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# Annotated Bibliography of Scientific Research on *Taeniatherum caput-medusae* Published from January 2010 to January 2022

Open-File Report 2023–1089

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

**Cover.** Medusahead (*Taeniatherum caput-medusae*), an exotic annual grass, gets its namesake from the appearance of its long and twisted awns late in its life cycle. Photograph by Steve Dewey, Utah State University, Bugwood.org, licensed under a Creative Commons Attribution 3.0 License.

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By Jennifer K. Meineke, Logan M. Maxwell, Alison C. Foster, Laine E. McCall, Tait K. Rutherford, Ella M. Samuel, Lea B. Selby, Joshua S. Willems, Nathan J. Kleist, and Samuel E. Jordan

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# Contents



## Table



# Conversion Factors

U.S. customary units to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 4,047 | square meter ($m^2$) |
| acre | 0.4047 | hectare (ha) |
| acre | 0.004047 | square kilometer ($km^2$) |

International System of Units to U.S. customary units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| meter (m) | 1.094 | yard (yd) |
| | Area | |
| hectare (ha) | 2.471 | acre |
| square kilometer ($km^2$) | 247.1 | acre |
| hectare (ha) | 0.003861 | square mile ($mi^2$) |
| square kilometer ($km^2$) | 0.3861 | square mile ($mi^2$) |

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

$$°C = (°F - 32) / 1.8.$$

# Abbreviations

| | |
|---|---|
| ARS | Agricultural Research Service |
| BLM | Bureau of Land Management |
| DNA | deoxyribonucleic acid |
| HLS | Harmonized Landsat and Sentinel-2 |
| NGO | nongovernmental organization |
| USDA | U.S. Department of Agriculture |
| FWS | U.S. Fish and Wildlife Service |
| URL | uniform resource locator |
| Forest Service | U.S. Department of Agriculture Forest Service |
| USGS | U.S. Geological Survey |
| WPA | weed prevention area |

# Species Names

| Common name | Scientific name |
|---|---|
| African rue | *Peganum harmala* Linnaeus |
| alfalfa | *Medicago sativa* Linnaeus |
| alkali swainsonpea | *Sphaerophysa salsula* (Pallas) de Candolle |
| amblyopyrum | *Amblyopyrum* Eig. |
| annual rye | *Lolium multiflorum* Lamarck |
| annual semaphoregrass | *Pleuropogon californicus* (Nees) Bentham ex Vasey |
| aphids | *Rhopalosiphum padi* Linnaeus |
| autumn olive | *Elaeagnus umbellata* Thunberg |
| bald brome | *Bromus racemosus* Linnaeus |
| barb (barbed) goatgrass | *Aegilops triuncialis* Linnaeus |
| barley | *Hordeum vulgare* Linnaeus |
| basin wildrye | *Leymus cinereus* (Lamson-Scribner and Merrill) A. Love |
| bees | Hymenoptera Linnaeus |
| big sagebrush | *Artemisia tridentata* Nuttall |
| big squirreltail | *Elymus multisetus* (J.G. Sm.) Burtt Davy |
| black sagebrush | *Artemisia nova* A. Nelson |
| Blando brome | *Bromus hordeaceus* Linnaeus |
| blue oak | *Quercus douglasii* Hooker & Walker-Arnott |
| blue wildrye | *Elymus glaucus* Buckley |
| bluebunch wheatgrass | *Pseudoroegneria spicata* (Pursh) A. Love |
| bottlebrush squirreltail | *Elymus elymoides* (Rafinesque) Swezey |
| Brewer's sparrow | *Spizella breweri* Cassin |
| bristly fiddleneck | *Amsinckia tessellata* A. Gray |
| brome | *Bromus* species Linnaeus |
| bulbous bluegrass | *Poa bulbosa* Linnaeus |
| bur buttercup | *Ranunculus testiculatus* von Crantz (Roth) |
| bur clover | *Medicago polymorpha* Linnaeus |
| California brome | *Bromus carinatus* Hooker & Walker-Arnott |
| California oatgrass | *Danthonia californica* Bolander |
| Canada thistle | *Cirsium arvense* (Linnaeus) Scopoli |
| canola meal | *Brassica napus* Linnaeus |
| cheatgrass | *Bromus tectorum* Linnaeus |

| | |
|---|---|
| cheatgrass pathogen | *Ustilago bullata* Berk. |
| Chinese tamarisk | *Tamarix chinensis* Loureiro |
| clover | *Trifolium* species Linnaeus |
| Columbia brome | *Bromus vulgaris* (Hooker) Shear |
| common dandelion | *Taraxacum officinale* (Linnaeus) Weber ex F.H. Wigg |
| common wheat | *Triticum aestivum* Linnaeus |
| corn | *Zea mays* Linnaeus |
| creeping bentgrass | *Agrostis stolonifera* Linnaeus |
| crested wheatgrass | *Agropyron cristatum* (Linnaeus) Gaertner |
| crested wheatgrass hybrid | *Agropyron cristatum* x *Agropyron desertorum (*Linnaeus) Gaertner x (Fischer ex Link) Schultes |
| crimson clover | *Trifolium incarnatum* Linnaeus |
| dalmatian toadflax | *Linaria dalmatica* (Linnaeus) Miller |
| desert wheatgrass | *Agropyron desertorum* (Fischer ex Link) Schultes |
| domestic cattle | *Bos Taurus* Linnaeus |
| downy brome | *Bromus tectorum* Linnaeus |
| durum wheat | *Triticum durum* Desfontaines |
| filaree | *Erodium* species Aiton |
| Fitch's tarweed | *Centromadia fitchii* (A. Gray) Greene |
| forage kochia | *Kochia prostrata* (Linnaeus) Schrader |
| foxtail barley | *Hordeum jubatum* Linnaeus |
| fungal seed pathogen | *Pyrenophora semeniperda* (Brittleb. & D.B. Adam) Shoemaker |
| giant knotweed | *Fallopia sachalinensis* (F. Schmidt) Nakai |
| goat | *Capra hircus* Linnaeus |
| goatgrass | *Aegilops* species Linnaeus |
| grass | *Poaceae* Linnaeus |
| greater sage-grouse | *Centrocercus urophasianus* Bonaparte |
| ground crab spiders | *Xysticus* species C.L. Koch |
| Idaho fescue | *Festuca idahoensis* Elmer |
| intermediate wheatgrass | *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey |
| Italian ryegrass | *Lolium multiflorum* Lamarck |
| Japanese brome | *Bromus japonicus* Thunberg |
| jointed goatgrass | *Aegilops cylindrica* Host |
| junegrass | *Koeleria macrantha* (Ledebour) Schultes |
| juniper | *Juniperus* species Linnaeus |
| knapweeds | *Centaurea* species Linnaeus |

| | |
|---|---|
| leafy spurge | *Euphorbia esula* Linnaeus |
| low sagebrush | *Artemisia arbuscula* Nuttall |
| mites | *Eriopyidae* Nalepa |
| medusahead | *Taeniatherum caput-medusae* (Linnaeus) Nevski |
| morning glory | *Convolvulus arvensis* Linnaeus |
| oak | *Quercus* species Linnaeus |
| oat | *Avena* species Linnaeus |
| orchardgrass | *Dactylis glomerata* Linnaeus |
| ponderosa pine | *Pinus ponderosa* Douglas ex P. Lawson & C. Lawson |
| pubescent wheatgrass | *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey |
| puncture vine | *Tribulus terrestris* Linnaeus |
| purple false brome | *Brachypodium distachyon* (Linnaeus) P. Beauv |
| purple needlegrass | *Stipa pulchra* (Hitchcock) Barkworth |
| pygmy rabbit | *Brachylagus idahoensis* Merriam |
| red brome | *Bromus rubens* Linnaeus |
| redtop | *Agrostis gigantea* Roth |
| rose clover | *Trifolium hirtum* Allioni |
| rubber rabbitbrush | *Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird |
| Russian wildrye | *Psathyrostachys juncea* (Fischer) Nevski |
| sagebrush | *Artemisia* species Linnaeus |
| saltgrass | *Distichlis spicata* (Linnaeus) Greene |
| Sandberg bluegrass | *Poa secunda* J. Presl |
| scotch thistle | *Onopordum acanthium* Linnaeus |
| sheep | *Ovis aries* Linnaeus |
| Sherman big bluegrass | *Poa secunda* J. Presl |
| Siberian wheatgrass | *Agropyron fragile* (Roth) P. Candargy |
| slender oat | *Avena barbata* Pott ex Link |
| small burnet | *Sanguisorba minor* Scopoli |
| small fescue | *Vulpia microstachys* (Nuttall) Munro |
| small sixweeks grass | *Vulpia microstachys* (Nuttall) Munro |
| smooth brome | *Bromus inermis* Leysser |
| smooth meadow-grass | *Poa pratensis* Linnaeus |
| snakeweed | *Gutierrezia sarothrae* (Pursh) Britton & Rusby |
| soft brome | *Bromus hordeaceus* Linnaeus |
| southern Idaho ground squirrel | *Urocitellus endemicus* Yensen |

| | |
|---|---|
| spiders | *Araneae* Clerck |
| squirreltail | *Elymus elymoides* (Rafinesque) Swezey |
| St. John's wort | *Hypericum perforatum* Linnaeus |
| strawberry guava | *Psidium cattleianum* Sabine |
| tall fescue | *Schedonorus arundinaceus (Schreb.) Dumort.* |
| tall wheatgrass | *Thinopyrum ponticum* (Podp.) (Podp.) Barkworth & D.R. Dewey |
| thickspike wheatgrass | *Elymus lanceolatus* (Lamson-Scribner and J.G. Sm.) Gould |
| Thurber's needlegrass | *Achnatherum thurberianum* (Piper) Barkworth |
| velvet grass | *Holcus lanatus* Linnaeus |
| velvet lupine | *Lupinus leucophyllus* Douglas ex Lindley |
| ventenata | *Ventenata dubia* (Leers) Coss. |
| vinegarweed | *Trichostema lanceolatum* Bentham |
| wall barley | *Hordeum murinum* Linnaeus |
| weed-suppressive bacteria | *Pseudomonas fluorescens* (Flugge) Migula |
| western blue-eyed grass | *Sisyrinchium bellum* S. Watson |
| western juniper | *Juniperus occidentalis* Hooker |
| western wheatgrass | *Pascopyrum smithii* (Rydberg) A. Love |
| western yarrow | *Achillea millefolium* Linnaeus |
| wheat | *Triticum* species Linnaeus |
| wheat straw | *Triticum aestivum* Linnaeus |
| wild oat | *Avena fatua* Linnaeus |
| woolly distaff thistle | *Carthamus lanatus* Linnaeus |
| Wyoming big sagebrush | *Artemisia tridentata* Nuttall subspecies *wyomingensis* Beetle & Young |
| yeast | *Saccharomyces cerevisiae* Meyen ex E.C. Hansen |
| yellow star thistle | *Centaurea solstitialis* Linnaeus |

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By Jennifer K. Meineke,[1] Logan M. Maxwell,[2] Alison C. Foster,[1] Laine E. McCall,[2] Tait K. Rutherford,[1] Ella M. Samuel,[1] Lea B. Selby,[2] Joshua S. Willems,[2] Nathan J. Kleist[1], and Samuel E. Jordan[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 is creating a series of annotated bibliographies on topics of management concern for western lands. Previously published reports introduced a methodology for preparing annotated bibliographies to facilitate the integration of recent, peer-reviewed science into resource management decisions. Therefore, relevant text from those efforts is reproduced here to frame the presentation. Invasive annual grasses are widely distributed throughout the western United States and threaten native ecosystems by altering fire regimes, replacing native plants, and altering grazing patterns, often with tremendous associated costs. One invasive annual grass, *Taeniatherum caput-medusae* (hereafter, medusahead), was first documented in the United States in 1887 and has been identified as a species of management concern. Medusahead's life history traits allow it to quickly and effectively dominate native plant communities, and it has already taken over millions of acres in western North America. Although medusahead can spread widely and disrupt ecosystem function, it has been studied less than other western invasive grass species. We compiled and summarized peer-reviewed journal articles, data products, and formal technical reports (such as U.S. Department of Agriculture Forest Service General Technical Reports and U.S. Geological Survey Open-File Reports) on medusahead, published between January 2010 and January 2022. We first performed a systematic search of three reference databases and three government databases using the search phrase "medusahead" OR "medusa head" OR "*Taeniatherum caput-medusae*" OR "*Taeniatherum caputmedusae*" OR "*Taeniatherum asperum*." We refined the initial list of products by removing (1) duplicates, (2) products not written in English, (3) publications that were not focused on North America, (4) publications that were not published as research, data products, or scientific review articles in peer-reviewed journals or as formal technical reports, and (5) products for which medusahead was not a research focus, or the study did not present new data or findings about medusahead. We summarized each product using a consistent structure (background, objectives, methods, location, findings, and implications) and identified the management topics (for example, species and population characteristics; habitat; and control and management efforts) addressed by each product. We also noted which publications included new geospatial data. 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 publication, and a formal peer review. Our initial searches resulted in 4,245 total products, of which 211 met our criteria for inclusion. The most commonly addressed management topics addressed in products summarized in the annotated bibliography were as follows: nonnative invasive plants, weed management, site-scale habitat characteristics, habitat restoration or reclamation, and cultural management of weeds. All published bibliographies, including the online version of this bibliography, are available at the Science for Resource Managers (https://apps.usgs.gov/science-for-resource-managers). This database is searchable by topic, location, and year and includes links to each original publication. The studies compiled and summarized here may inform planning and management actions that seek to maintain and restore sagebrush landscapes and associated native species across the western United States.

[1]U.S. Geological Survey.
[2]Fort Collins, Colorado, Contractor to the U.S. Geological Survey.

# Introduction

Reviewing the best available science relevant to potential land management decisions and resource planning efforts 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 number of scientific publications, the restrictive access to many publications and publication databases, and the time needed to perform a comprehensive search for the best available science on any given species or 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 western lands, the U.S. Geological Survey (USGS) initiated a program of work to compile and summarize recent, peer-reviewed scientific literature on a series of resources and topics of management concern.

The distribution, spread, and effect of invasive annual grasses are some of the biggest threats to native ecosystems and species across the western United States (DiTomaso, 2000). Managing and controlling invasive grasses requires synthesis and integration of knowledge about the ecology of each invasive species, and some species are better studied than others (Knezevic and others, 2002; Swanton and others, 2008). Native to Eurasia, *Taeniatherum caput-medusae* (hereafter, medusahead) was first collected in the United States in Oregon in 1887 (Young, 1992). Since its detection, medusahead has spread widely across the United States, dominating plant communities across millions of acres through multiple States, with severe infestations reported in California, Oregon, Nevada, Utah, and Colorado (Johnson and Davies, 2012; Nafus and Davies, 2014). Medusahead invasion occurs across several climatic conditions and habitat types, commonly grasslands, oak woodlands, chaparral communities, and sagebrush ecosystems (Young, 1992; Nafus and Davies, 2014; Davies and others, 2021). Medusahead is an effective invader because it rapidly overtakes native vegetation, produces large quantities of seeds, has high germination rates, germinates in the fall with roots that grow throughout the winter, and produces large quantities of slowly decomposing litter, all of which suppress native species (Hironaka, 1961; Young, 1992; Clausnitzer and others, 1999; Young and Mangold, 2008). Medusahead invasion has been linked to decreased biodiversity, increased fire risks, reduced palatability of forage for livestock, and reduced habitat quality for special-status wildlife species (Davies, 2011; Johnson and Davies, 2012; Hamilton and others, 2015; Fusco and others, 2019). Climate change may cause medusahead to spread more quickly across western North America (Bansal and others, 2014; Jarnevich and others, 2021) and into previously uninvaded areas (Chai and others, 2016). Despite its negative effects on ecosystem function and continued invasion potential, medusahead remains relatively understudied compared to other invasive annual grasses, like cheatgrass (Davies and Svejcar, 2008; Davies, 2011; Li and others, 2020). To aid managers in using and synthesizing the existing research, we compiled and summarized peer-reviewed literature and data products about medusahead published between January 2010 and January 2022.

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 the control of medusahead and its potential effects on natural resources in the United States. Each summary (and associated publication) is searchable by management topic, and we have provided links to the original publications to facilitate access to primary literature sources. Management of medusahead is a topic of ongoing scientific interest and management concern. As such, information in this document could be maintained and periodically updated to serve as a readily accessible, up-to-date resource for managers, planners, and policymakers who need a quick reference to recent peer-reviewed science and data about medusahead.

# Methods

Previous reports (Carter and others, 2018, 2020) introduced a methodology for generating annotated bibliographies to facilitate the integration of recent, peer-reviewed science into resource management decisions. This report and other annotated bibliography reports (for example, Poor and others, 2021) build on that methodology and apply it to new species and topics of management concern on western lands. Therefore, relevant text from these reports is reproduced herein to frame the presentation.

We performed a systematic search of three citation indices (Web of Science, Scopus [accessed through the USGS Library], and Google Scholar [accessed through Publish or Perish (Harzing, 2007)]) and three Federal Government publication databases (USGS ScienceBase, USGS Publications Warehouse, and U.S. Department of Agriculture Forest Service TreeSearch) using the search phrase "medusahead" OR "medusa head" OR "*Taeniatherum caput-medusae*" OR "*Taeniatherum caputmedusae*" OR "*Taeniatherum asperum*." We developed this search phrase through consultation with an interagency team of invasive-plant experts to help ensure that our searches would capture products relevant to management of the species on lands in the United States. Also, in consultation with an interagency team of invasive-plant experts, we chose to limit our search to products published since January 1, 2010, to better reflect the period of research focus on this species in the United States. We performed our final standard search of all databases on January 18, 2022. However, we opportunistically included products brought to our attention through other means (for example, products about medusahead shared with us by the authors we contacted to request input on the summaries of their publications; see "Review Process" section), and these products may have been published after the date we completed our final standard search. Because databases were not formally searched after January 18, 2022, any literature published after this search was included in this bibliography opportunistically and represents an incomplete list of relevant literature published after January 1, 2022. We required that any opportunistically obtained products met all the same criteria described in the following paragraph to be included in the annotated bibliography.

We refined the initial list of products returned from our searches in five ways. First, we removed duplicate items. Second, we removed products that were not written in English. Third, we removed publications that were not focused on North America because our aim was to provide managers with published products relevant to management of medusahead in the United States. Fourth, we excluded products that were not published as research, scientific review articles, or data products in peer-reviewed journals or as formal technical reports; this exclusion helped ensure that all products presented final work that had gone through a structured peer-review process. Accordingly, we excluded editorial content (such as policy perspectives and commentaries); reports without evidence of a formal peer-review process (such as project and annual reports without a technical series or volume number and a permanent digital object identifier); conference abstracts; article preprints; articles in magazines (for which there was no reference to a peer-review process); articles in journals for which we could not find evidence of a comprehensive peer-review process; manuscripts not yet in press; and theses, dissertations, and books regardless of peer-review status. We also excluded reports that provided short summaries of research projects (often published when those projects were still in progress) that were intended for sharing with a broad public audience because those research results would be published elsewhere once the studies were complete. Fifth, we retained only those publications for which medusahead was a main focus and for which the publication provided new data or findings about medusahead (for original research articles) or summarized or synthesized existing data about medusahead (for review papers). This was primarily accomplished by requiring that "medusahead" OR "medusa head" OR "*Taeniatherum caput-medusae*" OR "*Taeniatherum asperum*" be present in the publication title, abstract, or author-supplied keywords (when available), and be present in the main text of the article. Often, publications we removed using this step only mentioned medusahead as a comparison species in the introduction or discussion. For very large publications (for example, hundreds of pages) covering multiple topics and species, we explicitly confined our summaries to medusahead and stated this in the summary itself. Similarly, for products such as paleontological publications or review papers that covered a broad range of species, our summaries noted the full range of taxa covered in the publication but were primarily focused on those species that are of present-day management concern in North America.

