M. Roem.	Saskatoon serviceberry (western serviceberry)
Amsinckia tessellata A. Gray	bristly fiddleneck

Table 1.2. Conversion of scientific names to common names.—Continued

[The entries in this list include the currently accepted scientific names for all species mentioned in the articles and any historical scientific names that were directly referenced in the articles. In cases where more than one scientific name is listed for a given species (a historical scientific name and a currently accepted scientific name), all synonyms (syn.) are included for each listing for that species. For each entry, the common name referenced in the articles is listed first, and if different, the currently accepted common name is listed second, within parentheses. Currently accepted common names were derived from the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov).]

Scientific Name	Common Name
Aquila chrysaetos L.	Golden Eagle
Artemisia arbuscula Nutt. ssp. *arbuscula*	little sagebrush (low sagebrush)
Artemisia arbuscula Nutt. ssp. *longicaulis* Winward & McArthur	Lahontan little sagebrush
Artemisia cana Pursh	silver sagebrush
Artemisia frigida Willd.	prairie sagewort (fringed sage)
Artemisia ludoviciana Nutt.	white sagebrush (Lousiana sage)
Artemisia nova A. Nelson	black sagebrush
Artemisia tridentata Nutt.	big sagebrush
Artemisia tridentata Nutt. ssp. *tridentata*	basin big sagebrush
Artemisia tridentata Nutt. ssp. *wyomingensis* Beetle & Young	Wyoming big sagebrush
Aster glaucodes S.F. Blake syn. *Eurybia glauca* (Nutt.) G.L. Nesom	gray aster (blue leaf aster)
Astragalus canadensis L.	Canadian milkvetch
Atriplex × *aptera* A. Nelson (pro sp.) [*canescens* × *nutallii*]	moundscale
Atriplex canescens (Pursh) Nutt.	fourwing saltbush (**four-wing saltbush**)
Atriplex canescens (Pursh) Nutt. var. *angustifolia* (Torr.) S. Watson	fourwing saltbush (**four-wing saltbush**)
Atriplex canescens (Pursh) Nutt. var. *canescens* syn. *Atriplex canescens* (Pursh) Nutt. var. *occidentalis* (Torr. & Frém.) S.L. Welsh & Stutz	fourwing saltbush (**four-wing saltbush**)
Atriplex canescens (Pursh) Nutt. var. *occidentalis* (Torr. & Frém.) S.L. Welsh & Stutz syn. *Atriplex canescens* (Pursh) Nutt. var. canescens	fourwing saltbush (**four-wing saltbush**)
Atriplex confertifolia (Torr. & Frém.) S. Watson	shadscale saltbush
Atriplex falcata (M.E. Jones) Standl.	sickle saltbush
Atriplex polycarpa (Torr.) S. Watson	cattle saltbush
Atriplex powellii S. Watson	Powell’s saltweed
Atriplex rosea L.	tumbling saltweed
Atriplex saccaria S. Watson	sack saltbush
Bossiaea ornata (Lindl.) Benth.	broad leaved brown pea
Bouteloua curtipendula (Michx.) Torr.	sideoats grama
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	blue grama
Brassica L.	mustard

Table 1.2. Conversion of scientific names to common names.—Continued

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Scientific Name	Common Name
Brassica napus L.	rape
Bromus arvensis L.	field brome (Japanese brome)
Bromus inermis Leyss.	smooth brome
Bromus rubens L.	red brome
Bromus tectorum L.	cheatgrass (downy brome)
Butea monosperma (Lam.) Taubert	Bengal kino
Cardaria draba (L.) Desv.	whitetop
Carex filifolia Nutt.	threadleaf sedge
Carex pensylvanica Lam.	Pennsylvania sedge
Cassia fasciculata Michx. syn. *Chamaecrista fasciculata* (Michx.) Greene var. *fasciculata*	partridge pea
Centaurea diffusa Lam.	diffuse knapweed
Centrocercus urophasianus (Bonaparte)	greater sage-grouse
Ceratoides lanata (Pursh) J.T. Howell syn. *Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	winterfat
Chamaecrista fasciculata (Michx.) Greene var. *fasciculata* syn. *Cassia fasciculata* Michx.	partridge pea
Charadrius montanus J.K. Townsend	Mountain Plover
Chenopodium watsoni A. Nelson	Watson’s goosefoot
Chloris gayana Kunth	Rhodes grass
Chrysothamnus greenei (A. Gray) Greene	Greene's rabbitbrush
Chrysothamnus nauseosus (Pall. ex Pursh) Britton syn. *Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird	rubber rabbitbrush
Chrysothamnus nauseosus (Pall. Ex Pursh) Britton ssp. *consimilis* (Greene) H.M. Hall & Clem. syn. *Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird ssp. *consimilis* (Greene) G.L. Nesom & Baird	rubber rabbitbrush
Chrysothamnus viscidiflorus (Hook.) Nutt. ssp. *viscidiflorus*	yellow rabbitbrush
Cirsium arvense (L.) Scop.	Canada thistle
Cirsium undulatum (Nutt.) Spreng.	wavyleaf thistle
Cleome serrulata Pursh	Rocky Mountain beeplant
Cynodon dactylon (L.) Pers.	coastal Bermudagrass (Bermudagrass)