Several products presented new data or findings about medusahead but did not contain one of the search terms in the publication title, abstract, or author-supplied keywords. For example, many articles presented findings on medusahead but lumped the species within a larger category, such as "invasive annual grasses" or "exotic grasses" and then used these terms to refer to medusahead in the title, abstract, or keywords and throughout the article. We included these articles, where they were identified or opportunistically brought to our attention, when it was clear from language within the article that medusahead was included in a larger category. We cannot guarantee that our search process identified all these products, particularly for journals that do not have keywords or for which keywords are not indexed by Web of Science or Scopus. However, we made every effort to identify these types of articles through Google Scholar.

Google Scholar indexes a wider range of products than the other search engines and thus required slightly different methods. Many of the Google Scholar search results were not published products, were not written in English, or did not focus on systems in North America. Thus, for the Google Scholar search, we used R (R Core Team, 2020) to iteratively filter search results based on metadata provided by Google Scholar. We first removed products of type "citation" and then used identifiers in the uniform resource locator (URL) to remove products that were books, book chapters, patents, theses, or dissertations. We flagged products that included text in the abstract or title that was identified as a language other than English by either of two methods of language detection (Ooms, 2018, 2020). To ensure accurate results, we screened the abstracts and titles of flagged non-English products (Westgate, 2019) and reintegrated those that could not be reliably excluded by language recognition. We then excluded products from URLs that did not have a top-level domain of .com, .edu, .org, .us, .gov, .net, .ca, .uk, .mil, .au, or .info. Finally, we removed articles from any journals known to not meet our standards for peer review. We manually filtered the remaining articles so that our final list of products to be included in the annotated bibliography met all criteria described previously. During the manual filtering process, we identified an additional term used to refer to medusahead in a small number of articles: "*Elymus caput-medusae*." We included articles that used this term, but we did not include it in our list of terms used to search other databases.

We parsed the final list of publications among our group of scientists to develop summaries of each product. The scientist to whom the publication had been assigned then read each publication, summarized its contents using a consistent structure (background, objectives, methods, location, findings, and implications), and identified the management topics it addressed (table 1). Location information included the State(s) and (or) Province(s), county(ies), or continent where the study took place, depending on the information provided in the article. For studies involving translocated plants or plants held, studied, or bred in captive facilities or greenhouses, the location information reflects the release location of the individuals and (or) location where the individuals were collected when available. The site of the captive rearing or greenhouse facility is not included as part of the location information in our product summaries but can be located in the original published product. Scientific names were based on what authors used in original products; however, we used common names for all species within product summaries for ease of reading. If we had questions about scientific or common names, we checked with the Integrated Taxonomic Information System (https://doi.org/10.5066/F7KH0KBK). Considerable information was distilled from each publication in developing the summary, and where some products may address data and findings of several species, these summaries may focus on the species of interest to the annotated bibliography (for example, other exotic annual grass species). Thus, though we accurately represent each publication, there may be additional information in the original product that was not included in our 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 publication are provided for each summary whenever available). Each draft summary, and the associated original publication, was then reviewed by another scientist in the group to promote consistency across summaries and to provide an additional check on the accuracy of summaries in capturing key findings from the original publication.

**Table 1.** Management categories and topics assessed for each product included in the bibliography.

| Management topic | Definition |
|---|---|
| Management category—Species and population characteristics | |
| Survival | Study quantified survival rates for plant or animal species, often in relation to environmental conditions. For plants, this includes quantification of seed longevity and viability. |
| Behavior or demographics | Study measured or modeled aspects of behavior or demographics for plant or animal species (for example, seasonal movements, seeds per plant, seed mass, seed germination rate, vegetative reproduction, reproductive success, vital rates). |
| Population estimates or targets | Study estimated or modeled plant or animal species population numbers, trends, dynamics, assessment methods, or responses to the environment. |
| Captive breeding | Study developed methods for or evaluated the success of species captive breeding efforts. For plant species, this could include greenhouse breeding. Where this topic applies, "Location" refers to that of the wild population, not the breeding facility. |
| Translocation | Study developed methods for or evaluated the success of plant or animal species translocation efforts. |
| Genetics | Study used genetic evidence to investigate plant or animal species biology (for example, population structure, connectivity, behavior). |
| Dispersal, spread, vectors, and pathways | Study addressed species dispersal abilities, invasiveness, or factors affecting spread. |
| Other: Species and population characteristics | Study focused on another aspect of species biology or ecology not listed elsewhere. |
| Management category—Habitat | |
| Broad-scale habitat characteristics | Study addressed landscape-level habitat characteristics (for example, size, number, or connectivity of habitat patches, characteristics of linkage areas, effects of landscape context on habitat quality, availability or use of seasonal habitats), usually across large areas. |
| Site-scale habitat characteristics | Study addressed habitat characteristics at the local level (for example, nest sites or brood-rearing areas for wildlife species), typically based on field measurement of vegetation or soils. |
| Habitat selection | Study analyzed habitat characteristics used by species, typically based on a combination of habitat characterization and telemetry or direct observations of individuals. |
| Habitat restoration or reclamation | Study addressed methods for habitat restoration or the responses of species habitat, individuals, or populations to habitat reclamation or restoration efforts. |
| Management category—Human-caused and ecological disturbances | |
| Effect distances or spatial scale | Study addressed the spatial scale or distance effects of ecological or human-caused features on the species (for example, estimated distance that species may be displaced by or respond to a disturbance or environmental feature). |
| Hunting/collectors | Study addressed the effect of hunting, harvesting, collecting, or taking (in the sense of Endangered Species Act of 1973 as amended, 16 USC §1532[19]) by other methods on species populations or demographics. |
| Recreation | Study addressed the relationship between recreation infrastructure (such as trails) or activities and species habitat, populations, or individuals. |
| Predators or predator control | Study addressed predator or consumer populations, the effects of predators or consumers on the species, or the effects of predator control on the species. |
| Fire | Study addressed the relationship between fire and the species or their habitat, consisting of wildfire, wildland fire management, fire suppression, flame lengths, prescribed fire, controlled burn, and the use of fire for vegetation or weed management. |
| Fuels and fuels management | Study addressed the relationship between fuels management and the species or their habitat, consisting of fuel types, fuel loading, fuel models, and fuels treatments. |
| Fuel breaks | Study addressed the relationship between fuel breaks (sometimes referred to as "fire breaks," "ground strips," or "green strips") and the species or their habitat. |
| Nonnative invasive plants | Study addressed nonnative invasive plants or the effects of nonnative invasive plants (or efforts to control those species) on the species or its habitat. |
| Sagebrush removal | Study addressed the relationship between intentional sagebrush removal treatments and the species or its habitat. |

**Table 1.** Management categories and topics assessed for each product included in the bibliography.—Continued

| Management topic | Definition |
|---|---|
| Management category—Human-caused and ecological disturbances—Continued | |
| Conifer expansion | Study quantified the relationship between conifer expansion and the species or its habitat. |
| Grazing/herbivory | Study addressed the relationship between herbivory (wild or domestic) and species habitat, populations, or individuals, as well as consideration of grazing as a tool for vegetation or weed management. |
| Fences | Study assessed the relationship between fences and species persistence, survival, or behavior. |
| Other range management structures | Study addressed the relationship between other range improvement structures (for example, water developments, mineral licks) and species habitat, predators, or individuals. |
| Energy development | Study quantified effects of energy development on species habitat, populations, or individuals. |
| Mining | Study quantified effects of mining on species habitat, populations, or individuals. |
| Exurban development | Study addressed effects of exurban development on species habitat, populations, or individuals. |
| Infrastructure | Study addressed effects of various other infrastructure elements (for example, roads, pipelines, powerlines, cell towers) on species habitat, predators, populations, or individuals. |
| Agriculture | Study addressed effects of agriculture and agricultural conversion on species habitat, populations, or individuals. |
| Weather and climate patterns | Study addressed the effects of weather or climate patterns (for example, amounts or patterns of temperature or precipitation within a growing season, or past, historical, or prehistorical climate) on species habitat, populations, or individuals. |
| Climate change | Study explicitly addressed the effects of climate change on species habitat, populations, or individuals. Many products in this category are likely to consider projected future climate conditions. |
| Drought | Study addressed the effects of droughts or drought conditions on species habitat, populations, or individuals. |
| Management category—Invasive plant control or management efforts | |
| Weed management | Study addressed some aspect of weed management, which may include methods for controlling the abundance or spread of noxious weeds or nonnative invasive plants or assessed the effectiveness of weed control efforts. |
| Subtopic: Biocontrol | Study addressed invasive plant control efforts that use one or more species of introduced agent (for example, predator, herbivore, pathogen), often from the target species' native range. |
| Subtopic: Cultural control | Study addressed invasive plant control efforts that use soil solarization (clear plastic placed over moist soil), plastic mulches, grazing, flaming, prescribed burning, or competitive reseeding. |
| Subtopic: Herbicides | Study addressed invasive plant control efforts that use chemical agents. |
| Subtopic: Mechanical vegetation removal | Study addressed invasive plant control efforts that consist of mechanical removal using methods like hand pulling, removal with tools like loppers, girdling, shredding, hoeing, bulldozing or the use of other heavy equipment, tillage, cultivation, or mowing. |
| Management category—Relationships with other resources | |
| Wild horses and burros | Study addressed the relationship between wild horses or burros and species habitat, populations, or individuals. |
| Water | Study addressed the relationship between species habitat, populations, or individuals and water resources (for example, groundwater, surface water, hydrology, water quantity or quality, or water rights). |
| Soils or geology | Study addressed the relationship between species habitat, populations, or individuals and soils or geology, as well as biological soil crusts. |
| Cultural, historical, Native American, or archaeological sites or values | Study addressed cultural, historical, archaeological, or Native American resources. |
| Public health, safety, or enforcement | Study addressed public health or safety, or the enforcement of laws, statutes, or other regulations. |
| Paleontological resources | Study addressed fossils or fossilized remains. |
| Forest management/timber harvest | Study addressed the relationship between species habitat, populations, or individuals and forest or timber management. |

**Table 1.** Management categories and topics assessed for each product included in the bibliography.—Continued

| Management topic | Definition |
|---|---|
| Management category—Relationships with other resources—Continued | |
| Protected lands or areas | Study addressed lands with a formal protective designation such as national parks or monuments, Areas of Critical Environmental Concern, National Conservation Areas, National Scenic Byways, Wild and Scenic Rivers, wilderness areas, or areas with wilderness characteristics. |
| Wetlands/riparian | Study addressed the relationship between species habitat, populations, or individuals and wetland or riparian areas. |
| Sensitive/rare wildlife | Study addressed one or more sensitive, rare, or protected wildlife species, as well as insects. |
| Sensitive/rare fish | Study addressed one or more sensitive, rare, or protected fish species. |
| Sensitive/rare plants | Study addressed one or more sensitive, rare, or protected plant species. |
| Management Category—Other | |
| Includes new geospatial data | Study makes publicly available newly created geospatial data relevant to species policy, planning, or management. |
| Human dimensions or economics | Study addressed the human dimensions or economics of species policy, planning, or management. |

# Results and Conclusions

In our searches, we identified 138 potential products from Web of Science, 148 from Scopus, 6 from the U.S. Geological Survey Publications Warehouse, 45 from ScienceBase, 25 from the U.S. Department of Agriculture Forest Service TreeSearch, and 3,871 from Google Scholar (published products and unpublished products). For Google Scholar, using the automated filtering methods described in the "Methods" section, we removed unpublished products and manually filtered 2,149 products based on the same inclusion criteria. We included nine additional products that were brought to our attention opportunistically and fit our criteria for inclusion but were not detected during our standard search process. After manually removing duplicates, publications not written in English, publications that were not peer reviewed, publications focused outside of North America, and publications that did not present new data or focus on medusahead, we retained a total of 211 peer-reviewed published science and data products from all sources. Thirteen of these products had previously been summarized in Carter and others (2020) or Poor and others (2021).

These 211 products addressed 40 of the 52 management topics. Every product addressed nonnative invasive plants, and 136 products (64 percent) addressed weed management. An additional six topics were used in more than 30 percent of products: site-sale habitat characteristics (37 percent); habitat restoration or reclamation (36 percent); weed management subtopic: cultural control (35 percent); soils or geology (34 percent); population estimates or targets (34 percent); and dispersal, spread, vectors, and pathways (32 percent). Twenty-eight (13 percent) products included new geospatial data. Of the addressed management topics, 1 percent of products addressed agriculture, forest management/timber harvest, or fuel breaks. Only 0.5 percent of products addressed cultural, historical, Native American, or archaeological sites or values; predators or predator control; recreation; sagebrush removal; or wild horses and burros.

These studies are the recent (since 2010) body of published, peer-reviewed articles, reports and data products that are written in English and focus on *Taeniatherum caput-medusae* in North America. We present this annotated bibliography as a resource for managers to easily access and integrate this information into their decisions. Because medusahead and other invasive annual grasses are of growing management concern, this annotated bibliography may be updated periodically to incorporate new knowledge.

## Review Process

In addition to our internal author-team review, we organized external reviews. This process was twofold and included (1) requesting input on each summary from one or more authors of the original peer-reviewed publication, and (2) a formal review of the entire document by five independent reviewers and by the USGS Bureau Approving Official. This process is consistent with U.S. Geological Survey Fundamental Science Practices (Fundamental Science Practices Advisory Committee, 2011).

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# Annotated Bibliography of Scientific Research on *Taeniatherum caput-medusae* Published from January 2010 to January 2022

## Applestein, C.V., 2021, Presence and cover of exotic annual and perennial grass species during five years post-fire on the Soda Wildfire: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9TG16C5

**Background:** Data on the presence of invasive species is important to inform effective land management decisions, particularly after disturbance events.

**Objectives:** The author sought to collect data for the assessment of vegetative recovery and potential resistance to invasion after a wildfire in support of management decisions about grazing and postfire treatment.

**Methods:** The author collected data on cover and presence of three exotic annual grasses (cheatgrass, medusahead, and ventenata) and four perennial bunchgrasses (crested wheatgrass, bluebunch wheatgrass, Sandberg bluegrass, and bottlebrush squirreltail) in the area where the Soda Fire occurred. They measured grass cover the first 5 years after the fire and correlated these measurements with variables related to weather, landscape position, soil clay percentage, and treatment (drill, herbicide—imazapic) to provide information that could be used to test landscape resistance to invasion. Methods were derived from Applestein and Germino (2021; https://doi.org/10.1007/s10530-021-02669-3).

**Location:** Idaho, Oregon

**Findings:** The author created a dataset of presence for seven grass species, consisting of cover and presence of three exotic annual grass species. They also included landscape and weather variables in the dataset.

**Implications:** The author states that they collected these data as a part of a monitoring program to understand vegetative effects resulting from fire. They also caution that their data should be treated as a case study.

**Topics:** broad-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; soils or geology

## Applestein, C., and Germino, M.J., 2021, Patterns of post-fire invasion of semiarid shrub-steppe reveals a diversity of invasion niches within an exotic annual grass community: Biological Invasions, v. 24, p. 741–759.

**DOI:** https://doi.org/10.1007/s10530-021-02669-3

**Background:** Disturbances, such as wildfire, change resource availability and may create invasion opportunities for nonnative species. Managers are working to increase perennial grasses and reduce invasive annual grasses after fire, but how landscape variables and species interactions affect annual grass invasion is not known.

**Objectives:** The authors sought to understand niches of annual invasive grasses (medusahead, cheatgrass, and ventenata) after wildfire in a cheatgrass-dominated area by assessing invasive grass: (1) relations with perennial grasses, (2) spatial changes in invasion hotspots, and (3) associations between landscape variables and occurrence and abundance.

**Methods:** The authors established plots within the 2015 Soda Fire burned area where they applied one or both of the following treatments to suppress invasive annual grasses: herbicide application (imazapic) in the winters of 2015 to 2016 and 2016 to 2017, drill seeding of perennial grasses in the falls of 2015 to 2017. They also left some plots untreated. They monitored plots for plant species presence, took aerial photos yearly during the growing season from 2016 to 2020, and calculated total perennial bunchgrass cover from photos for a total of 1,347 data points. Then, they performed statistical and spatial analyses to test annual invasive grass species relations, spatial distributions, and associations with landscape variables.

**Location:** Idaho, Oregon

**Findings:** The authors identified that cheatgrass and ventenata were both positively associated with medusahead whereas cheatgrass and ventenata were negatively associated. No bunchgrass species was negatively associated with all annual invasive grasses, and cheatgrass was positively associated with Sandberg bluegrass. Cheatgrass hotspots were concentrated in lower elevations near the fire boundary, medusahead hotspots were in geographically similar areas, and ventenata hotspots were unique to the species; all hotspots fluctuated between years. Ventenata and medusahead occurrence increased with drill seeding. Numerous landscape variables were associated with medusahead and ventenata occurrence and abundance; strong relations were medusahead in low elevations and low winter and spring precipitation, and ventenata in higher elevations and higher winter and spring precipitation.

**Implications:** The authors suggest that the annual invasive grasses in this study inhabit different niches, but cheatgrass and medusahead may occupy similar niches and cheatgrass may facilitate medusahead invasion. They state that postfire treatments should consider the dominant invader when choosing treatments and seed mixes because different treatments may be more effective for certain invasive species.

**Topics:** broad-scale habitat characteristics; site-scale habitat characteristics; habitat selection; fire; nonnative invasive plants; weather and climate patterns; weed management; soils or geology

## Applestein, C., Germino, M.J., and Fisk, M.R., 2018, Vegetative community response to landscape-scale post-fire herbicide (imazapic) application: Invasive Plant Science and Management, v. 11, no. 3, p. 127–135.

**DOI:** https://doi.org/10.1017/inp.2018.18

**Background:** Exotic annual grasses, like medusahead and cheatgrass, have altered Great Basin ecosystems. Herbicides are important for controlling invasive grasses when applied before emergence. However, little is known about the effectiveness of herbicides after the exotic annual grass growing season.

**Objectives:** The authors assessed the effects of spraying herbicide during the first winter or second fall postfire on (1) dominant plant type and community assemblage, (2) frequency of perennial shrubs and forbs, and sought to (3) determine factors that affect herbicide effectiveness.

**Methods:** In January 2016, the Bureau of Land Management (BLM) seeded perennial grass, forb, and sagebrush in a previously burned area. They sprayed herbicide (imazapic) on these sites at two times to create herbicide treatments postfire: the first winter (February to March) and the second fall (October) following the August 2015 Soda fire. The authors established sampling blocks of similar sites that had and had not received herbicide for treatment and control sites, respectively, for both herbicide treatments. They measured cover and performed frequency-density monitoring for each species and functional group in the 2016 and 2017 growing seasons. They also included several landscape-level variables in the analysis. They used statistical analyses to investigate the effects of timing of herbicide application on species and functional group cover and shrub and forb abundance.

**Location:** Idaho, Oregon

**Findings:** The authors identified no difference in community structure or species diversity among site types. However, exotic grass cover was higher in control plots compared to both treated plot types. Perennial bunchgrass cover was not affected by either herbicide treatment, though Sandberg bluegrass declined after first winter spraying. Alfalfa and small burnet also declined with first winter spraying. However, alfalfa and sagebrush abundance increased when spraying occurred in the second fall. Landscape-level variables did not account for much of the observed variation.

**Implications:** The authors state their results suggest waiting to apply herbicides 9 to 10 months after seeding could provide better results than applying herbicide soon after planting. They note, however, that if necessary, applying herbicide soon after planting can still be effective, and loss of nontarget species could be mitigated by increasing the density of seeds applied.

**Topics:** population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Arterburn, M., Kleinhofs, A., Murray, T., and Jones, S., 2011, Polymorphic nuclear gene sequences indicate a novel genome donor in the polyploid genus *Thinopyrum*: Hereditas, v. 148, no. 1, p. 8–27.

**DOI:** https://doi.org/10.1111/j.1601-5223.2010.02084.x

**Background:** The *Thinopyrum* genus of wheatgrass is used as a source of competitive traits by plant breeders. This genus contains species with complex evolutionary histories that are widely capable of hybridization, which makes classification difficult. New genetic techniques could improve understanding of this genus' evolution, including its relationship to other genera within the tribe Triticea, such as *Taeniatherum* (medusahead), and could aid crop improvement.

**Objectives:** The authors sought to provide molecular sequence data to previously implemented studies to better understand the evolutionary history of the *Thinopyrum* genus.

**Methods:** The authors obtained seeds from 12 wild grass species of the tribe Triticeae, including medusahead. Using up-to-date genetic techniques, they extracted genetic material and amplified deoxyribonucleic acid (DNA) sequences of each species. They estimated the evolutionary relatedness among species and constructed phylogenetic trees.

**Location:** Not specified

**Findings:** The authors identified that bluebunch wheatgrass was most distantly related to other potential *Thinopyrum* ancestors. They also identified that medusahead was closely related to two of the species tested: tall wheatgrass and intermediate wheatgrass. The authors stated that the Bmy1 gene showed more divergence than the intergene region, which was highly consistent across all species tested.

**Implications:** The authors suggest that of the species tested, *Thinopyrum elongatum* is most closely related to a common ancestor. They suggest that the close relationship to medusahead could substantially change the understanding of the evolutionary history of species in the *Thinopyrum* genus, specifically that medusahead was likely involved in a hybridization that led to *Thinopyrum* species with multiple chromosome copies and that this complexity in the genus had made previous phylogenetic analyses challenging. The authors conclude by stating that their results indicate previously unknown species likely contributed to the evolution of the *Thinopyrum* genus, including medusahead, and that understanding this evolutionary history can help inform our understanding of the invasiveness of medusahead.

**Topics:** genetics; nonnative invasive plants

## Averett, J.P., McCune, B., Parks, C.G., Naylor, B.J., DelCurto, T., and Mata-González, R., 2016, Non-native plant invasion along elevation and canopy closure gradients in a middle Rocky Mountain ecosystem: PLOS ONE, v. 11, no. 1, article e0147826, 24 p.

**DOI:** https://doi.org/10.1371/journal.pone.0147826

The summary for this article was previously published in Poor and others (2021, p. 9; https://doi.org/10.3133/ofr20211031).

## Bansal, S., James, J.J., and Sheley, R.L., 2014, The effects of precipitation and soil type on three invasive annual grasses in the western United States: Journal of Arid Environments, v. 104, p. 38–42.

**DOI:** https://doi.org/10.1016/j.jaridenv.2014.01.010

The summary for this article was previously published in Poor and others (2021, p. 11–12; https://doi.org/10.3133/ofr20211031).

## Bansal, S., and Sheley, R.L., 2016, Annual grass invasion in sagebrush steppe—The relative importance of climate, soil properties and biotic interactions: Oecologia, v. 181, p. 543–557.

**DOI:** https://doi.org/10.1007/s00442-016-3583-8

**Background:** Annual grass invasion is a major threat to ecosystems throughout the west. The potential spread of invasive species could be constrained by several factors such as climate, soil characteristics, and biotic interactions. Understanding which variables most heavily affect the distribution of invasive and native plants is critical for predicting and managing invasions.

**Objectives:** The authors sought to investigate which environmental factors affected the abundance of different plant functional groups across ecological gradients.

**Methods:** From September 2011 to September 2012, the authors measured a suite of variables at 90 plots within their survey area related to factors linked to plant communities, ground cover characteristics, plant physiology and reproduction, soil variables, climate, microbial factors, and grazing pressure. They then used several different models to assess the influence of biotic and abiotic variables on the amount of annual grass cover.

**Location:** Oregon

**Findings:** Invasive annual grass abundance was most strongly negatively affected by climatic and biotic factors, consisting of species richness, species density (species per square meter), shrub density (shrub individuals per square meter), biological soil crust cover, and perennial grass cover. Annual grass cover increased with warmer winter temperatures and was strongly positively related to the litter layer. Microbial biomass had no effect on annual grass cover whereas soil nutrients only weakly affected them. Soil characteristics more directly affected native plants. Perennial grass cover was positively related to elevation and precipitation.

**Implications:** The authors state their findings indicate that biotic and climatic interactions are highly important in influencing annual grass cover. They suggest that warmer winters will likely alter the interactions between native and invasive species and that increasing perennial grass cover, while simultaneously providing soil amendments, may be the most effective method of managing invasive annual grasses. They conclude by emphasizing the importance of including biotic interactions in climate-based distribution models and that, to be most effective, predicting and managing annual grass invasion requires a multifaceted approach that considers the many interconnected factors that control ecosystem structure: biotic and abiotic conditions, biodiversity patterns, and species interactions.

**Topics:** behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat selection; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weather and climate patterns; weed management; weed management subtopic: cultural control; soils or geology

## Bartolome, J., Brown, A., Hopkinson, P., Hammond, M., Macaulay, L., and Ratcliff, F., 2019, Evaluating prescribed fire effect on medusa head and other invasive plants in coastal prairie at Point Pinole: Grasslands, v. 29, no. 1, p. 9–12.

**URL:** https://www.cnga.org/resources/Documents/Grasslands%20Journal/Grasslands%20Articles/Research%20articles/Bartolome%20et%20al%20Fire%20Effect%20on%20Medusa%20Head_Winter%202019.pdf

**Background:** Medusahead is a high-priority weed that has spread rapidly across the State of California, affecting plant and wildlife communities. Invasive grasses can be controlled in several ways, but burning in late spring has been effective in reducing seeds and thatch. Although burning can be used as an effective method to control invasive grasses, the effects of fire in California's coastal prairie plant community are less known.

**Objectives:** The researchers sought to understand the effects of prescribed burning on vegetation frequency for (1) target invasive and other invasive grasses, (2) native perennial grasses, and (3) native forbs.

**Methods:** In 2016 and 2017, researchers implemented prescribed burns in two different areas of a coastal prairie protected park. They established 11 transects between both areas and measured vegetation frequency of each species preburn and postburn. They collected medusahead seeds from burned and unburned plants for germination trials. They performed statistical analyses to compare preburn and postburn vegetation to detect changes in species composition through time.

**Location:** California

**Findings:** In the first area, velvet grass frequency did not change postburn; however, this species did appear on new transects after the burn. Nonnative purple false brome decreased postburn and in unburned transects. California oatgrass frequency slightly decreased postburn, and western blue-eyed grass frequency decreased significantly after the burn. In the second area, medusahead decreased toward almost no occurrence after the burn, and saltgrass frequency increased after the burn in both years. None of the burned medusahead seeds germinated after prescribed burning.

**Implications:** The authors suggest that prescribed burning effectively reduces medusahead plants and seeds in the soil seed bank. They note minimal effects to most native species and suggest that burning may either control or promote other weedy species. They recommend closely monitoring effects to other species when managers use fire to control invasive species.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; protected lands or areas

## Bateman, T.M., Villalba, J.J., Ramsey, R.D., and Sant, E.D., 2020, A multi-scale approach to predict the fractional cover of medusahead (*Taeniatherum caput-medusae*): Rangeland Ecology and Management, v. 73, no. 4, p. 538–546.

**DOI:** https://doi.org/10.1016/j.rama.2020.04.006

**Background:** Controlling and preventing the spread of medusahead is challenging due to its ability to outcompete and suppress native species and cheatgrass. Efforts to use remote sensing to map invasive grasses have been useful for helping managers prioritize and target management actions, but the capacity for large-scale mapping efforts that can distinguish high-priority single species such as medusahead is needed.

**Objectives:** The objectives of this study were to use remote sensing technologies to (1) map the distribution of the fractional cover of medusahead, meaning cover as a proportion of a pixel in an image, and (2) model the predicted distribution of medusahead cover at a landscape scale.

**Methods:** The authors selected three study areas excluding landforms, agricultural areas, and urban areas from their assessment. They performed field sampling during fall 2015 to measure presence or absence of medusahead monoculture. They used the field sampling data to train visual learning software to classify areas of medusahead monoculture in 1-meter (m)-resolution aerial photography using life history differences among species. Specifically, the fall data collection that the authors used allowed them to compare spectral signatures of senesced medusahead monocultures to other vegetation types experiencing fall senescence. The authors then converted this 1-m presence or absence data into fractional cover at a 30-m resolution for one of the study areas that the authors used for model training. They used this fractional cover estimate to create a model to predict the proportion of medusahead in 30-m-resolution satellite imagery across all three study areas.

**Location:** Washington

**Findings:** The authors determined that the high-resolution learning classification software was generally accurate at identifying medusahead but was less accurate in areas where medusahead was shorter or less dense. Both the visual classification and the predictive model effectively identified areas of medusahead monoculture at the model training area, but with less accuracy than the remaining two study areas. Beyond monocultures, the fractional cover map the authors created from the predictive model matched field observations from across the study areas.

**Implications:** The authors state that their multi-scale method for mapping fractional cover of medusahead is overall accurate but they recommend that incorporating more diverse land cover types into training data could improve model accuracy. The authors suggest that their mapping techniques can be used by managers to create targeted plans for preventing or controlling medusahead invasion.

**Topics:** population estimates or targets; nonnative invasive plants; weed management

## Bean, T.M., Davy, J.S., Kyser, G.B., and Gornish, E.S., 2021, Integration of grazing and herbicide application improves management of barb goatgrass and medusahead in pasture and rangelands: California Agriculture, v. 75, no 2, p. 83–89.

**DOI:** https://doi.org/10.3733/ca.2021a0011

**Background:** Invasive annual grasses, like medusahead and barb goatgrass, cause many ecological and economic problems. Existing studies on invasive annual grass management have primarily focused on the effectiveness of single treatment methods. More information on combined herbicide and grazing treatments of invasive grasses, particularly focused on treatment timing, are needed to improve management practices.

**Objectives:** The authors sought to compare the effects of (1) different herbicide (glyphosate) application timings, (2) herbicide concentrations, and (3) grazing treatments on barb goatgrass and medusahead spikelet density and seed production.

**Methods:** In fall 2015, the authors established five pastures, each with three replicated treatment plots split into grazed and ungrazed areas in invaded areas. They applied herbicides at three application timings: the tillering stage in March 2016 and the boot and heading stages in May 2016. They also applied herbicides (glyphosate) at low and high rates for all three stages. The authors grazed sheep in the pastures prior to the boot-stage herbicide treatments. In June 2016, the authors measured the spikelet density and seed production of barb goatgrass and medusahead. They used statistical tests to compare the effectiveness of herbicide application rates and timing.

**Location:** California

**Findings:** The authors determined that both herbicide and grazing treatments alone reduced barb goatgrass spikelet density and that there were no differences between the high and low herbicide application rates. They identified that herbicide application at the tillering stage nearly eliminated the spikelets. Medusahead spikelet density was lower in all plots, but they identified that herbicide application at the tillering stage was most effective. Overall, barb goatgrass seed production was higher in untreated plots and was nearly eliminated when treated with herbicide at the tillering stage. They determined that the combined effects of herbicide and grazing treatments decreased seed numbers of both species relative to the controls in the tillering stage.

**Implications:** The authors suggest that applying herbicides at early vegetative stages reduces medusahead and barb goatgrass spikelet densities. They suggest that lower herbicide application rates are as effective as high rates. The authors recommend that managers consider combined treatments, such as grazing and herbicide application, to control invasive annual grasses long term.

**Topics:** survival; behavior or demographics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Beckstead, J., Meyer, S.E., Ishizuka, T.S., McEvoy, K.M., and Coleman, C.E., 2016, Lack of host specialization on winter annual grasses in the fungal seed bank pathogen *Pyrenophora semeniperda*: PLOS ONE, v. 11, no. 3, 20 p.

**DOI:** https://www.doi.org/10.1371/journal.pone.0151058

**Background:** Fungal pathogens present in seed banks of invasive annual grasses can cause mortality in plant populations. Cheatgrass seeds are susceptible to infection, but tolerance varies depending on the seed stage. Infection dynamics in other closely related invasive annual grasses remain unclear.

**Objectives:** The authors sought to determine if populations of a fungal pathogen have (1) genetic differences, (2) host specificity, and (3) differences in infection levels depending on seed dormancy stages for invasive winter annual grasses.

**Methods:** In summer 2012, the researchers collected seeds and soil seed bank samples for five annual grass species (medusahead and species of brome). For each grass species, they selected 30 infected seeds. They extracted each strain of pathogen for genetic comparison across host species and regions, including against strains extracted from previously collected cheatgrass. In a series of experiments to test for host specificity, they transferred pathogens collected from the soil seed bank samples of cheatgrass and one of the other host species onto dormant seeds of those same two species. The researchers monitored seeds for mortality and germination for one month and tested ungerminated seeds for viability. To test resistance and tolerance, they looked at four species with two dormancy treatments, three pathogen densities, and two pathogen strains. They quantified levels of mortality, germination, and viability.

**Location:** Arizona, Idaho, Utah, Washington

**Findings:** Genetic characteristics of pathogen populations of a single host species were more similar across regions than pathogen populations of different host species closer in distance. Pathogen populations did not show host specificity. Pathogen strains within populations caused varying levels of mortality; however, strains that caused high mortality were consistent across hosts. Seed infection levels were greatest at the highest pathogen density for dormant and nondormant seeds, but high seed mortality occurred only on dormant seeds.

**Implications:** The authors suggest that seed pathogens do not show host specificity on any of the annual grasses included in this study and that infection tolerance increases with seed germination rate. The authors concluded that this pathogen has adapted to infect this group of winter annual grasses that have similar seed biology.

**Topics:** survival; genetics; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: biocontrol; soils or geology

## Beckstead, J., Meyer, S.E., Reinhart, K.O., Bergen, K.M., Holden, S.R., and Boekweg, H.F., 2014, Factors affecting host range in a generalist seed pathogen of semi-arid shrublands: Plant Ecology, v. 215, p. 427–440.

**DOI:** https://www.doi.org/10.1007/s11258-014-0313-3

**Background:** Seed pathogens, such as fungi, have been introduced to areas outside their native range alongside their original hosts. This pattern has occurred with a specific fungal pathogen and cheatgrass. Where cheatgrass occurs in seed banks, this pathogen can persist and infect a range of native and nonnative grass species. Intolerance to infection can lead to seed mortality, and resistance to infection can affect germination.

**Objectives:** The authors sought to determine the effects of pathogen strains on host traits, infection susceptibility, and mortality for (1) native grass species and (2) exotic grass species.

**Methods:** The researchers applied two strains of the same fungal pathogen to the seeds of 26 grass species consisting of nonnative annual grasses (for example, medusahead), introduced forage grasses, native perennial grasses, and both dormant and nondormant cheatgrass seeds. For each species, they applied pathogen strains to 2 replicates of 50 seeds and compared the 4 total treated replicates with 2 replicates of nontreated seeds. They assessed seed infection and mortality weekly. After 42 days, they evaluated ungerminated seeds and scored them as viable, dormant, nonviable, or killed. The researchers also applied several concentrations of the pathogen to cheatgrass seeds and four native grass hosts. They performed statistical analyses to understand the relationship between pathogen concentrations, infection potential, and mortality.

**Location:** Utah, Washington

**Findings:** Across all species, seeds were susceptible to pathogen infection. Most native species had high infection levels, but only three species had high levels of seed mortality. All nonnative annual grass and forage species had moderate to high infection levels. Cheatgrass and ventenata had the highest levels of annual grass mortality, and crested wheatgrass had the highest level of forage grass mortality. Species related more closely to cheatgrass showed lower resistance and higher infection levels; however, seed mortality was related to longer germination times. Medusahead seeds were infected when the pathogen was introduced, but they did not experience higher seed mortality than the controls. Cheatgrass seed mortality was high across most pathogen concentrations, and native seed mortality increased at a moderate concentration rate. Native grass seed banks had low levels of pathogens, most likely due to the low seed density.

**Implications:** The authors suggest that the generalist pathogen did not negatively affect most native grass species but caused increases in infection and seed mortality in cheatgrass and similar species.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: biocontrol

## Bennett, A.E., and Strauss, S.Y., 2012, Response to soil biota by native, introduced non-pest, and pest grass species—Is responsiveness a mechanism for invasion?: Biological Invasions, v. 15, no. 6, p. 1343–1353.

**DOI:** https://www.doi.org/10.1007/s10530-012-0371-1

**Background:** Soil communities play a role in predicting plant performance and may indicate invasive potential. However, it is unclear if native and invasive species respond differently to soil microorganisms.

**Objectives:** The authors sought to determine how sterilized soils and soil containing microorganisms from two different areas affect the responses of (1) introduced pest, (2) introduced nonpest, and (3) native grasses.

**Methods:** The researchers grew 15 species of grass (for example, medusahead) in 4 soil treatments, with 8 replicates for each species by soil paring for 32 plants total from each species. The treatments included sandy loam soil inoculated with sterile soil or soil with intact or live microorganisms from two different locations. Plant species included 4 introduced pest, 6 introduced nonpest, and 5 native species. Researchers harvested plants after 14 weeks to determine growth; aboveground, belowground, and reproductive biomass; and fungal colonization. They performed statistical analyses to compare how species responded to each soil type.

**Location:** California

**Findings:** Introduced species had greater biomass than native plants throughout the experiment. Plants performed better overall in the soil containing microorganisms from the first location, regardless of species status. Plants performed better in the sterilized soil from the second location. Native plants had greater differences in growth between locations than both groups of introduced species. Fungi colonized at greater rates in the roots of native plant species with soil from the first location.

**Implications:** The authors suggest that invasive species may not be affected by variation in soil microorganisms across locations, allowing for increased establishment. They also suggest that the differences in native plant growth may be due to the presence of soil organisms and vary depending on the area.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Berleman, S.A., Suding, K.N., Fry, D.L., Bartolome, J.W., and Stephens, S.L., 2016, Prescribed fire effects on population dynamics of an annual grassland: Rangeland Ecology and Management, v. 69, no. 6, p. 423–429.

**DOI:** https://www.doi.org/10.1016/j.rama.2016.07.006

**Background:** Medusahead invasions have increased in North American rangelands, reducing grazing capacity, species diversity, and ecosystem services. Prescribed fires have been shown to reduce medusahead populations in some circumstances, but it is unknown how burn size and edges affect postfire medusahead and other grassland species' population dynamics.

**Objectives:** The authors sought to determine the effects of prescribed burns and burn edges on (1) seed dispersal, (2) density, and (3) vegetative reproduction of medusahead and other dominant species.

**Methods:** In May 2013, the authors established 60 units, each with a 1-m buffer edge, categorized by three dominant focal species: oat (a grouped combination of wild oat and slender oat), purple needlegrass, or medusahead. They assigned treatments across units, consisting of burned, seed-limited (cutting current year's vegetation growth), combined burn and seed-limited, or non-seed-limited (no cutting) and unburned (untreated) treatments. The authors installed posttreatment seed rain traps to collect dispersing seeds and unburned surface seeds, which they identified, counted, and tested for germinability. They measured stem

count densities, reproductive characteristics, and percent cover of all species pretreatment and posttreatment (1 year) and used statistical analysis to compare treatment effects for each focal species. They also analyzed transitions between vegetation types pretreatment to posttreatment.

**Location:** California

**Findings:** Burning reduced medusahead surface seed germination but not wild oat. Medusahead seed rain counts were highest in burn-only plots and lowest in seed-limited plots. Medusahead density was greatly reduced in burn-only and combined burn and seed-limited treatments in all plots. Burning did not affect medusahead fecundity but positively affected wild oat and negatively affected needlegrass flowering stalks. Vegetation transition toward medusahead was most prevalent on seed-limited and unburned plots or in untreated units.

**Implications:** The authors suggest that limiting seed dispersal from edges may increase the effectiveness of burn treatments to reduce medusahead populations. They also suggest having a treatment scale large enough to reduce seed encroachment from edges. If a wild oat seed bank is present within a prescribed burn, the authors propose that this can subsequently promote more preferrable species.

**Topics:** survival; behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: mechanical vegetation removal

## Bernhardt, N., Brassac, J., Dong, X., Willing, E.-M., Poskar, C.H., Kilian, B., and Blattner, F.R., 2020, Genome-wide sequence information reveals recurrent hybridization among diploid wheat wild relatives: The Plant Journal, v. 102, no. 3, p. 493–506.

**DOI:** https://www.doi.org/10.1111/tpj.14641

**Background:** Wheat wild relatives are important resources for genetic improvements of cultivated wheat, but varied techniques and datasets have resulted in conflicting hypotheses on the relations among these species. The authors suggest that advances in genomic techniques facilitate experiments that shed light on the role of hybridization in the evolution of these species, which can improve taxonomic hypotheses.