Table 1.2. Conversion of scientific names to common names.—Continued

[The entries in this list include the currently accepted scientific names for all species mentioned in the articles and any historical scientific names that were directly referenced in the articles. In cases where more than one scientific name is listed for a given species (a historical scientific name and a currently accepted scientific name), all synonyms (syn.) are included for each listing for that species. For each entry, the common name referenced in the articles is listed first, and if different, the currently accepted common name is listed second, within parentheses. Currently accepted common names were derived from the following databases: for plants, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (https://plants.usda.gov), or, for plants not listed on the USDA site, https://florabase.dpaw.wa.gov.au/ and https://www.ipni.org/; and for animals, the Integrated Taxonomic Information System (https://itis.gov).]

Scientific Name	Common Name
Cynomys ludovicianus (Ord)	black-tailed prairie dog
Descurainia sophia (L.) Webb ex Prantl	herb sophia
Desmanthus illinoensis (Michx.) MacMill. ex B.L. Rob. & Fernald	Illinois bundleflower
*Elaeagnus umb*ellata Thunb.	autumn olive
Elymus angustus Trin. syn. *Leymus angustus* (Trin.) Pilg.	Altai wildrye
Elymus dahuricus Turcz. ex Griseb.	Dahurian wild rye
Elymus elymoides (Raf.) Swezey ssp. *elymoides* syn. *Sitanion hystrix* (Nutt.) J.G. Sm.	squirreltail
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould	northern wheatgrass (thickspike wheatgrass)
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould ssp. *Lanceolatus* syn. *Agropyron dasystachyum* (Hook.) Scribn. & J.G. Sm.	thickspike wheatgrass
Elymus trachycaulus (Link) Gould ex Shinners	slender wheatgrass
Elymus trachycaulus (Link) Gould ex Shinners ssp. *trachycaulus* syn. *Agropyron trachycaulum* (Link) Malte ex H.F. Lewis	slender wheatgrass
Eriastrum hooveri (Jeps.) H. Mason	Hoover's woollystar
Ericameria nauseosa (Pall. Ex Pursh) G.L. Nesom & Baird syn. *Chrysothamnus nauseosus* (Pall. ex Pursh) Britton	rubber rabbitbrush
Ericameria nauseosa (Pall. ex Pursh) G.L. Nesom & Baird ssp. *consimilis* (Greene) G.L. Nesom & Baird syn. *Chrysothamnus nauseosus* (Pall. Ex Pursh) Britton ssp. *consimilis* (Greene) H.M. Hall & Clem.	rubber rabbitbrush
Eurybia glauca (Nutt.) G.L. Nesom syn. *Aster glaucodes* S.F. Blake	gray aster (blue leaf aster)
Festuca campestris Rydb.	rough fescue
Festuca hallii (Vasey) Piper	plains rough fescue
Festuca ovina L.	sheep fescue
Festuca rubra L.	red fescue
Gambelia sila (Stejneger)	blunt-nosed leopard lizard
Grayia spinosa (Hook.) Moq.	spiny hopsage
Grindelia squarrosa (Pursh) Dunal	curlycup gumweed
Gutierrezia sarothrae (Pursh) Britton & Rusby	broom snakeweed
Halogeton glomeratus (M. Bieb.) C.A. Mey.	saltlover