**Objectives:** The authors sought to produce an updated hypothesis on the evolutionary relations among wild wheat species.

**Methods:** The authors grew plants from seeds and identified species using morphological traits. The authors collected the genetic material of 97 individuals from all diploid species of wheat wild relatives from the goatgrass, *Amblyopyrum*, and the wheat genus *Triticum*, and from three outgroup taxa, one of which was medusahead. They always included more than one individual from each taxon. They used genetic analysis techniques to determine species relations.

**Location:** Not specified

**Findings:** The evolutionary history of wild wheat relatives was more complex than previously believed. Most of the wild wheat relatives appeared to be shaped by an ancient homoploid hybrid speciation event, except for one species of goatgrass. No hybridization signal between medusahead and any species of diploid wheat wild relatives was noted.

**Implications:** The authors suggest that having a clearer picture of the taxonomical relations among these species facilitates the search for alleles that could be useful for plant breeding.

**Topics:** genetics; species and population characteristics; nonnative invasive plants

## Blank, R.R., 2010, Intraspecific and interspecific pair-wise seedling competition between exotic annual grasses and native perennials—Plant-soil relationships: Plant and Soil, v. 326, p. 331–343.

**DOI:** https://www.doi.org/10.1007/s11104-009-0012-3

**Background:** Previous studies have shown that when medusahead and cheatgrass invade new areas, there is often a lag time between the initial invasion and overrunning the space. These studies have indicated that during this lag time, invasive species alter soil characteristics, which may increase competitive abilities. However, it is unclear how plant-soil relations drive within- or between-species competition

**Objectives:** The author examined if cheatgrass or medusahead's ability to alter soil nutrients depends on (1) nearby plants and (2) within- or between-species competition.

**Methods:** The author collected two soil types (dry and moist) from two different sites. They planted cheatgrass, medusahead, squirreltail, and bluebunch wheatgrass into each soil type in all possible paired combinations. They compared treatments to unplanted soil controls. They replicated treatments and controls six times totaling 132 containers. The author watered all replicates twice weekly and harvested aboveground plant tissue and soil after 85 days. They measured aboveground biomass, determined total nitrogen in plant tissue, and compared plant and soil available nutrients.

**Location:** California, Nevada

**Findings:** Cheatgrass biomass was lowest when planted with other cheatgrass plants and highest when planted with squirreltail and bluebunch wheatgrass in both soil types. Medusahead biomass was similar across species pairings in dry soil but was greater when planted with bluebunch wheatgrass in moist soil. Native grass biomass was not significantly affected by plant pairing. Total aboveground biomass was greater in containers with one or two exotic grasses compared to those with only native grasses across both soil types. Both native and exotic species tended to have greater tissue nutrient concentrations in moist soils, but exotic species had higher nutrient concentrations overall. In moist soil, a few soil nutrients (nitrogen, potassium, and magnesium) were higher under native grasses compared to exotic grasses.

**Implications:** The author suggests that exotic annual grasses have a higher competitive advantage when growing near native grasses, compared to other plants of the same species, and that this advantage is more pronounced in moist soils. The author poses that exotic grasses may divert nutrients away from native species in shared rooting zones, giving exotics a competitive advantage.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; soils or geology; water

## Bohnert, D.W., and Stephenson, M.B., 2016, Supplementation and sustainable grazing systems: Journal of Animal Science, v. 94, no. 6, p. 15–25.

**DOI:** https://www.doi.org/10.2527/jas.2016-0520

**Background:** Supplemental feeding of range animals has typically been used to counteract nutrient deficiencies in natural forage. More recently, however, supplementation has also been used to prevent localized overgrazing and control invasive species to improve rangeland health.

**Objectives:** The authors sought to review the relevant science of using targeted supplementation to alter grazing behavior to improve rangeland and ecosystem health and improve grazing sustainability.

**Methods:** The authors reviewed relevant literature on using supplemental feeding to influence livestock grazing behavior and summarized key findings and results from past studies.

**Location:** Not specified

**Findings:** The authors identified several factors influencing grazing behavior and livestock distribution. Factors include the following: variability in forage quality and quantity across the landscape, seasonal variation in plant species' nutrition, location of water and riparian areas, refuges from thermal extremes, variability in the terrain, fire history, and presence of animal trails. They determined that targeted grazing by season can be used to control invasive species, such as medusahead and cheatgrass, and help reduce fire intensity and frequency. They also determined that a few types of supplementation, such as salt and protein, can strongly influence grazing patterns. They identified some evidence that providing supplementation in invaded areas could increase the amount of medusahead consumed by livestock. They also suggested that maximizing grazing of invasive species as a supplement itself or in complement to other forages may offset the pressure on preferred grasses and aid in invasive species control.

**Implications:** The authors state that developing land management practices centered on ecological principles is critical for livestock ranchers to continue operating successfully. They suggest that supplementation and targeted grazing by season offers two methods of addressing concerns about both livestock foraging and ecosystem health.

**Topics:** fire; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Bollman, M.A., Storm, M.J., King, G.A., and Watrud, L.S., 2012, Wetland and riparian plant communities at risk of invasion by transgenic herbicide-resistant *Agrostis spp.* in central Oregon: Plant Ecology, v. 213, no. 3, p. 355–370.

**DOI:** https://www.doi.org/10.1007/s11258-011-0015-z

**Background:** Naturalized creeping bentgrass and redtop pose threats to wetland plant communities in the northwestern United States where herbicide-resistant cultivars have spread. These herbicide-resistant populations give rise to additional challenges for invasive species management in wetland environments, where there are few effective, low-toxicity herbicide options.

**Objectives:** The authors aimed to (1) characterize plant communities with naturalized creeping bentgrass and redtop populations and (2) identify which plant communities were most likely to be affected by herbicide-resistant plants.

**Methods:** The researchers collected seeds from naturalized populations of creeping bentgrass and redtop in 2003. They grew 300 plants from seed to monitor gene flow between genetically modified plants and local creeping bentgrass and redtop populations. From 2003 to 2005, they identified more than 200 creeping bentgrass and redtop populations and categorized them into four distinct habitat categories. From 2004 to 2005, they surveyed habitats for the presence of plants with herbicide-resistant characteristics. From 2005 to 2006, they collected data at 62 plots, including plots with and without herbicide-resistant plants. The researchers estimated cover of all species present, noted environmental characteristics and disturbance factors, and collected soil samples. They performed statistical analyses to characterize wetland species and typify plant communities based on identified indicator species.

**Location:** Oregon

**Findings:** The authors detected differences in plant communities across the four habitat types and across plot types, but they did not detect differences between genetically modified and non-genetically modified plots. They determined that soil moisture primarily affected species composition and that disturbance and moisture gradients equally affected plant cover. They identified that cheatgrass was the most abundant species and preferred drier upland areas. The creeping bentgrass-medusahead plant

community mostly occurred in drier, less disturbed sites. Plots with naturalized creeping bentgrass or redtop were generally wetter, and plots containing genetically modified species were also more disturbed. The authors concluded that creeping bentgrass and redtop were invasive in wetland and riparian habitats in the study area.

**Implications:** The authors determined that genetically modified creeping bentgrass is likely to proliferate in wetland contexts. They suggest that herbicide-resistant plants pose threats to wetland environments where herbicide treatment is restricted by limited low-toxicity herbicides. They caution against the genetic modification of species with naturalized or invasive populations, and species that are genetically compatible with naturalized or invasive species.

**Topics:** genetics; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: herbicides; soils or geology; wetlands/riparian

## Borer, E.T., Seabloom, E.W., Mitchell, C.E., and Power, A.G., 2010, Local context drives infection of grasses by vector-borne generalist viruses: Ecology Letters, v. 13, no. 7, p. 810–818.

**DOI:** https://doi.org/10.1111/j.1461-0248.2010.01475.x

**Background:** Risk of infection from plant pathogens can vary with host traits and regional and local factors. Understanding the relative importance of these factors in plant communities is important for species conservation and disease management.

**Objectives:** The authors sought to understand how (1) host species' traits, (2) regional factors, and (3) site-specific factors affect risk of infection in grasses by the barley and cereal yellow dwarf virus pathogen group.

**Methods:** The research team established two blocks at five sites across two States, which differed in annual and perennial grass abundance and fertilization treatment. Each block had four plots with a combination of nitrogen or phosphorous additions for a total of 40 experimental units. They applied fertilization treatments four times per year starting in December 2005 and planted host grasses in winter 2008. They planted three annual and three perennial grass species in each plot and evaluated survival and aboveground tissue 5 months after exposure. They sampled for the virus and its aphid vector, which occurred naturally at each site. The researchers analyzed host individuals for infection and measured plant biomass, species cover, and soil characteristics.

**Location:** California, Oregon

**Findings:** Infection rates did not differ by host traits or among plant groups but did vary by host species and among blocks. Medusahead individuals experienced high rates of infection (22 percent). Plant survival was high and did not differ across host species. Plant biomass, species richness, and soil characteristics were not associated with infection rate. Variation in infection rate occurred at local scales and was not driven by regional climate factors, such as precipitation amounts or timing. Infection risks increased in plots with greater perennial grass abundance and experimental phosphorous additions but were not associated with nitrogen additions.

**Implications:** The authors suggest that infection risk increased with the local presence of perennial grasses and additional phosphorous. They emphasize that local-scale characteristics may predict infection risk more than host traits or regional factors in these disease systems.

**Topics:** survival; other: species and population characteristics; broad-scale habitat characteristics; site-scale habitat characteristics; nonnative invasive plants; weather and climate patterns; soils or geology

## Boyd, C.S., and Davies, K.W., 2012, Spatial variability in cost and success of revegetation in a Wyoming big sagebrush community: Environmental Management, v. 50, no. 3, p. 441–450.

**DOI:** https://doi.org/10.1007/s00267-012-9894-6

**Background:** Invasive annual grasses can increase fire frequency, resulting in loss of native species and further invasions. Because funds for restoration are meager, knowing where efforts are most likely to succeed is imperative for managers to effectively manage invasive annual grasses.

**Objectives:** The authors sought to (1) assess the importance of soil characteristics and vegetative competition on revegetation success postfire and (2) investigate spatial variability in restoration costs.

**Methods:** In October 2007, the authors established 51 plots along a transect in a previously burned and seeded area. In July of 2008 and 2009, they measured the density of seeded nonnative and native species. They also estimated the density of nonseeded herbaceous plants in 2008. They then collected a suite of soil characteristics at each plot and recorded if the plot was successfully restored. Finally, they used statistical analyses to examine the relationship between restoration success and both soil and vegetation characteristics and calculate the cost of restoration per hectare (ha) for each plot.

**Location:** Oregon

**Findings:** The authors determined that 21 of 51 plots were restored. They observed that forbs were the most abundant nonseeded plants and shrubs the least abundant. They also identified five soil characteristics that affected restoration success, consisting of potassium supply rate, surface nitrogen percentage, and surface clay percentage. The only vegetation variable that had an effect on restoration success was cover of large, nonseeded perennial grasses, which reduced restoration success. The soil characteristics model was more accurate at predicting restoration success than the vegetation model. At a 500-m scale, the cost of restoration varied between $247.81 to $695.44 per ha.

**Implications:** The authors determined that environmental variables can be predictors of restoration success and that soil characteristics were more informative than vegetation. They suggest their results show that small improvements in restoration methods can reduce costs of restoration. Finally, they state that their study provides a methodology for estimating the likelihood of successful restoration based on ecological factors.

**Topics:** population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; soils or geology

## Boyte, S.P., and Wylie, B.K., 2018, Early estimates of herbaceous annual cover in the sagebrush ecosystem (May 1, 2018): U.S. Geological Survey data release.

**DOI**: https://doi.org/10.5066/P9KSR9Z4

The summary for this article was previously published in Poor and others (2021, p. 13; https://doi.org/10.3133/ofr20211031).

## Boyte, S.P., and Wylie, B.K., 2018, Near-real-time herbaceous annual cover in the sagebrush ecosystem, USA, July 2018: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9RIV03D

The summary for this article was previously published in Poor and others (2021, p. 14; https://doi.org/10.3133/ofr20211031).

## Boyte, S.P., and Wylie, B.K., 2019, Near-real-time herbaceous annual cover in the sagebrush ecosystem, USA, July 2019: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P96PVZIF

The summary for this article was previously published in Poor and others (2021, p. 14; https://doi.org/10.3133/ofr20211031).

## Bradley, B.A., 2013, Distribution models of invasive plants over-estimate potential impact: Biological Invasions, v. 15, no. 7, p. 1417–1429.

**DOI:** https://doi.org/10.1007/s10530-012-0380-0

**Background:** Habitat suitability models are commonly used by managers to prioritize areas of focus for preventing the spread of invasive plants. Most of these models use occurrence data, but it is unknown if these projections can accurately predict overall effect of invasive species. Using abundance data instead of occurrence data in models could more accurately reflect potential effect and therefore be more useful for managers.

**Objectives:** The author sought to (1) compare abundance and occurrence data with herbarium and regional occurrence records for nine invasive species, (2) examine the degree to which occurrence data accurately reflect areas of high abundance, and (3) examine how accurately habitat suitability models estimate risk.

**Methods:** The author obtained qualitative abundance estimates for nine invasive species, including medusahead, from regional weed managers. Estimates were combined into three categories: absent, low abundance, and high abundance. They compared these data with herbarium and regional occurrence records for each species. They also created four separate habitat suitability models for each species using herbarium occurrence records, regional occurrence records, manager-identified occurrences, and manager-identified high-abundance locations. They then compared the amount of area identified as suitable among each of the models.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming

**Findings:** The author determined that regional management occurrence data better matched abundance data than herbarium occurrence records did. For most species, habitat suitability models built with expert-identified occurrences and herbarium records identified much greater land area as being at risk of invasion and overestimated abundance suitability than the other models. Models using regional occurrences resulted in lower false positive rates than the other models but captured less of the areas dominated by invasive species identified by abundance data.

**Implications:** The author states that their results show that habitat suitability models constructed with abundance records will provide more accurate assessments of risks of effect than models constructed with occurrence data. They suggest that researchers and managers collect abundance data on invasive species whenever possible, even if only qualitative assessments are possible. They claim that using abundance data in suitability models instead of occurrence data will allow managers to focus resources on areas where invasive species are most likely to cause significant effects.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; nonnative invasive plants; weather and climate patterns

## Bradley, B.A., 2016, Predicting abundance with presence-only models: Landscape Ecology, v. 31, no. 1, p. 19–30.

**DOI:** https://doi.org/10.1007/s10980-015-0303-4

**Background:** Understanding the relations between species distributions, abundance, and the environment is important for managing invasive species. Predicting abundance is likely to be more informative to managers than occurrence, but abundance data are rare at regional scales. However, there are several low-cost methods that could help inform distribution models.

**Objectives:** The author sought to (1) compare performance of climatic suitability models using different data types, (2) test the models' ability to distinguish presence/absence and high or low abundance, and (3) demonstrate the important role abundance data can have in describing abundance patterns of invasive species.

**Methods:** The author compiled abundance, percent cover, and occurrence data for 15 invasive species, with medusahead and cheatgrass present in the dataset. These data were collected from three sources: (1) herbarium records, (2) occurrence data from regional expert surveys, and (3) locations of high abundance from regional experts. The author selected minimum January temperature, maximum July temperature, and quarterly precipitation as climate predictors. They then modeled climatic suitability for each species using the three types of compiled data.

**Location:** United States

**Findings:** The author identified that nearly all models accurately distinguished presence and absence, but models based on regional occurrence were more accurate than models based on high-abundance points. When distinguishing intermediate abundance ranks (for example, rare versus few), models using regional high abundance were most accurate. For identifying areas of high abundance, models using regional high abundance performed best. For all analyses, models based on herbarium records were least accurate.

**Implications:** The author states their results provide further evidence that species distribution models based solely on occurrence data are not good at predicting abundance. They also suggest that climatic conditions in areas where a species is likely to be present may not be the same as those in areas of high abundance. They further suggest that factors beyond climate affect the relationship between abundance and occurrence at regional scales. Finally, they state that abundance data are needed to accurately predict regional abundance patterns and that using these data would improve the ability of ecologists to understand factors influencing regional distribution and abundance.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat selection; nonnative invasive plants; weather and climate patterns

## Brownsey, P., Davy, J., Becchetti, T., Easley, M.L., James, J.J., and Laca, E.A., 2016, Barb goatgrass and medusahead—Timing of grazing and mowing treatments: University of California Agriculture and Natural Resources, Publication 8567, 9 p.

**DOI:** https://doi.org/10.3733/ucanr.8567

This product presents the same information as was published by Brownsey and others (2017; https://doi.org/10.1016/j.rama.2016.08.011). Therefore, please refer to the product summary for Brownsey and others (2017) for information about this product.

## Brownsey, P., James, J.J., Barry, S.J., Becchetti, T.A., Davy, J.S., Doran, M.P., Forero, L.C., Harper, J.M., Larsen, R.E., Larson-Praplan, S.R., Zhang, J., and Laca, E.A., 2017, Using phenology to optimize timing of mowing and grazing treatments for medusahead (*Taeniatherum caput-medusae*): Rangeland Ecology and Management, v. 70, no. 2, p. 210–218.

**DOI:** https://doi.org/10.1016/j.rama.2016.08.011

**Background:** Medusahead invasion is a major threat to rangeland health in the western United States. Mowing and grazing are methods of controlling medusahead, though effectiveness can vary depending on the life stage of the plants. Identifying at which stages medusahead is most vulnerable to mowing and grazing will help managers control medusahead invasion.

**Objectives:** The authors sought to (1) assess effects of clipping at different times and plant heights on medusahead seed production, (2) evaluate changes in nutritional quality through time, and (3) identify timeframes that would optimize the ability of mowing and grazing treatments to reduce medusahead.

**Methods:** The authors established 54 plots April to May 2007 and clipped plants at a mix of nine dates and three clipping intensities. In July 2007, they measured the number of seedheads per plot. To evaluate nutritional quality, they sampled a few life stages and measured crude protein, acid detergent fiber, and silicon content. To assess timing of life stage progression across the study region, the authors sampled 16 locations from 2006 to 2010 and collected 393 plant samples to assess their life stage. The authors then used several different models to determine patterns of life stage change through time.

**Location:** California

**Findings:** Defoliation at all life stages and intensities was effective at reducing seed production. Nutritional quality was determined to decrease as plants got older. Medusahead had the greatest reduction in seed production from grazing and mowing in late June to early July, though there was variation among regions. The authors determined that the best window of opportunity for successfully managing medusahead via mowing or grazing, considering both the nutritional quality and the management goal of reducing seed production, was early April to early May.

**Implications:** The authors suggest that there is a small, early window in medusahead life stage progression where defoliation can greatly reduce seed production but still be nutritious to livestock, specifically the boot stage of its life cycle. They state that medusahead is most vulnerable to grazing for a 10- to 15-day period but still vulnerable to mowing for up to 35 days. The timing of these windows varies across regions. The authors conclude by stating that rapid, local-scale assessments of medusahead life stage progression could allow managers to use their resources more effectively.

**Topics:** survival; behavior or demographics; broad-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: mechanical vegetation removal

## Brunson, J.L., Pyke, D.A., and Perakis, S.S., 2010, Yield responses of ruderal plants to sucrose in invasive-dominated sagebrush steppe of the northern Great Basin: Restoration Ecology, v. 18, no. s2, p. 304–312.

**DOI:** https://www.doi.org/10.1111/j.1526-100X.2009.00644.x

**Background:** High nitrogen levels in Great Basin soils, resulting from agriculture and grazing, contribute to the dominance of invasive annual grasses. Limiting soil nitrogen by adding carbon could help reduce invasive species and restore native plant communities.

**Objectives:** The authors sought to apply carbon in the form of sucrose to invaded sites and assess effects to (1) aboveground biomass and (2) seed production of annual invasive species.