Table 1.2. Conversion of scientific names to common names.—Continued

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Scientific Name	Common Name
Helianthus annuus L.	common sunflower (annual sunflower)
Helianthus petiolaris Nutt.	prairie sunflower
Hesperostipa comata (Trin. & Rupr.) Barkworth syn. *Stipa comata* Trin. & Rupr.	needle and thread
Hilaria jamesii (Torr.) Benth. syn. *Pleuraphis jamesii* Torr.	James' galleta (galleta grass)
Hippophae rhamnoides L.	seaberry
Holodiscus dumosus (Nutt. ex Hook.) A. Heller	rockspirea
Hordeum vulgare L.	common barley
Hyoscyamus niger L.	black henbane
Juniperus monosperma (Engelm.) Sarg.	one-seed juniper (oneseed juniper)
Juniperus osteosperma (Torr.) Little	Utah juniper
Juniperus scopulorum Sarg.	Rocky Mountain juniper
Kochia scoparia (L.) A.J. Scott	burningbush
Koeleria cristata auct. Non Pers. p.p. syn. *Koeleria macrantha* (Ledeb.) Schult.	prairie Junegrass
Koeleria macrantha (Ledeb.) Schult. syn. *Koeleria cristata* auct. Non Pers. p.p.	prairie Junegrass
Krascheninnikovia lanata (Pursh) A. Meeuse & Smit syn. *Ceratoides lanata* (Pursh) J.T. Howell	winterfat
Larrea tridentata (DC.) Coville	creosote bush
Lepidospartum squamatum (A. Gray) A. Gray	California broomsage
Lespedeza cuneata (Dum. Cours.) G. Don	sericea lespedeza
Lespedeza daurica (Laxm.) Schindl.	Dahurian lespedeza
Leymus angustus (Trin.) Pilg. syn. *Elymus angustus* Trin.	Altai wildrye
Leymus cinereus (Scribn. & Merr.) Á. Löve	basin wildrye
Linum lewisii Pursh	Lewis flax
Linum perenne L.	blue flax
Lolium multiflorum Lam. syn. *Lolium perenne* L. ssp. multiflorum (Lam.) Husnot	Italian ryegrass

Table 1.2. Conversion of scientific names to common names.—Continued

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Scientific Name	Common Name
Lolium perenne L. ssp. *multiflorum* (Lam.) Husnot syn. *Lolium multiflorum* Lam.	Italian ryegrass
Machaeranthera canescens (Pursh) A. Gray	hoary tansyaster
Medicago sativa L.	alfalfa
Melilotus Mill.	sweetclover
Mentzelia obscura H.J. Thomp. & Roberts	Pacific blazingstar
Millettia pinnata (L.) Panigrahi syn. *Pongamia pinnata* (L.) Pierre	pongame oiltree
Molothrus ater (Boddaert)	brown-headed cowbird
Nassella pulchra (Hitchc.) Barkworth syn. *Stipa pulchra* Hitchc.	purple needlegrass
Opuntia fragilis (Nutt.) Haw.	brittle pricklypear
Oryzopsis hymenoides (Roem. & Schult.) Ricker ex Piper syn. *Achnatherum hymenoides* (Roem. & Schult.) Barkworth	Indian ricegrass
Ovis canadensis Shaw	bighorn sheep
Panicum coloratum L.	kleingrass
Panicum virgatum L.	switchgrass
Pascopyrum smithii (Rydb.) Á. Löve syn. *Agropyron smithii* (Rydb.) Á. Löve	western wheatgrass
Pennisetum ciliare (L.) Link	buffelgrass
Pennisetum clandestinum Hochst. ex Chiov.	kikuyugrass (kikuyu)
Penstemon bicolor (Brandegee) Clokey & D.D. Keck ssp. *bicolor*	pinto beardtongue (yellow twotone beardtongue)
Penstemon bicolor (Brandegee) Clokey & D.D. Keck ssp. *roseus* Clokey & D.D. Keck	pinto beardtongue (rosy twotone beardtongue)
Penstemon eatonii A. Gray	firecracker penstemon
Penstemon eriantherus Pursh	fuzzytongue penstemon
Phacelia fremontii Torr.	Fremont's phacelia
Phacelia hastata Douglas ex Lehm	sliverleaf phacelia
Phacelia parishii A. Gray	Parish’s phacelia
Phacelia tanacetifolia Benth.	lacy phadelia
Phleum pratense L.	timothy