**Methods:** The researchers collected cheatgrass and medusahead seeds at two experimental sites in summer 2005. They subsequently established 108 plots at each site and cleared existing vegetation. They mixed sucrose with sand and raked the mixture across plots at 12 different application rates before spreading cheatgrass or medusahead seeds, watering, and installing silt fences. They randomly selected 16 individuals from cheatgrass and medusahead subplots and removed, dried, and weighed aboveground biomass, and then counted mature seeds. They also counted cheatgrass and medusahead stems and removed all vegetation from the remaining subplots to calculate total plant biomass. They collected soil core samples in November, March, and July and analyzed for microbial biomass carbon and nitrogen. They also estimated soil nitrate content at each site. They performed statistical analyses to assess the relationship between soil nutrients, plant biomass, and seed production.

**Location:** Oregon

**Findings:** The authors determined that total plant biomass decreased with carbon applications. Seeding treatments were largely unsuccessful, but medusahead established successfully at one site and both biomass and seed production decreased with increasing carbon. Cheatgrass establishment was not sufficient to reliably detect responses to soil amendments. Microbial biomass increased with carbon additions in November and March but decreased to pretreatment levels by the end of the first year. Soil nitrates decreased with increases in soil carbon.

**Implications:** The authors suggest that increasing soil carbon can reduce the biomass or limit the growth of a ruderal species in semiarid ecosystems. However, they also suggest that one-time soil carbon amendments may have meager, short-term effects on soil dynamics and may not effectively restore soil nitrogen processes to support native plant communities.

**Topics:** behavior or demographics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; soils or geology

## Brunson, J.L., Pyke, D.A., and Perakis, S.S., 2021, Invasive grasses cheatgrass and medusahead yield responses to sucrose in experimental plots in the northern Great Basin, USA Dataset, 2005-2006: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9TN4J3L

**Background:** Treating soils with carbon can alter site characteristics and may affect growth and seed production of invasive annual grasses.

**Objectives:** The authors sought to measure the effect of varying soil carbon treatments on (1) cheatgrass and medusahead biomass and seed production, (2) soil microbial biomass carbon and nitrogen, and (3) soil nitrogen content.

**Methods:** The authors established 216 plots at two sites dominated by cheatgrass and medusahead. In 2005, they cleared vegetation, applied sucrose to plots using 12 application rates, and seeded plots with cheatgrass or medusahead seeds that had originated at the sites. They also maintained a group of unseeded control plots. They then watered and installed silt fences. In 2006, the authors randomly harvested 16 individuals of cheatgrass or medusahead in each seeded plot to measure biomass and count seeds. They also calculated total biomass of all vegetation and total cheatgrass and medusahead individuals per plot. In November, March, and July between seeding and harvesting, the authors collected soil samples to measure microbial biomass carbon and nitrogen. They also measured inorganic nitrogen for the duration of the experiment.

**Location:** Idaho, Oregon

**Findings:** The authors produced spreadsheets containing measurements of seeds per plant, seeds per plot, plant biomass and density per plot, and inorganic nitrogen per plot. The authors listed all data by seeded species and carbon fertilization dosage.

**Implications:** These data may inform the management of cheatgrass and medusahead.

**Topics:** behavior or demographics; nonnative invasive plants; soils or geology

## Carey, C.J., Beman, J.M., Eviner, V.T., Malmstrom, C.M., and Hart, S.C., 2015, Soil microbial community structure is unaltered by plant invasion, vegetation clipping, and nitrogen fertilization in experimental semi-arid grasslands: Frontiers in Microbiology, v. 6, article 466, 14 p.

**DOI:** https://www.doi.org/10.3389/fmicb.2015.00466

**Background:** Nitrogen deposition, grazing or vegetation removal, and invasive species are common disturbances across semiarid grasslands that could affect soil communities. The effect of multiple, co-occurring environmental disturbances on soil microbial communities has not been well documented in places with strong seasonal variability.

**Objectives:** The authors sought to understand the effects of (1) invasion, (2) elevated nitrogen, and (3) aboveground vegetation removal on abiotic soil properties and the soil microbial community in an ecosystem that experiences high seasonal variation.

**Methods:** The researchers sampled from five treatments with eight replicates each. Treatments had combinations of seeded native and invasive species—some of which contained barbed goatgrass and medusahead—nitrogen fertilization, and biomass removal. The researchers estimated percent cover every spring throughout 6 years to track species composition through time. They added nitrogen and clipped aboveground biomass annually in treatments dominated by higher proportions of naturalized (species introduced in the mid- to late 1800s now present across California grasslands) and invasive (introduced species spreading across California grasslands that pose a threat to ecosystem function) species. They collected composite soil cores in April 2013 for each replicate across the five treatments. For each soil sample, they measured water content, pH, total carbon and nitrogen, inorganic nitrogen, and potential rates of nitrification and denitrification. They also measured soil moisture and temperature at the study site. They extracted microbial DNA from 40 soil samples and sequenced 1.1 million microorganisms. The researchers performed statistical analyses to understand different responses of native and invaded communities, effects of fertilization and clipping, and the relationship between treatments and soil microbial community responses.

**Location:** California

**Findings:** The researchers determined that soil abiotic components and soil nitrification rates changed depending on treatment type, but the diversity of microorganisms was not affected by invasion, clipping, or fertilization. Specifically, they determined that invaded areas had lower total carbon and nitrogen, clipped treatments had lower nitrate concentrations and higher maximum soil temperature, and fertilized treatments were associated with increased nitrate availability and reduced soil pH.
**Implications:** The authors suggest that microbial communities in the study area are resilient to environmental disturbance. This adaptive response could have been linked to the strong seasonality or the cultivation history of the study area. They also suggest that future work is needed to understand the thresholds at which microbial communities change.

**Topics:** genetics; site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; climate change; soils or geology

## Carey, C.J., Blankinship, J.C., Eviner, V.T., Malmstrom, C.M., and Hart, S.C., 2017, Invasive plants decrease microbial capacity to nitrify and denitrify compared to native California grassland communities: Biological Invasions, v. 19, p. 2941–2957.

**DOI:** https://www.doi.org/10.1007/s10530-017-1497-y

**Background:** New-wave invasive species, like barb goatgrass and medusahead, can alter soil nutrients and thus affect the long-term health of invaded ecosystems. Understanding soil nitrogen dynamics associated with native, naturalized, and invasive plant communities can point to mechanisms that support healthy functioning ecosystems.

**Objectives:** The researchers sought to compare soil nutrient cycling, microbial biomass, and abundance of microorganisms between (1) native plant communities and invasive exotic species actively invading California grassland plant communities and (2) naturalized exotic species that have been common in California grasslands for 250 years and native plant communities.

**Methods:** The researchers established plots in an experimental grassland site in fall 2007 and seeded native, naturalized, and new-wave invasive species into separate plots in a randomized design. Each spring, for 5 consecutive years, the researchers visually estimated plant cover. They collected five soil samples per plot in October, January, April, and July 2011 to 2012. They also repeatedly measured soil characteristics like temperature, water content at two depths, and nitrogen availability. For each composite soil sample, they analyzed soil moisture, total carbon, total nitrogen, and pH. They estimated rates of nitrification (a key nitrogen cycling process), abundance of microorganisms that cause nitrification, and denitrification potential. They estimated microbial biomass and abundance by measuring soil respiration and counting organisms under a microscope. They performed statistical analyses to quantify the differences between plant community types related to nitrogen dynamics and the biomass of microorganisms.

**Location:** California

**Findings:** The authors determined that nitrogen dynamics associated with new-wave invasive species differed significantly from the native plant community with respect to nitrate availability through time, nitrification, denitrification, and microbial biomass. However, they did not detect differences in the abundance of microorganisms between native and invasive plant communities. Nitrogen dynamics were not significantly different between invaded and naturalized communities. Overall, they determined that invaded communities had reduced decomposition, total nitrogen, and microbial biomass compared to native communities.

**Implications:** The researchers suggest that invasion by barb goatgrass and medusahead affects soil nitrogen dynamics and nutrient cycling, causing changes that could support the persistence of naturalized or invasive species and alter broader ecosystem dynamics. These changes to soil characteristics could also negatively affect the future success of restoration projects.

**Topics:** site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Chai, S.-L., Zhang, J., Nixon, A., and Nielsen, S., 2016, Using risk assessment and habitat suitability models to prioritise invasive species for management in a changing climate: PLOS ONE, v. 11, no. 10, article e0165292, 11 p.

**DOI:** https://www.doi.org/10.1371/journal.pone.0165292

**Background:** Invasive species are predicted to expand north as the climate warms. Thus, considering climate change when developing risk assessments and understanding future habitat suitability of invasive species is increasingly important. Gaining insight into the future potential distribution of invasive species can support management decisions.

**Objectives:** The authors sought to (1) use risk assessments combined with habitat suitability models to predict how invasive species could expand their distribution and (2) prioritize species for management.

**Methods:** The authors obtained records from the Global Biodiversity Information Facility on the location data of 15 invasive species near Alberta. The authors modeled suitable habitat by first considering soil properties and estimating habitat under recently observed (1961 to 1990) and future projected (2041 to 2070) climate scenarios. They categorized habitat suitability as suitable low-risk habitat and high-risk habitat. They developed risk assessment scores to quantify invasiveness based on 21 criteria related to invasiveness and predicted ecological effects. Using information from habitat suitability model projections and risk assessment scores, they prioritized invasive species for management.

**Location:** Alberta

**Findings:** The authors determined that most species were projected to have significantly increased suitable low-risk habitat and suitable high-risk habitat and that a smaller subset had very high-risk assessment scores. African rue and puncturevine had the greatest increase in high-risk areas based on habitat suitability models. Chinese tamarisk, autumn olive, and giant knotweed had the highest-risk assessment scores. Medusahead was also classified as a highly invasive species with suitable high-risk habitat projected to expand from 0 up to 28,000 square kilometers. Chinese tamarisk, giant knotweed, and alkali swainsonpea had the highest combined threat given results from risk assessment scores and habitat suitability models.

**Implications:** The authors suggest that the combination of risk assessments and habitat suitability models provides a basis for prioritizing management efforts. These methods can be applied widely to develop effective management strategies to prevent the spread of invasive species resulting from climate change. The authors propose that using this combination of information to inform management could slow or prevent the spread of invasive species that pose the greatest ecological threats.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; nonnative invasive plants; climate change; weed management; soils or geology

## Chuong, J., Huxley, J., Spotswood, E.N., Nichols, L., Mariotte, P., and Suding, K.N., 2016, Cattle as dispersal vectors of invasive and introduced plants in a California annual grassland: Rangeland Ecology and Management, v. 69, no. 1, p. 52–58.

**DOI:** https://doi.org/10.1016/j.rama.2015.10.009

**Background:** Domestic livestock play an important role in transporting the seeds of invasive species. Seeds can be transported long distances through the digestive tract of livestock or by adhering to their skin or fur. Understanding these dispersal mechanisms can point to potential future distribution patterns of invasive plants.

**Objectives:** The authors sought to assess (1) which species are transported by different dispersal mechanisms, (2) if species' abundance is related to seed dispersal, (3) how far cattle can transport seeds through two dispersal methods, and (4) how far medusahead seeds can be transported.

**Methods:** The researchers used three approaches to see how cows might transport seeds from invasive plants. In one experiment in July 2014, researchers herded 40 cattle through dense stands of medusahead in a pasture that contained additional invasive species. After the cattle were herded through the pasture, they were systematically gleaned for any seeds. The researchers compared the species composition of the seeds the cattle had transported with seven 100-m transects the researchers measured in the pasture. The authors' second experimental approach was in October 2013, when they collected dung patties from 45 random plots in the same pasture and quantified species composition and percent cover in each plot they collected dung in. They processed the samples to encourage germination of any viable seeds within the dung, and they tracked germination and identified seedlings twice per week for 3 months. In the authors' third experiment approach, in May 2013, the researchers constructed a model cow, attached 40 medusahead seeds to the model, and walked it along a 100-m transect to measure average dispersal distance of the seeds they had attached. The researchers performed statistical analyses to understand relations between dispersal mechanisms and the abundance and characteristics of invasive species.

**Location:** California

**Findings:** The authors determined that cattle were more likely to disperse invasive species and do so across greater distances on their skin or fur than through dunging. The authors observed more legume and forb diversity for seeds transported through ingestion. They identified that vegetation composition did not determine dispersal trends, but species' abundance was negatively correlated with the number of seeds dispersed on cattle fur (in other words, seed abundances transported by cattle did not correlate with pasture composition), both results that they did not expect and that invoked experimental design issues as a possible explanation. They detected that medusahead seeds can travel across large distances on the fur of the model cow.

**Implications:** The authors suggest that managers can use information about the dispersal of invasive species by cattle to prevent or minimize invasion. For example, managers could prevent the spread of viable seeds by limiting grazing in invaded pastures when seeds are being dispersed, or delay moving cattle in corrals after grazing invaded pastures.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Churchill, A.C., and Faist, A.M., 2021, Consequences of above-ground invasion by non-native plants into restored vernal pools do not prompt same changes in below-ground processes: AoB Plants, v. 13, no. 6, 12 p.

**DOI:** https://doi.org/10.1093/aobpla/plab042

**Background:** Invasive plants can alter litter accumulation and decomposition, soil nutrients, and the soil microbial community, which can amplify subsequent invasions. Human activity also drives invasions, and the effect of surface disturbance during wetland restoration in annual-dominated ecosystems is unknown.

**Objectives:** The authors sought to assess effects of (1) invasive species on litter decomposition, (2) vegetation composition on litter inputs, and (3) vegetation composition on soil dynamics in vernal pools, which are seasonal wetlands.

**Methods:** The researchers focused on three vernal pool types, using naturally occurring native or invasive-dominated reference pools and invasive-dominated pools created during prior restoration projects, totaling 24 pools. They sampled three elevation bands in each vernal pool. They surveyed aboveground species, collected plant tissue, and assessed plant chemistry in 2011. They clipped and dried native (annual semaphoregrass) and invasive (Italian ryegrass) plant material to place in 144 mesh litter bags and placed litter bags at different elevation bands within each pool, both on top and below invasive grass

litter. They installed litter bags during two wet (September to April 2011 to 2013) and one dry (April to September 2013) season. They collected three soil samples per pool and measured soil physical and organic properties. They performed statistical analyses to examine differences in community composition, litter decomposition, and soil characteristics among pools.

**Location:** California

**Findings:** The authors detected that plant chemistry varied by species, resulting in significant differences in vegetation community chemistry between pool types. Year drove decomposition of invasive plant litter more than pool type. Native grass decomposed significantly more than invasive grass, and native litter decomposed more above the litter layer. Soil texture did not differ by pool type, but naturally occurring invaded pools had higher soil moisture than created pools and lower pH than native-dominated pools. The soil carbon-to-nitrogen ratio and trends in microbial biomass were lower in created pools than naturally occurring pools.

**Implications:** The authors suggest that decomposition of invasive litter in their study system amplifies further invasion, but effects to soil dynamics may be delayed, allowing for opportunities to focus on restoring aboveground vegetation to prevent changes to soil properties.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; water; soils or geology; wetlands/riparian

## Clark, S.L., da Silva, P.V., Dayan, F.E., Nissen, S.J., and Sebastian, D.J., 2019, The influence of winter annual grass litter on herbicide availability: Weed Science, v. 67, no. 6, p. 702–709.

**DOI:** https://www.doi.org/10.1017/wsc.2019.45

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## Clenet, D.R., Davies, K.W., Johnson, D.D., and Kerby, J.D., 2019, Native seeds incorporated into activated carbon pods applied concurrently with indaziflam—A new strategy for restoring annual-invaded communities?: Restoration Ecology, v. 27, no. 4, p. 738–744.

**DOI:** https://www.doi.org/10.1111/rec.12927

**Background:** Invasive annual grasses have affected rangelands, resulting in increased fire return intervals and altered ecosystem dynamics. Single-entry approaches, which simultaneously apply preemergent herbicides and native seeds to control invasive grasses and increase native vegetation, are being used more frequently. However, less is known about single-entry approaches that combine use of activated carbon herbicide protection pods to protect seeds from damage with a new preemergent herbicide (indaziflam).

**Objectives:** The authors sought to determine seedling growth of two native species when using (1) herbicide protection pods and (2) differing herbicide concentrations.

**Methods:** In a controlled setting, the authors established 20 boxes, each containing 5 treatment containers. They implemented separate planting treatments—bare seed or seed incorporated—into herbicide protection pods for two native species, Wyoming big sagebrush or bluebunch wheatgrass. They also planted medusahead bare seed separately to test herbicide effectiveness. They applied the herbicide (indaziflam) at four concentration rates (none, low, medium, high) replicated five times across treatments. After 7 weeks, they measured aboveground biomass, final density, height, leaf number, and leaf length. After 10 weeks, they measured the same characteristics in addition to canopy diameter for sagebrush. They performed statistical analysis to compare treatments on the measured variables.

**Location:** Oregon

**Findings:** Bare seed wheatgrass failed to establish and survive at medium and high herbicide rates. Without herbicides, protection pods negatively affected the height, leaf number, length, and width of wheatgrass. With herbicides, protection pods positively affected wheatgrass abundance and other measured variables. With protection pods, increasing herbicide rates reduced wheatgrass density, height, leaf length, and biomass. Sagebrush density and biomass were greater in the bare seed treatment without herbicides. However, with all herbicide application rates, sagebrush density, height, diameter, and biomass were higher in protection pods. Medusahead density decreased with any herbicide concentration rate.

**Implications:** The authors suggest that using herbicide protection pods and herbicides concurrently can protect multiple plant functional groups from damage, while controlling invasive species. They suggest that the herbicide protection pods can be modified depending on seed size and can be used with other preemergent herbicides.

**Topics**: survival; behavior or demographics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Clenet, D.R., Davies, K.W., Johnson, D.D., and Kerby, J.D., 2020, Herbicide protection pods (HPPs) facilitate sagebrush and bunchgrass establishment under imazapic control of exotic annual grasses: Rangeland Ecology and Management, v. 73, no. 5, p. 687–693.

**DOI:** https://www.doi.org/10.1016/j.rama.2020.07.002

**Background:** Exotic annual grasses are negatively affecting rangelands and may outcompete seeded desirable species after wildfires. Preemergent herbicides are commonly used to control invasive annual grasses but may pose risk of damaging nontarget species if not enough time has elapsed prior to seeding restoration species. In previous greenhouse studies, herbicide protection pods have been effective in protecting seeded species by inactivating herbicides with active carbon, but there have been no studies testing the effectiveness of these postwildfire throughout multiple growing seasons.

**Objectives:** The authors sought to determine herbicide protection pod effectiveness in protecting seeded species from herbicides in a postfire invaded rangeland for seeded (1) shrub species and (2) perennial bunchgrasses.

**Methods:** In September 2017, researchers evaluated two seeding treatments using seeds within herbicide protection pods and bare seeds, replicated four times in two recently burned sites. They planted two shrub species and five perennial bunchgrasses, then sprayed sites with a preemergent herbicide (imazapic) 1 day postseeding. They monitored exotic grasses and seeded species for the next two summers measuring density, plant height, cover, and canopy diameter for shrubs. They used statistical analyses to compare treatment, year, and the interaction of both on the measured variables for each seeded species.

**Location:** Oregon

**Findings:** Wyoming big sagebrush densities and cover were greater in the pod treatment during the second year, but height and diameter did not differ between pods and bare seed. Exotic grasses decreased in both locations, but to a lesser extent at one field site during the second year. Squirreltail did not differ for any measured variable between treatments through time. Basin wildrye

and Sandberg bluegrass densities were higher in pod treatments but differed between years. Height and cover were not affected by treatment in either year. Bluebunch wheatgrass and crested wheatgrass had greater densities, cover, and heights in the pod treatment in both years.

**Implications:** The authors suggest herbicide protection pods increase seeded species' survival with simultaneous herbicide application to reduce exotic annual grasses. Protection pods can be modified depending on seed size and can be used to protect multiple plant groups.

**Topics:** dispersal, spread, vectors, and pathways; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Coppock, D.L., Hart, R.A., and Burritt, B., 2017, Technical and human factors hinder medusahead control in northern Utah: Rangelands, v. 39, no. 2, p. 35–45.

**DOI:** https://doi.org/10.1016/j.rala.2017.03.001

**Background:** Medusahead invasion can have widespread negative ecological and socioeconomic effects. Some communities cooperatively manage land for weed invasions and prevention through a collective weed prevention area (WPA). Community-based approaches can promote effective weed management, but factors that affect success are understudied.

**Objectives:** The authors examined how (1) social, (2) economic, (3) technical, and (4) institutional factors affect medusahead control efforts.

**Methods:** From 2012 to 2015, the authors worked within a WPA established in 2008 with a target area of more than 300,000 acres. They established five semirandom focus groups with one group each for (1) relevant weed professionals, (2) WPA-active landowners, (3) recently active WPA landowners, (4) inactive WPA landowners with less than 20 acres, and (5) inactive WPA landowners with more than 20 acres. They collected additional information through surveys with 12 weed professionals, 11 active or recently active resident landowners, and 25 inactive nonresident landowners.

**Location:** Utah

**Findings:** The authors identified that although more than 1,300 people owned land within the target area, 40 landowners owned 80 percent of the land area and only 3 were WPA members. Every focus group identified medusahead as a threat, though it was not every group's priority species of concern. Weed professionals agreed that more cost-effective technical solutions and more funding for research were needed to enhance medusahead control. Active WPA landowners highlighted the need for better communication between stakeholders and more effective leadership. Inactive resident and nonresident landowners indicated their disconnect to the WPA was due to lack of communication but showed interest in community-based medusahead control. Nearly all groups identified a need for a dedicated, highly trained weed coordinator to lead the WPA.

**Implications:** The authors state that consistent and sufficient funding is the main factor constraining medusahead management because funding affects scientific research and outreach needed to communicate advancements and solutions. They identified that scarce funding also limited the retention of a long-term, multitalented weed coordinator who understands rangeland management, target population sampling, and how to communicate with diverse landowners and build trust. The authors suggest that institutional factors are the most limiting to medusahead control because institutions control access to funding and weed management staff.

**Topics:** nonnative invasive plants; weed management; weed management subtopic: cultural control; human dimensions or economics

## Creutzburg, M.K., Henderson, E.B., and Conklin, D.R., 2015, Climate change and land management impact rangeland condition and sage-grouse habitat in southeastern Oregon: AIMS Environmental Science, v. 2, no. 2, p. 203–236.

**DOI:** https://www.doi.org/10.3934/environsci.2015.2.203

The summary for this article was previously published summarized in Carter and others (2020, p. 67; https://doi.org/10.3133/ofr20201103).

## Creutzburg, M.K., Olsen, A.C., Anthony, M.A., Maestas, J.D., Cupples, J.B., Vora, N.R., and Allred, B.W., 2022, A geographic strategy for cross-jurisdictional, proactive management of invasive annual grasses in Oregon: Rangelands. v. 44, no. 3, p. 173–180.

**DOI:** https://doi.org/10.1016/j.rala.2021.12.007

**Background:** Due to the widespread loss of sagebrush habitat caused by invasive species, stakeholder collaboration has increased to provide proactive strategies to reduce infestations across land ownerships. Proactive management approaches include defending the core sagebrush habitat, reducing invasive species in transition zones, and mitigating effects of invasive species in degraded areas. Multi-scale spatial datasets can be used as a tool to map the extent of invasion and facilitate management guidance.

**Objectives:** The authors sought to develop geographic strategy maps to facilitate coordination and communication about shared goals and strategies for addressing invasive annual grasses across large landscapes, with an emphasis on proactive management.

**Methods:** The authors used a spatial dataset to create resource management-focused maps that hierarchically prioritize landscape areas according to vegetation status. They averaged vegetation cover values from 2015 to 2019 to account for weather variability across their study area. They combined their remote sensing approach with resilience and resistance maps to determine the potential for site recovery based on soil types and climate factors. The authors categorized vegetation into 12 management classes based on 4 levels of vegetation condition and 3 levels of resilience and resistance. They created two maps for use at different spatial scales.

**Location:** Oregon

**Findings:** The authors developed two maps, based on purpose and audience, to inform planners across various agencies. The generalized strategy map highlights large blocks of intact core areas and is intended for a general audience. The management strategy map provides finer-scale detail of potential management outcomes to guide multiagency projects and focuses on landscape-scale goals for managers. These maps are designed to be used as part of a framework for collaboration across stakeholder groups to strategically plan landscape-scale treatments.

**Implications:** The authors suggest that proactive management across organizations is crucial for invasive species management. They suggest that the geographic strategy is a tool that can help land managers at multiple phases of a project and can be used to facilitate communication about common goals and approaches to implement these goals. They recommend using the geographic strategy map with other data sources, management tools, and local knowledge to make decisions about where to invest meager resources.

**Topics:** broad-scale habitat characteristics; nonnative invasive plants; weather and climate patterns; weed management; soils or geology; includes new geospatial data; human dimensions or economics

## Cristofaro, M., Roselli, G., Marini, F., de Lillo, E., Petanovic, R.U., Vidovic, B., Augé, M., and Rector, B.G., 2020, Open field evaluation of *Aculodes altamurgensis*, a recently described eriophyid species associated with medusahead (*Taeniatherum caput-medusae*): Biocontrol Science and Technology, v. 30, no. 4, p. 339–350.

**DOI:** https://www.doi.org/10.1080/09583157.2019.1711021

**Background:** Management strategies for medusahead need to be efficient and economical to tackle its pervasive spread and resulting habitat degradation. Highly specific and targeted options such as grazing and mowing are possible but difficult to achieve on a large scale. The use of selective parasitic mites could be a feasible management option.

**Objectives:** The authors sought to evaluate how a recently discovered mite, *Aculodes altamurgensis*, colonizes host plants by comparing (1) infestation density on medusahead and other grass species, and (2) infestation success in geographically distinct populations of medusahead.

**Methods:** In February 2016, the authors began growing plants from seeds of barley, oat, corn, common wheat, durum wheat, and foxtail barley and seeds from five subpopulations of medusahead. In March 2016, 10 pots of each species or population of medusahead were placed outdoors in the field to simulate field conditions. In May 2016, the authors attached a cutting of locally collected medusahead infested with the mite to plants in each pot. They collected a sample leaf from each plant to assess infestation success after 15 days. After 40 days, they collected all the mites from each plant and weighed the aboveground portion of the plants. They performed statistical analyses to compare plant weight, medusahead population, and mite density.

**Location:** California, Idaho, Nevada

**Findings:** No mites were detected on species other than medusahead after 40 days, though a few of the original mites persisted initially on a few species. Two other nontarget native mite species were detected on all plant species but only modestly infested medusahead. Medusahead plant size did not correlate to mite density of *A. altamurgiensis.* Mite density varied among the medusahead populations that were tested, and the population from Idaho had the greatest mite density per gram of plant.

**Implications:** The authors state that they do not yet fully understand the ecology of the recently discovered mite given that the medusahead samples from the United States they included in this experiment had higher infestation rates than medusahead collected near Rome, Italy for this study. It is unknown where the medusahead populations in the United States originated from, and the authors advocate that more study of this dynamic relationship between medusahead genetics and the mite species is needed with additional medusahead populations. Because the mite infestations were largest on the medusahead stock from the United States, using this mite species as a biocontrol may be possible.

**Topics:** nonnative invasive plants; weed management; weed management subtopic: biocontrol; population estimates or targets

## Cronin, J.P., Rua, M.A., and Mitchell, C.E., 2014, Why is living fast dangerous? Disentangling the roles of resistance and tolerance of disease: The American Naturalist, v. 184, no. 2, p. 172–187.

**DOI:** https://www.doi.org/10.1086/676854

**Background:** Human-caused ecosystem changes have increased pathogen transmission rates and the likelihood of transmission to new host species. A better understanding of how host traits contribute to pathogen transmission may help to identify species that are more likely to contribute to the spread of pathogens.

**Objectives:** The authors sought to develop a statistical model that could help clarify the relations between host physiological traits and resistance (host's capacity to prevent damage) or tolerance (host's capacity to limit the effect of any damage that occurs) to pathogens.

**Methods:** Between 2010 and 2011, researchers planted 6 grass species (3 native perennial and 3 exotic annual grasses), 88 to 112 individuals per species, in pots in a greenhouse setting. They obtained viruses from Columbia brome and applied them onto six grass species using aphids. Treatments included no aphids, uninfected aphids, and infected aphids. Across treatments, they included a combination of soil nutrients, such as phosphorous (low or high) and nitrogen (low or high). They measured root and shoot biomass, photosynthesis, and nitrogen and phosphorous concentrations to determine responses to infection. The researchers then developed statistical models to determine the relationship between these host traits and resistance and tolerance to pathogens.

**Location:** California, Missouri, New York, Oregon

**Findings:** Grasses studied ranged from slow-return (low tissue nutrients, tough leaves, more root biomass) to quick-return (high tissue nutrients, flimsy leaves, more shoot biomass). Exotic annual grasses were considered quick-return. Slow-return grasses were able to limit virus replication in their tissue and, consequently, had more total biomass. Although quick-return grasses were better at increasing photosynthesis when infected, slow-return grasses may have been better at increasing soil resources uptake.

**Implications:** The authors suggest that exotic annual grasses are less resistant to the virus infections, which results in more severe reductions in total biomass. They note that although the greenhouse findings indicate that exotic annuals may be less tolerant, the ability of exotic annuals to increase photosynthesis when infected could allow them to be more tolerant in the field where light availability could more strongly limit growth. The authors also suggest that native perennials are more resistant to the virus infections and may be better resource competitors.

**Topics**: other: species and population characteristics; nonnative invasive plants; soils or geology

## Cronin, J.P., Welsh, M.E., Dekkers, M.G., Abercrombie, S.T., and Mitchell, C.E., 2010, Host physiological phenotype explains pathogen reservoir potential: Ecology Letters, v. 13, no. 10, p. 1221–1232.

**DOI:** https://doi.org/10.1111/j.1461-0248.2010.01513.x

**Background:** To control emerging infectious diseases in plant populations, it is important to understand which plant species could serve as sources of disease transmission. The relationship between physiological factors of host plants and their competence as pathogen reservoirs is vital to this understanding but has not yet been adequately studied.

**Objectives:** The authors sought to test if a plant species' physiological traits could explain its susceptibility to infection, competence (ability to transmit pathogens to vectors), and ability to support vector populations by exploring (1) the physiological traits related to these epidemiological properties, and (2) if host lifespan, provenance (for example, native or exotic status), and phylogeny explain the relationship between physiology and the epidemiological parameters.

**Methods:** The authors organized two greenhouse experiments between 2007 and 2009 using six grass species from three grass tribes—medusahead, wild oat, soft brome, California brome, blue wildrye, and prairie Junegrass—where they created three species pairs with one native and one exotic species. In the first experiment, the authors grew each grass species (61 total individuals) at low and high soil nitrogen and measured physiological leaf characteristics, consisting of leaf mass area, nitrogen concentration, photosynthetic capacity, longevity, and growth rate. In the second experiment, they inoculated 30 to 165 individuals from each of the six grass species with aphids; 15 of the individuals were "mock-inoculated" with uninfected aphids and 15 to 150 were inoculated with aphids infected with the barley yellow dwarf virus-PAV. Through an eight-step protocol, the authors allowed host growth, vector feeding, and virus replication. Both the virus and grass seed were collected from wild populations.

**Location:** Oregon

**Findings:** The results supported the authors' physiological phenotype hypotheses. Grasses studied ranged from slow-return (low tissue nitrogen, photosynthesis, and growth) to quick-return (high tissue nitrogen, photosynthesis, and growth), and quick-return grasses were more susceptible, competent, and able to support vectors. Adding soil nitrogen caused grasses to become more quick-return, except medusahead, which was not affected. Medusahead's tribe (*Triticeae*) was more quick-return compared to other tribes, and exotic annual grasses were more quick-return compared to native perennials grasses. However, phylogenetic group and exotic or lifespan status were not as good predictors of susceptibility to the pathogen as slow-quick status.

**Implications:** The authors suggest that quick-return phenotypes are more likely to be sources of infectious disease, and that this pattern extends beyond grasses to other plants and animal systems. The authors posit that quick-return hosts assume the role of disease source because, when compared to slow-return hosts, they are more likely to become infected, have a higher probability of disease transmission, and have a greater ability to function as a disease vector.

**Topics:** behavior or demographics; genetics; dispersal, spread, vectors, and pathways; nonnative invasive plants

## Dahal, D., Parajuli, S., Pastick, N.J., Boyte, S.P., Oimoen, M.J., and Megard, L.J., 2021, Fractional estimates of multiple exotic annual grass (EAG) species and Sandberg bluegrass in the sagebrush biome, USA, 2016–2020 (ver. 1.0): U.S. Geological Survey data release. [Superseded in 2023 by version 3.0, which is available at the same DOI.]

**DOI:** https://doi.org/10.5066/P9GC5JVG

**Background:** Remotely sensed data can provide historical estimates of vegetation cover for exotic and native grass species across the sagebrush biome.

**Objectives:** The authors aimed to produce (1) a map that shows fractional cover estimates for 17 exotic annual grasses and (2) separate maps of cheatgrass, medusahead, and Sandberg bluegrass.

**Methods:** The authors synthesized field-collected data, geophysical factors, and remotely sensed imagery to create datasets to model historical grass cover. They used field data from 17,536 plots, spanning 2016 to 2019, to train and validate spatial models. They used these datasets to create annual fractional cover maps for invasive plant species and one native perennial bunchgrass species.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The authors created maps with percent cover estimates of exotic annual grasses and a native perennial grass across the sagebrush ecosystem at an annual time step from 2016 to 2020. They provided maps of fractional cover for 17 exotic annual grasses and separate maps depicting cheatgrass, medusahead, and Sandberg bluegrass independently.

**Implications:** The authors suggest that these maps of cover estimates can provide managers and researchers with historical datasets of grass abundances for exotic annual grasses and a perennial bunchgrass. They note that these estimates should be interpreted as relative abundances, and they suggest caution when comparing this dataset to products with different spatial resolutions or dates.

**Topics:** nonnative invasive plants; includes new geospatial data

## Dahal, D., Pastick, N.J., Boyte, S.P., Parajuli, S., and Oimoen, M.J., 2021, Early estimates of exotic annual grass (EAG) in the sagebrush biome, USA, July 2021 (ver 2.0, January 2022): U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9FG6X9Q

**Background:** Remote sensing data can be used to provide maps that help land managers identify and respond to invasive and native species cover across large areas.

**Objectives:** The authors aimed to produce (1) a map showing percent cover estimates of a group of 17 exotic annual grasses and (2) separate maps of cheatgrass, medusahead, and Sandberg bluegrass cover estimates.

**Methods:** The authors created datasets using field-collected data, geophysical data, and satellite imagery data collected from January 2021 until June 28, 2021, to predict grass cover. They used field-collected data from 17,536 plots, spanning the period from 2016 to 2019, to train and crossvalidate the spatial models. They used these datasets to create three fractional cover maps for invasive plant species (multispecies, cheatgrass, and medusahead) and one native plant species (Sandberg bluegrass).

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The authors created four maps with percent cover estimates of exotic annual grasses and a native perennial grass across the western United States for early 2021. They provide a map that includes fractional cover for 17 exotic annual grass species combined and separate maps for cheatgrass, medusahead, and Sandberg bluegrass.

**Implications:** The authors suggest that this dataset can provide managers and researchers with early estimates of percent cover for exotic annual grasses and a native perennial grass across western rangelands. They note that these estimates should be interpreted as relative abundances, and they suggest considering potential differences in comparing this dataset with other products that have different spatial resolutions or dates.

**Topics:** nonnative invasive plants; includes new geospatial data

## Dahal, D., Pastick, N.J., Boyte, S.P., Parajuli, S., and Oimoen, M.J., 2021, Early estimates of exotic annual grass (EAG) in the sagebrush biome, USA, May 2021, v1: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9AVGRH8

**Background:** Remotely sensed datasets can provide land managers with data about cover of exotic annual grasses in the western United States.

**Objectives:** The authors aimed to produce a map of predicted exotic annual grass cover.

**Methods:** The researchers used field-collected data from 17,536 field plots, collected from 2016 to 2019, to train models used to predict exotic annual grass cover on May 3, 2021. They incorporated remotely sensed imagery and other environmental factors, such as soil texture and water content, climate variables, and other site conditions into the data models. They excluded areas above 2,250 m in elevation and areas classified other than shrub and grassland by the 2016 National Land Cover Database. They produced five separate maps based on model predictions to create one final map, as an average of the five, that presents percent cover estimates primarily for cheatgrass but includes other brome species and medusahead. They also developed a confidence map calculated using the mean absolute error of the five maps.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The authors produced datasets of estimated cover for invasive annual grasses. The final dataset had an associated confidence map.

**Implications:** The authors suggest that their data provide land managers with early-season predictions of exotic annual grasses in sagebrush ecosystems in the western United States. They note that their estimates should be viewed as relative abundances and to consider spatial resolutions when comparing datasets.

**Topics**: nonnative invasive plants; includes new geospatial data

## Dahal, D., Pastick, N.J., Parajuli, S., and Wylie, B.K., 2020, Early estimates of annual exotic herbaceous fractional cover in the sagebrush ecosystem, USA, May 2020: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9ZZSX5Q

**Background:** Remotely sensed data can provide estimates of the percent cover of annual invasive species throughout large areas. These data can be used to guide management priorities.

**Objectives:** The researchers sought to produce a 30-m-resolution map of early-season, near-real-time exotic annual grass cover estimates across rangelands in 2020 based on (1) field observations, (2) satellite imagery, and (3) biophysical maps.

**Methods:** The researchers used 11,002 field vegetation monitoring observations from 2016 to 2019, two kinds of satellite imagery data, and other relevant biophysical maps to map and crossvalidate exotic herbaceous species cover in sagebrush systems at a 30-m spatial resolution. They mapped percent cover estimates across a geographic area that included rangelands extending from the Great Basin to the Snake River Plain and excluded areas above 2,700 m in elevation. Researchers also used the 2016 National Land Cover Database to exclude geographic areas classified as something other than shrub or grassland.

**Location:** California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The researchers created a high-resolution map with estimates of exotic plant cover, predicted on May 1, 2020, that can be used by scientists and managers as a tool to identify areas dominated by invasive annual grasses, including medusahead and several noxious brome species.

**Implications:** The researchers suggest that remotely sensed data that can be used to provide estimates of percent cover of species across large areas can lead to early detection of invasive species and inform future monitoring and management. The authors present caveats that cover estimates should be interpreted as relative abundances and that differences in the spatial resolution or date range of similar datasets could significantly alter results.

**Topics:** nonnative invasive plants; includes new geospatial data

## Dahal, D., Pastick, N.J., Parajuli, S., and Wylie, B.K., 2020, Near real time estimation of annual exotic herbaceous fractional cover in the sagebrush ecosystem 30m, USA, July 2020: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P91NJ2PD

**Background:** High-resolution remote sensing data can be used to produce maps that help land managers detect and respond to exotic annual grass cover across landscapes.

**Objectives:** The authors aimed to produce a dataset with near-real-time herbaceous annual grass cover estimates at a 30-m resolution.

**Methods:** The researchers used satellite imagery from January 2020 to July 1, 2020, to extract data on environmental conditions, vegetative growth, and biophysical variables. They used field data collected from 11,065 vegetation plots, spanning from 2016 to 2019, to train and crossvalidate spatial models. They excluded areas above 2,700 m in elevation and areas classified other than shrub or grassland by the 2016 National Land Cover Database. They used models to predict exotic fractional grass cover at the 30-m resolution (previously at the 250-m resolution, seen in Boyte and Wylie (2019; https://doi.org/10.5066/P96PVZIF.)

**Location:** California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The authors created a spatially explicit dataset that provides managers with high-resolution, near-real-time estimates of percent cover of exotic annual vegetation. The authors identified the most common invasive species as cheatgrass, followed by other brome species, and medusahead.

**Implications:** The authors suggest that high-resolution maps identifying estimates of exotic annual vegetation cover can be used by researchers and resource managers in the study area. However, they note that cover estimates should be viewed as relative abundances and similar datasets may differ substantially depending on the timeframe and spatial resolution.