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Scientific Name	Common Name
Phlox hoodii Richardson	spiny phlox
Phlox stansburyi (Torr.) A. Heller	cold-desert phlox
Picea glauca (Moench) Voss	white spruce
Pinus banksiana Lamb.	jack pine
Pinus contorta Douglas ex Loudon	lodgepole pine
Pinus ponderosa Lawson & C. Lawson	ponderosa pine
Plantago L.	plantain
Pleuraphis jamesii Torr. syn. *Hilaria jamesii* (Torr.) Benth.	James' galleta (galleta grass)
Poa compressa L.	Canada bluegrass
Poa pratensis L.	Kentucky bluegrass
Pongamia pinnata (L.) Pierre syn. *Millettia pinnata* (L.) Panigrahi	pongame oiltree
Pooecetes gramineus (J.F. Gmelin)	Vesper Sparrow
Populus tremuloides Michx.	quaking aspen
Psathyrostachys juncea (Fisch.) Nevski	Russian wildrye
Pseudoroegneria spicata (Pursh) Á. Löve	bluebunch wheatgrass
Purshia tridentata (Pursh) DC.	antelope bitterbrush (bitterbrush)
Quercus rubra L.	northern red oak
Rhus trilobata Nutt.	skunkbush sumac
Rhynchosia sublobata (Schumach.) Meikle	(no common name listed)
Ribes cereum Douglas	wax currant
Robinia pseudoacacia L.	black locust
Salsola collina Pall.	slender Russian thistle
Salsola kali L. ssp. *tragus* (L.) Celak syn. *Salsola tragus* L.	prickly Russian thistle
Salsola tragus L. syn. *Salsola kali* L. ssp. *tragus* (L.) Celak	prickly Russian thistle
Senecio douglasii DC. syn. *Senecio flaccidus* Less. var. *douglasii* (DC.) B.L. Turner & T.M. Barkley	Douglas' ragwort

Table 1.2. Conversion of scientific names to common names.—Continued

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Scientific Name	Common Name
Senecio flaccidus Less. var. *douglasii* (DC.) B.L. Turner & T.M. Barkley syn. *Senecio douglasii* DC.	Douglas' ragwort
Senegalia catechu (L.f.) P.J.H. Hurter & Mabb. syn. *Acacia catechu* (L.f.) Willd. [excluded]	Black cutch
Sitanion hystrix (Nutt.) J.G. Sm. syn. *Elymus elymoides* (Raf.) Swezey ssp. *elymoides*	Squirreltail
Sonchus arvensis L.	field sowthistle (sow-thistle)
Sphaeralcea ambigua A. Gray	desert globemallow
Sphaeralcea rusbyi A. Gray ssp. *eremicola* (Jeps.) Kearney	Rusby's desertmallow
Spiza americana (J.F. Gmelin)	Dickcissel
Sporobolus airoides (Torr.) Torr.	alkali sacaton
Sporobolus contractus Hitchc.	spike dropseed
Stipa capillata L.	(no common name listed)
Stipa comata Trin. & Rupr. syn. *Hesperostipa comata* (Trin. & Rupr.) Barkworth	Needle and thread
Stipa pulchra Hitchc. syn. *Nassella pulchra* (Hitchc.) Barkworth	purple needlegrass
Symphoricarpos oreophilus A. Gray	mountain snowberry
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey syn. *Agropyron intermedium* (Host) P. Beauv. syn. *Agropyron trichophorum* (Link) K. Richt.	intermediate wheatgrass
Trifolium repens L.	white clover
Triodia R. Br.	(no common name listed)
Triticum aestivum L.	common wheat (spring wheat)
*Urochloa mosambic*ensis (Hack.) Dandy	African liverseed grass
Ursus arctos L.	grizzly bear
Ventenata dubia (Leers) Coss.	North African grass
Vicia sativa L.	garden vetch (vetch)
Vigna unguiculata (L.) Walp.	cowpea
Vulpes macrotis mutica Merriam	San Joaquin kit fox
Zea mays L.	corn

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