**Topics:** nonnative invasive plants; includes new geospatial data

## Dahal, D., Pastick, N.J., Parajuli, S., and Wylie, B.K., 2021, Fractional estimates of exotic annual grass cover in dryland ecosystems of western United States (2016–2019): U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9XT1BV2

**Background:** Invasive annual grasses have invaded large parts of the western United States, altering disturbance regimes and reducing biodiversity. Remotely sensed data can be used to provide landscape-scale estimates of exotic annual grass cover. These data can guide management across large areas, contributing to managers' ability to engage in early detection and rapid response.

**Objectives:** The authors sought to map exotic annual grass cover in dryland ecosystems of the western United States.

**Methods:** The authors used field data, satellite imagery, and information about site characteristics, such as vegetation and geophysical factors, to model percent cover of exotic annual grasses, including many species of invasive brome and medusahead, at a 30-m spatial resolution. Field data included information from 10,906 plots from 2016 to 2019, and the authors sampled satellite data to match the timing of field data collection. They divided the data into five random subsets for initial modeling, and they used median values across the subsets to produce final cover maps. They used one subset of the data to validate the model. They also averaged differences among the subset outputs to create maps depicting the overall model confidence.

**Location:** California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The authors produced confidence maps and maps of the proportional cover of exotic annual grasses, consisting of cheatgrass, other invasive brome species, and medusahead, annually for the years 2016 to 2019.

**Implications:** The authors suggest that maps of exotic annual grasses produced using remotely sensed data can enable early identification of invasions important to inform management. The authors also indicate that application of this geospatial data can be user defined but that users should be aware that the estimates are relative and may differ from other grass cover datasets because of differences in spatial resolution or date of data collection.

**Topics:** nonnative invasive plants; includes new geospatial data

## Davies, K.W., 2010, Revegetation of medusahead-invaded sagebrush steppe: Rangeland Ecology and Management, v. 63, no. 5, p. 564–571.

**DOI:** https://doi.org/10.2111/REM-D-09-00127.1

**Background:** Medusahead negatively affects biodiversity, wildlife habitat, and forage production. Methods to control medusahead include herbicide application and prescribed burns, but these treatments have had varied levels of success. Combining treatment strategies and pairing them with revegetation of desirable species may increase effectiveness.

**Objectives:** The author compared (1) prescribed burns, (2) herbicide (imazapic) application, and (3) combinations of the two to determine the most effective treatment for controlling medusahead and promoting the establishment of seeded desired species.

**Methods:** The author selected six medusahead-invaded sites and established seven plots on each site. They applied one treatment to each plot: (1) fall herbicide application and seed, (2) fall herbicide with spring prescribed burn and seed, (3) fall herbicide with fall prescribed burn and seed, (4) spring prescribed burn and seed, (5) fall prescribed burn and seed, (6) seed only, and (7) no seed or other treatment (control). The author implemented prescribed burns in May and October 2006 and applied

herbicide to plots in October 2006 after burning. They seeded plots with desert wheatgrass and squirreltail in September 2007 and sampled vegetation characteristics in June 2008 and 2009. The author used statistics to determine how treatments affected vegetation.

**Location:** Oregon

**Findings:** The treatments that combined a spring or fall prescribed burn with a subsequent fall preemergent herbicide application followed up a year later with seeding bunchgrasses increased desirable vegetation and decreased exotic annual grass cover and density more than the other treatments. The combined herbicide and burn treatments also had the highest amounts of bare ground and lowest amounts of litter cover. The spring-burn-only treatment had the highest annual forb density, whereas herbicide application generally decreased annual forb density overall. Plant diversity was higher in the spring-burn-only and the combined herbicide and burn treatments.

**Implications:** The author suggests that combined treatments that use herbicides and prescribed burns, followed by seeding, are most effective at reducing medusahead and establishing desired species, stating that just one treatment type is not enough to effectively control medusahead. The author also states the importance of controlling medusahead invasion first, before attempting to seed and establish desired species.

**Topics:** habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Davies, K.W., 2011, Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass: Oecologia, v. 167, p. 481–491.

**DOI:** https://doi.org/10.1007/s00442-011-1992-2

**Background:** Invasive annual grasses are a major threat to ecosystems worldwide, but their effect on biodiversity and plant community dynamics remains unclear. Further understanding of the effects of invasive grasses on native plant communities is important to identify the stages where effects of invasion appear and in focusing restoration efforts where they will be most effective.

**Objectives:** The author sought to (1) investigate how plant diversity related to increased invasive annual grass abundance and (2) examine how native plant communities, bare ground, and biological soil crusts related to invasive annual grass abundance.

**Methods:** From May to June 2007 to 2009, the author sampled vegetation at 65 sites. At each site, they measured canopy cover and density for both shrubs and herbaceous plants, cover of bare ground and biological soil crust, biomass production of herbaceous plants, and several environmental variables: aspect, slope, elevation, topographic position, soil texture, and precipitation. They calculated plant diversity and species richness and used models to investigate how medusahead abundance affected the plant communities.

**Location:** Oregon

**Findings:** The author determined that medusahead density had a negative effect on both total and perennial species richness. There was no effect on perennial and annual forb density, but there was a negative effect on the density of all other plants and functional groups measured, including sagebrush. Except for annual forbs, cover of all plants, bare ground, and biological soil crusts decreased as medusahead density increased. Nonannual grass biomass production also decreased as medusahead density increased.

**Implications:** The author states that their data indicate medusahead invasion is a major source of ecosystem degradation. They state that the loss of important functional groups could be detrimental to animals that rely on them, such as greater sage-grouse. They also indicate that medusahead may more strongly affect plant communities by increasing fire regimes than through direct competition with native species. The author concludes by stating that their results indicate there is a small window for restoration before medusahead density increases to the point where restoration is likely to be unsuccessful and recommends prioritizing restoration efforts based on medusahead abundance.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; soils or geology

## Davies, K.W., 2018, Incorporating seeds in activated carbon pellets limits herbicide effects to seeded bunchgrasses when controlling exotic annuals: Rangeland Ecology and Management, v. 71, no. 3, p. 323–326.

**DOI:** https://doi.org/10.1016/j.rama.2017.12.010

**Background:** Invasive annual grasses are a major threat to sagebrush ecosystems. Herbicides are commonly used to control invasive grasses but require managers to wait to plant perennial grasses until the herbicide becomes inert. This waiting period can allow for reinvasion of invasive grasses such that the perennial grasses do not establish. Using active carbon pellets when seeding could protect seeds from herbicides and allow for seeding simultaneously with herbicide application.

**Objectives:** The author sought to examine how well activated carbon pellets protect perennial species commonly used in revegetation efforts from herbicide (imazapic) application.

**Methods:** The author established plots at two sites. In November 2016, they treated each site with herbicide to remove medusahead and cheatgrass. In March 2017, the author established two treatments, one with activated carbon pellets and one with bare seeds. They planted a mix of bottlebrush squirreltail, bluebunch wheatgrass, Sandberg bluegrass, Siberian wheatgrass, Wyoming big sagebrush, and forage kochia and applied a preemergent herbicide to all plots within 24 hours of seeding. They measured the density and vegetative characteristics of all species in August 2017 and used statistical analyses to compare treatments.

**Location:** Oregon

**Findings:** Invasive annual grasses were 100 percent controlled at all treated plots. All seeded species failed to establish at one of the two study sites. At the second site, only bottlebrush squirreltail and Siberian wheatgrass established in high-enough densities to be compared. Bottlebrush squirreltail only established in the activated carbon pellet treatment. Siberian wheatgrass was taller and had longer leaves, greater density, and greater stem and leaf density in the activated carbon treatment plots than in the bare seed plots.

**Implications:** The author suggests that activated carbon pellets can protect seeds from herbicides. They were not able to assess the effectiveness of activated carbon at protecting shrub seeds because no shrub species established. They suggest that the lack of establishment of seedlings at one site was likely due to meager rainfall but could be due to the pellets not adequately protecting seeds from the herbicide. They state that carbon pellets could provide multiple benefits such as increased nutrients and protection from toxic compounds. They concluded by stating that the addition of activated carbon pellets could improve the likelihood of successful restoration efforts.

**Topics:** behavior or demographics; population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Davies, K.W., Bates, J.D., and Clenet, D., 2020, Improving restoration success through microsite selection—An example with planting sagebrush seedlings after wildfire: Restoration Ecology, v. 28, no. 4, p. 859–868.

**DOI:** https://www.doi.org/10.1111/rec.13139

**Background:** Postfire restoration of sagebrush steppe systems is challenging due to reduced resource availability and competition with exotic species. Identifying areas with a combination of former shrub canopy spaces and interspaces between shrubs could greatly increase the success of restoration projects.

**Objectives:** The authors sought to (1) compare establishment and survival of Wyoming big sagebrush seedlings in former shrub canopy spaces and interspaces between shrubs and (2) determine other dominant vegetation group characteristics.

**Methods:** Researchers identified five study sites and randomly selected 50 former shrub canopy and interspace microsites at each site. They grew Wyoming big sagebrush seedlings from August to November 2014 and then planted one seedling at each microsite. They collected cover and density data in sagebrush seedling plots in June of 2015 to 2018 from six vegetation groups. These groups included sagebrush, Sandberg bluegrass, large bunchgrass, perennial forb, exotic annual grass, and annual forb. The exotic annual grass vegetation group included cheatgrass and medusahead. They performed statistical analyses that compared cover and density measurements for the vegetation groups in each microsite.

**Location:** Oregon

**Findings:** Sagebrush density, cover, and survival were significantly higher in former shrub canopy microsites than interspace microsites. Conversely, Sandberg bluegrass and large perennial bunchgrasses had greater density and cover at interspace microsites. Annual forb cover was greater in former shrub canopy sites. In the first growing season, exotic annual grass density was higher in the interspaces with equivalent cover at both sites, but ultimately density and cover were significantly greater in former shrub canopy sites. Annual forb density, perennial forb density and cover, bare ground, and litter did not differ significantly between treatment types.

**Implications:** The authors suggest that shrub canopy sites can provide favorable conditions for seedling establishment; however, these sites may also benefit exotic annual grasses postfire. The authors recommend enhancing plant establishment by targeting landscapes with former shrub canopy spaces and lower competition to improve restoration outcomes.

**Topics:** survival; site-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants

## Davies, K.W., Bates, J.D., Perryman, B., and Arispe, S., 2021, Fall-winter grazing after fire in annual grass-invaded sagebrush steppe reduced annuals and increased a native bunchgrass: Rangeland Ecology and Management, v. 77, p. 1–8.

**DOI:** https://doi.org/10.1016/j.rama.2021.03.001

**Background:** Exotic annual grass invasion has altered fire regimes across western North American sagebrush communities, causing declines in native sagebrush-dependent plant and animal species. Postfire fall-winter grazing may help restore native perennial vegetation because livestock can selectively graze invasive grasses when native plants are dormant and reduce litter accumulation favorable to invasive grass establishment and growth.

**Objectives:** This study explored if fall-winter livestock grazing after wildfire (1) reduces exotic annual vegetation and (2) increases native perennial vegetation.

**Methods:** The researchers measured vegetation cover and density by species, litter cover, and bare ground at grazed and ungrazed sites at seven locations that had burned in a wildfire. Moderate levels of grazing occurred between November and February each year postfire, and researchers measured vegetation cover and density for the 4 years postfire. Study sites had varied physical and plant community characteristics. The researchers used statistical analysis to compare grazed to ungrazed areas across sites by vegetation type, consisting of Sandberg bluegrass, large perennial bunchgrasses (mostly native species), exotic annual grasses (mostly cheatgrass with some medusahead), perennial forbs (all native species), and annual forbs (mostly exotic species).

**Location:** Oregon

**Findings:** Fall-winter grazing decreased exotic annual grass and forb density and cover relative to ungrazed areas in most years during the study, with variation among years. Sandberg bluegrass density and cover were greater in grazed than ungrazed areas in most years during the study, including the final year. Bunchgrass cover was greater in ungrazed areas throughout the study, but results did not otherwise show differences in bunchgrass and perennial forb density and cover between grazed and ungrazed areas. Grazed areas had more bare ground and less litter cover than ungrazed areas in the final year of measurements.

**Implications:** The authors suggest that fall-winter livestock grazing can reduce annual grass dominance and increase Sandberg bluegrass cover after fire in sagebrush communities. Without definitive results regarding perennial bunchgrasses, the authors recommend that longer-term studies may be needed to determine grazing effects on plant community dynamics and the duration of treatment effects. The authors also suggest that decreased annual grass biomass may reduce wildfire risk.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; fire; fuels and fuels management; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Davies, K.W., and Boyd, C.S., 2018, Longer-term evaluation of revegetation of medusahead-invaded sagebrush steppe: Rangeland Ecology and Management, v. 71, no. 3, p. 292–297.

**DOI:** https://doi.org/10.1016/j.rama.2018.02.001

**Background:** Exotic annual grass invasion reduces ecosystem function, decreases habitat quality for wildlife, and increases wildfire risk. Reestablishing perennial grasses may reduce the amount of soil nutrients available to exotic plants, decreasing invasion risk. However, the long-term effectiveness of seeding invaded areas with perennial grasses has limited study and the effect on soil nutrients is unknown.

**Objectives:** The authors sought to determine 5-year effects of revegetation on (1) perennial and exotic annual vegetation and (2) soil nutrient availability.

**Methods:** The authors established plots at five sites within medusahead-invaded sagebrush rangelands and applied two treatments at each site. For treatment 1, the authors implemented a prescribed burn in September 2010 followed by herbicide (imazapic) application; then, 1 year later in October 2011, they applied a seed mix consisting of a crested wheatgrass hybrid (Hycrest) and Siberian (Vavilov) wheatgrass. They compared the seeded plots to an untreated control (no burning, herbicides, or seeding; treatment 2). In June 2012 to 2016, the authors measured herbaceous cover, density, and soil nutrient concentrations. They used statistics to estimate treatment effects.

**Location:** Oregon

**Findings:** Sandberg bluegrass density was higher in treated areas than controls; however, cover did not differ between treatments. Perennial bunchgrass cover increased in treated areas through time and density was greater in treated areas. Exotic annual grass cover and density were higher within controls; however, density increased in treated areas through time. Perennial forb cover and density varied by year but were not affected by treatment. Exotic annual forb cover and density were higher in controls than treated areas. After 5 years, bare ground was higher in treated areas whereas litter was higher in controls. Nitrogen was higher in treated areas, whereas phosphorus and potassium were similar between treatments.

**Implications:** The authors suggest that seeding after controlling medusahead with burning and herbicides can establish desired perennial species and reduce exotic annuals. However, because exotic annuals increased in treated areas during the final 2 years, they state that followup treatments may be necessary. The authors note that establishing perennials in great-enough abundance to suppress exotic annuals is key. They suggest that available nitrogen increased in treated areas because reestablished perennials affected nutrient cycling.

**Topics:** population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: herbicides; weed management subtopic: cultural control; soils or geology

## Davies, K.W., Boyd, C.S., Johnson, D.D., Nafus, A.M., and Madsen, M.D., 2015, Success of seeding native compared with introduced perennial vegetation for revegetating medusahead-invaded sagebrush rangeland: Rangeland Ecology and Management, v. 68, no. 3, p. 224–230.

**DOI:** https://www.doi.org/10.1016/j.rama.2015.03.004

**Background:** Medusahead invasions are negatively affecting the sagebrush steppe, reducing native plant diversity and abundance. To restore rangelands, medusahead can first be reduced by prescribed burns and preemergent herbicides, then seeded with desirable species 1 year after application. However, it is unclear how independently seeded native and introduced perennial bunchgrasses and shrubs will respond after treating medusahead.

**Objectives:** The authors sought to compare how seeding mixes with (1) native perennial grasses and a shrub species and (2) introduced perennial grasses and a forb species affected plant community composition after controlling medusahead.

**Methods:** In fall 2010, the researchers treated medusahead by prescribed burning followed by herbicide (imazapic) application at five sites. One year after spraying, they applied two seeding treatments (native perennial and introduced perennial vegetation). They measured vegetation cover and density for three growing seasons after seeding for five herbaceous vegetation groups (perennial bunchgrasses, Sandberg bluegrass, perennial forbs, exotic annual grasses, and annual forbs). They also measured shrub cover and density, biological soil crust, bare ground, and litter cover.

**Location:** Oregon

**Findings:** Perennial bunchgrass cover and density were greater in the introduced than the native seeded treatment. Exotic annual grass cover and density (primarily medusahead with some cheatgrass) were greater in the native seeded treatment and increased throughout the study period. Sandberg bluegrass, perennial forb, and annual forb cover did not differ across treatments or years. Sandberg bluegrass density increased in the introduced seed plots. Shrub cover and density did not differ between treatments or years. Soil crust, bare ground, and litter did not differ between treatments; however, bare ground decreased, and litter increased through time.

**Implications:** The authors suggest that seeding introduced perennial bunchgrasses, such as crested wheatgrass and Siberian wheatgrass, into medusahead-invaded communities after fire and herbicide application will increase the likelihood of vegetation establishment. Although native perennial bunchgrass establishment was low, the authors suggest that repeated seeding and invasive grass control efforts or using locally sourced seeds could improve success rates.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control

## Davies, K.W., and Dean, A.E., 2019, Prescribed summer fire and seeding applied to restore juniper-encroached and exotic annual grass-invaded sagebrush steppe: Rangeland Ecology and Management, v. 72, no. 4, p. 635–639.

**DOI:** https://doi.org/10.1016/j.rama.2019.03.006

**Background:** Expansion of western juniper has significantly altered many ecosystems, such as sagebrush communities. Prescribed burns are used to reduce juniper encroachment, but little information exists on the effectiveness of this method in areas invaded by exotic annual grasses. There is also little information regarding the effectiveness of seeding native species compared to nonnative species in hot, dry sagebrush communities after fire treatment.

**Objectives:** The authors sought to (1) examine the effects of prescribed burns to control invasive grass establishment in juniper-encroached areas and (2) compare success of different seed mixes postfire.

**Methods:** In July 2011, managers implemented controlled burns at a sagebrush steppe site invaded by annual grasses and juniper. In December 2011, the authors established 28 plots in 4 treatments: unburned, burned, burned and seeded with natives, and burned and seeded with nonnatives. They estimated cover of each species within the plots in June 2011, 2013, 2015, and 2017. They then used statistical analyses to examine the effects of treatment and year on the amount of invasive grasses present.

**Location:** Oregon

**Findings:** The authors determined that medusahead cover was initially lower in burned treatments but by 2017 was greater in burned than unburned treatments. Cheatgrass increased throughout time in all treatments. Both native and nonnative forbs were more common in burned treatments whereas soil crust cover was greater in unburned treatments. Nonnative bulbous bluegrass was more common in burned areas, large bunchgrasses were more common in unburned areas, and native Sandberg bluegrass was not affected by any treatment. Neither of the seed mixes increased bunchgrass cover during the study duration.

**Implications:** The authors state that the increase in invasive grasses in the burned treatments was likely due to reduced competition from native bunchgrasses and biological soil crusts. They state that although there was an increase in native forbs postfire, any positive effects of this were likely outweighed by the increase in exotic grasses. Finally, they suggest that applying preemergent herbicides after juniper burning, prior to seeding, may help avoid exotic grass dominance in hot, dry, previously invaded sagebrush communities.

**Topics:** population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; conifer expansion; weed management

## Davies, K.W., and Hamerlynck, E., 2019, Ventenata and other coexisting exotic annual grass control and plant community response to increasing imazapic application rates: Rangeland Ecology and Management, v. 72, no. 4, p. 700–705.

**DOI:** https://doi.org/10.1016/j.rama.2019.02.010

The summary for this article was previously published in Poor and others (2021; p. 15–16; https://doi.org/10.3133/ofr20211031).

## Davies, K.W., and Johnson, D.D., 2017, Established perennial vegetation provides high resistance to reinvasion by exotic annual grasses: Rangeland Ecology and Management, v. 70, no. 6, p. 748–754.

**DOI:** https://doi.org/10.1016/j.rama.2017.06.001

**Background:** Invasion by exotic annual grasses is a major threat to sagebrush ecosystems. Establishment of perennial vegetation is critical to limit reinvasion after treatment. However, the effectiveness of different nonnative and native species at limiting reinvasion by annual grasses is mostly unknown.

**Objectives:** The authors sought to investigate (1) if frequently planted species or species mixes were effective at reducing invasive grasses, (2) if there was any difference between seed mixes containing natives, nonnatives, or a mix of both, and (3) which nonnative species most effectively reduced invasive grasses and if single or multiple nonnative species were more effective.

**Methods:** The authors established plots in an area that had burned 15 years prior to the experiment. In May and October 2010, herbicide (glyphosate) was applied to control invasive annual grasses. In November 2010 and March 2011, the authors planted seedlings in six treatments: unplanted controls, desert wheatgrass (also referred to as crested wheatgrass), desert wheatgrass with forage kochia, forage kochia, bluebunch wheatgrass with Wyoming big sagebrush, and desert wheatgrass with Wyoming big sagebrush. In fall 2012, they seeded medusahead and cheatgrass on all treatments. In June 2015 and 2016, they measured foliar cover and density for all species as well as litter and bare ground. They then used statistical analyses to compare treatments.

**Location:** Oregon

**Findings:** All treatments resulted in lower annual grass cover compared to unplanted controls. Desert wheatgrass, both on its own and mixed, was the most effective species at limiting annual grass invasion. Forage kochia in particular was identified as less effective alone compared to when mixed with desert wheatgrass. Planted native species were also effective at reducing annual grasses once established.

**Implications:** The authors state that their results indicate that establishing perennial grasses is critical to limiting reinvasion by exotic annual grasses and should be a priority of any management efforts. They also state that lower establishment success of native plants is more limiting to their use against exotic invasives rather than their competitive abilities. Finally, they state that shrubs, such as forage kochia or sagebrush, should be used in conjunction with bunchgrasses to maximize resistance to reinvasion.

**Topics:** population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control

## Davies, K.W., Johnson, D.D., and Nafus, A.M., 2014, Restoration of exotic annual grass-invaded rangelands—Importance of seed mix composition: Invasive Plant Science and Management, v. 7, no. 2, p. 247–256.

**DOI:** https://doi.org/10.1614/IPSM-D-12-00093.1

**Background:** Medusahead is a rapidly expanding invasive grass causing significant damage to North American rangelands. After controlling exotic grass invasion, competitive vegetation must be planted to combat reinvasion. However, it remains unclear if single-species seed mixes are better than multiple-species mixes at limiting medusahead reinvasion.

**Objectives:** The authors sought to compare the effects of sowing different seed mixes on plots with medusahead invasion and perennial vegetation that had burned and been sprayed with herbicide (imazapic).

**Methods:** The authors established plots at two sites that had been burned and treated with herbicide in October 2007 to remove all vegetation. One year later at each site, they established eight seeding treatments: (1) crested wheatgrass, (2) bottlebrush squirreltail, (3) Sandberg bluegrass, (4) a mix of crested wheatgrass and bottlebrush squirreltail, (5) a forb mix, (6) a mix of crested wheatgrass, bottlebrush squirreltail, and forbs, (7) a mix of all tested species, and (8) a nonplanted control. They measured vegetation cover and density at each plot in June 2009, 2010, and 2011 and compared vegetation characteristics across treatments using statistical analyses.

**Location:** Oregon

**Findings:** The authors determined that seed mixes with more species did not change vegetation response posttreatment. During the study, the amount of perennial grass cover in the crested wheatgrass/bottlebrush squirreltail plots increased whereas the amount of cover did not change in the other treatments. There was no effect of any of the treatments on invasive grass density or cover in any year. In every year, control plots had lower density of perennial grasses and overall perennial vegetation than other treatments.

**Implications:** The authors state that the most productive species or plant group is likely most critical to prohibiting invasion but that the importance of additional species may vary by ecosystem. They also state their findings are limited by the short duration of the study and are only applicable to ecosystems dominated by a single species, such as Wyoming big sagebrush. Finally, the authors state that managers may still want to include multiple species in seed mixes to promote nondominant species that may be important for wildlife.

**Topics:** survival; behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; fire; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Davies, K.W., Leger, E.A., Boyd, C.S., and Hallett, L.M., 2021, Living with exotic annual grasses in the sagebrush ecosystem: Journal of Environmental Management, v. 288, article 112417, 11 p.

**DOI:** https://doi.org/10.1016/j.jenvman.2021.112417

**Background:** Invasive annual grasses have invaded vast areas of western North America and converted perennial-dominated plant communities into annual-dominated plant communities. This shift has reduced wildlife habitat and food sources for wildlife and livestock. The invasion of annuals has altered fire regimes and imposed high economic costs that are anticipated to be an increasingly larger issue into the future.

**Objectives:** The authors sought to create and describe a framework for managing existing invasive grasslands and preventing further spread.

**Methods:** The authors synthesized existing literature findings about invasive annual grass communities and their management. They also reviewed additional considerations from long-term invasion management of California's annual grasslands.

**Location:** North America

**Findings:** The authors present a five-part framework for managing sagebrush habitats that have been invaded by annual grasses such as medusahead and cheatgrass. First, they suggest prioritizing prevention of invasive grass spread by focusing on maintaining perennial vegetation, carefully managing grazing, and ensuring that plant communities can tolerate periodic fire. Second, they suggest ending the annual grass-fire cycle through fire suppression, fuel breaks, and strategic grazing to allow species like sagebrush to reestablish. Third, they suggest using introduced perennials, such as crested wheatgrass, when they may be more competitive with annual grasses than native species. Fourth, they suggest thoughtful seeding of native species, including considering if seeding is necessary, using locally adapted and competitive seed, using seed enhancement technologies, and planning for additional treatments. Finally, the authors suggest accepting invasive annual grasslands as a new ecotype where restoration of perennial community is highly unlikely and prohibitively expensive and focusing management on land uses and values rather than historical communities.

**Implications:** The authors suggest that it may not be possible to restore all areas and that managers need to accept some areas as invasive annual grasslands. Management priorities in these areas may shift toward more grazing management, and restoration efforts should be focused on areas with higher probability of success.

**Topics:** dispersal, spread, vectors, and pathways; habitat restoration or reclamation; fire; fuels and fuels management; fuel breaks; nonnative invasive plants; grazing/herbivory; weather and climate patterns; climate change; drought; weed management; weed management subtopic: cultural control; wild horses and burros; soils or geology; human dimensions or economics

## Davies, K.W., Madsen, M.D., and Hulet, A., 2017, Using activated carbon to limit herbicide effects to seeded bunchgrass when revegetating annual grass-invaded rangelands: Rangeland Ecology and Management, v. 70, no. 5, p. 604–608.

**DOI:** https://doi.org/10.1016/j.rama.2017.04.004

**Background:** Invasive annual grasses, such as medusahead and cheatgrass, are a major threat to rangeland health. Preemergent herbicides and seeding perennial grasses are commonly used to limit the spread of exotic annuals, though there is often a delay between spraying and seeding to avoid mortality of seeded grasses, which can provide a window for invasive species to return. Activated carbon herbicide protection pods can protect seeds from herbicides and may allow for simultaneous application of herbicide and seed, possibly improving restoration success.

**Objectives:** The authors sought to determine if activated carbon could be used to protect desert wheatgrass (also referred to as crested wheatgrass), a frequently seeded perennial bunchgrass, from herbicide treatment to control medusahead and cheatgrass.

**Methods:** The authors applied three treatments (activated carbon herbicide protection pods containing desert wheatgrass seeds and application of the herbicide imazapic, unprotected desert wheatgrass seeds with imazapic application, and unplanted, untreated control) to 24 plots at two sites, one dominated by cheatgrass and one by medusahead. The noncontrol treatments were seeded and treated with herbicide in September 2015. Leaf density and length, plant height, and leaves per seedling were measured in March 2016. In March and June of 2016, the authors measured the density of herbaceous vegetation, perennial vegetation, and annuals. They then used statistical analyses to compare the effects of treatments on seedlings.

**Location:** Oregon

**Findings:** Desert wheatgrass density differed by site and date and was greatest in activated carbon plots and lowest in control plots. Desert wheatgrass seedling density and leaf density were higher on activated carbon plots than unprotected plots. Density of invasive annual grasses and annual forbs was highest on control plots but did not vary between imazapic treatments. Density of other large perennial bunchgrasses, Sandberg bluegrass, and perennial forbs did not vary between any treatments.

**Implications:** The authors suggest that using activated carbon herbicide protection pods can allow for simultaneous herbicide use and seeding. They note that this method would enable single-entry treatment of sites, thus reducing costs and allaying challenges with controlling invasive grasses. They also suggest that this single-entry approach may be applicable across different sites, climates, and vegetation communities.

**Topics:** behavior or demographics; population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Davies, K.W., Madsen, M.D., Nafus, A.M., Boyd, C.S., and Johnson, D.D., 2014, Can imazapic and seeding be applied simultaneously to rehabilitate medusahead-invaded rangeland? Single vs. multiple entry: Rangeland Ecology and Management, v. 67, no. 6, p. 650–656.

**DOI:** https://www.doi.org/10.2111/REM-D-14-00019.1

**Background** Rangeland managers have been working to find cost-effective solutions for treating medusahead, including a single-entry strategy where managers seed desired vegetation while simultaneously applying preemergent herbicide. More research is needed to determine if the single-entry strategy is more cost effective and efficient than other methods.

**Objectives:** The authors sought to compare how (1) single-entry and (2) multiple-entry herbicide and seeding treatments for medusahead after prescribed fire affect the cover and density of desired vegetation.

**Methods:** The authors divided five medusahead-dominated study sites into one control and two treatment plots. They burned treatment plots in the fall and applied imazapic herbicide. They seeded introduced bunchgrass (desert wheatgrass, also referred to as crested wheatgrass, and Siberian wheatgrass) in October 2011, concurrent with herbicide application in one treatment plot (single-entry) and 1 year after herbicide application in the remaining treatment plot (multiple-entry). They measured cover of herbaceous canopy, biological soil crusts, litter, and bare ground and measured soil nutrient concentrations in 60 quadrats per treatment plot in June of 2012 and 2013. They divided vegetation into six groups for analysis and estimated the effectiveness of treatments.

**Location:** Oregon

**Findings:** The authors determined that introduced bunchgrass and total perennial grass cover and density were highest in the multiple-entry plots and very low in the single-entry plots, which were not significantly different from the control. The difference in bunchgrass cover and total perennial grass cover between treatments increased in the second year after seeding. Control

plots had the highest annual grass cover, annual forb cover, litter cover, and annual forb density. Herbicide treatments had increased bare ground, reduced litter, and reduced annual forb cover in the second year. Additionally, herbicide plots had higher soil nitrogen concentrations than the control plots.

**Implications:** The authors recommend multiple-entry approaches over single-entry approaches to minimize herbicide damage to seeded species. They suggest that any cost savings from single-entry methods may be overridden by the increased possibility of reinvasion whereas the multiple-entry approach used in this study appeared to result in successful establishment of bunchgrasses and reduced potential for medusahead reinvasion.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; soils or geology; human dimensions or economics

## Davies, K.W., Nafus, A.M., and Johnson, D.D., 2013, Are early summer wildfires an opportunity to revegetate exotic annual grass-invaded plant communities?: Rangeland Ecology and Management, v. 66, no. 2, p. 234–240.

**DOI:** https://www.doi.org/10.2111/REM-D-12-00034.1

**Background:** Managing invasive annual grasses is costly, and the effectiveness of management actions can vary. Managed fire is often used to control invasive species, but it is unknown if naturally occurring wildfires followed by vegetation treatments is an effective management strategy.

**Objectives:** The authors sought to investigate if opportunistically seeding rangelands after naturally occurring wildfires is a viable strategy to manage areas invaded by medusahead.

**Methods:** For this study, the authors took advantage of wildfires that occurred in July 2007 at their medusahead-invaded study site. Prior to the wildfire, the authors had collected baseline data at the field site in spring 2007 for a different project. After the fire, they selected six burn sites and paired them with an unburned site that had similar characteristics before the fire. The authors then drill seeded the burned sites with a mix of perennial species and measured vegetation characteristics including canopy cover and density along transects from May to June 2008 to 2010. They divided vegetation into six functional groups (native perennial grasses, introduced perennial grasses, Sandberg bluegrass, perennial forbs, annual forbs, and exotic annual grasses) and ran statistical analyses to track their establishment after the burn.

**Location:** Oregon

**Findings:** The authors determined seeding after an early summer fire decreased exotic annual grass cover and increased introduced, but not native, bunchgrass cover compared to control areas that were unburned and not seeded. Exotic annual grass density was lower in the burn and seeded treatments than controls, but density was still high. Annual forb cover was greater in treated areas than controls, and perennial forbs were unaffected by treatments.

**Implications:** Although the burned and seeded sites showed an increase in perennial grasses, the authors caution that the improvements may not be long term. They recommend additional studies to determine the long-term outcome of burned and seeded sites in areas of medusahead invasion and suggest including preemergent herbicide treatments in future research. The authors note that they cannot conclusively state that both the burn and drill seeding treatments are needed to reduce medusahead dominance because they did not study the two treatments separately.

**Topics:** survival; behavior or demographics; population estimates or targets; dispersal; spread, vectors, and pathways; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control

## Davies, K.W., Nafus, A.M., and Madsen, M.D., 2013, Medusahead invasion along unimproved roads, animal trails, and random transects: Western North American Naturalist, v. 73, no. 1, p. 54–59.

**DOI:** https://www.doi.org/10.3398/064.073.0105

**Background:** Medusahead invasion is a significant threat to sagebrush ecosystems in the western United States. Adaptations to medusahead seeds allow them to easily adhere to animals and vehicles, and thus, medusahead invasion may be more common along roads. However, more research is needed on the prevalence of medusahead invasions along unimproved roads and trails.

**Objectives:** The authors sought to (1) identify areas where medusahead invasion was more common and (2) compare features of medusahead invasion between animal trails, unimproved roads, and random locations.

**Methods:** The authors sampled six sites in total, performing one sampling event per site in either July 2010 or 2011. They sampled three locations at each site; a random location, a randomly selected unimproved road, and a randomly selected animal trail. At each location, the authors placed a 500-m transect, recorded the presence/absence of medusahead, and calculated medusahead patch density and average patch size. They used a 10-centimeter (cm) by 100-cm plot at every meter along the transect and line intercepts to measure medusahead frequency and cover. They used statistics to analyze differences in medusahead invasion across the three location types.

**Location:** Oregon

**Findings:** Medusahead frequency, cover, and average patch size were highest along roads when compared to both animal trails and random locations. Medusahead frequency and average patch size were also higher along animal trails when compared to random locations. Medusahead patch density was greater along roads when compared to random locations, but there was no variation in patch density between animal trails and roads or animal trails and random locations.

**Implications:** The authors identified medusahead invasion was higher along unimproved roads and animal trails than along transects in random locations. Because medusahead invasion was highest along roads, the authors suggest that vehicles may be a primary factor in spreading medusahead. They also note that managing medusahead invasion in areas where animals gather may prevent animal trails from becoming a larger invasion factor. The authors state that environmental differences between the three location types may have also played a role in where medusahead invasion was highest but conclude by saying road and trail pathways should be a priority for medusahead management.

**Topics:** population estimates or targets; broad-scale habitat characteristics; dispersal, spread, vectors, and pathways; habitat selection; recreation; nonnative invasive plants; infrastructure; weed management

## Davies, K.W., Nafus, A.M., and Sheley, R.L., 2010, Non-native competitive perennial grass impedes the spread of an invasive annual grass: Biological Invasions, v. 12, no. 9, p. 3187–3194.

**DOI:** https://www.doi.org/10.1007/s10530-010-9710-2

**Background:** Efforts to control invasive annual grasses and restore native grasses are costly and often ineffective. There is a need to evaluate novel methods that could increase grassland resistance to further invasion. One potential method involves establishing an area of competitive vegetation ahead of the invasion front as a barrier to further spread.

**Objectives:** The authors sought to evaluate the effectiveness of a nonnative perennial bunchgrass to (1) establish a barrier to impede further medusahead invasion, and (2) outcompete medusahead by reducing available soil nutrients.

**Methods:** In February 2006, the authors seeded a nonnative perennial bunchgrass, desert wheatgrass, near an area heavily invaded by medusahead. They seeded six experimental plots and left another six plots as undisturbed control plots. In June 2008, they measured species cover, species density, and nutrient availability within the plots. They also measured medusahead cover and density in the plant community without a vegetative protection barrier. They statistically analyzed plant cover and density and soil nutrient availability between treatments.

**Location:** Oregon

**Findings:** In plots seeded with desert wheatgrass, medusahead and total annual grass cover and density were lower than in undisturbed plots. Cover and density of other plants were similar between seeded and undisturbed plots. Potassium and ammonium decreased in seeded plots compared to undisturbed plots, whereas nitrate and phosphorus did not vary. In the plant community with a protective vegetation barrier of desert wheatgrass, medusahead had 42 times less cover and was 47 times less dense than in unprotected plots.

**Implications:** The authors suggest that implementing competitive vegetation barriers may be a tool to help prevent further spread of invasive grasses in combination with other management approaches. The authors caution that introducing another nonnative species, such as desert wheatgrass, could also unintentionally outcompete native grasses. Although the long-term effects are unknown, the authors indicate that it may be a worthwhile risk to take, given the substantial negative effects of medusahead.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; effect distances or spatial scale; nonnative invasive plants; weed management; weed management subtopic: cultural control; soils or geology

## Davies, K.W., and Sheley, R.L., 2011, Promoting native vegetation and diversity in exotic annual grass infestations: Restoration Ecology, v. 19, no. 2, p. 159–165.

**DOI:** https://www.doi.org/10.1111/j.1526-100X.2009.00548.x

**Background:** Invasive grass infestations are known to contribute to increased fire cycles that perpetuate exotic grass dominance and spread. Invasive grass treatments have focused mainly on reducing infestations; however, it is unclear which efforts also promote intact native vegetation resilience.

**Objectives:** The researchers sought to determine if (1) prescribed burning, (2) herbicide application, and (3) the combination of both burning and applying herbicides can increase native vegetation in medusahead-infested areas.

**Methods:** The researchers established six sites with varying soil and vegetation characteristics, each consisting of six plots separated by a 1-m buffer. Treatments included herbicide (imazapic) only, spring prescribed burn only, fall prescribed burn only, spring prescribed burn and herbicide, fall prescribed burn and herbicide, and no treatment. The researchers implemented spring burns in May 2006 and fall burns in October 2006. The researchers applied herbicides after the fall burning. In June 2007 and 2008, they measured herbaceous cover and density, litter, and bare ground and performed statistical analyses to determine the effects of treatments on vegetation characteristics.

**Location:** Oregon

**Findings:** Perennial grass density and cover increased in both of the combined treatments (fall or spring burns with herbicides). Sandberg bluegrass density did not vary with treatment, but cover increased in the fall burn treatment. The researchers determined that medusahead density was highest in plots without herbicide treatments. Medusahead density was lowest in the herbicide-only treatment and the spring and fall burn treatments with herbicides, and cover was lowest in the spring and fall burns with herbicides but increased in those treatments the second year. Annual forb density and cover were greatest in the

spring burn treatment. The spring burn and herbicide treatment resulted in the greatest diversity compared to other treatments but did not differ from the fall burn with herbicide treatment. Both combined burn and herbicide treatments had more bare ground and less litter compared to no-treatment plots.

**Implications:** The authors suggest that prescribed burning and herbicide application reduce medusahead and increase native perennial plants; however, applying herbicides may negatively affect annual forbs. They recommend that managers prioritize restoration efforts in areas invaded by annual grasses but with intact native vegetation rather than invasive-dominant areas.

**Topics:** habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Davy, J., and Dykier, K., 2017, Longevity of a controlled burn's impacts on species composition and biomass in northern California annual rangeland during drought: Rangeland Ecology and Management, v. 70, no. 6, p. 755–758.

**DOI:** https://www.doi.org/10.1016/j.rama.2017.06.009

**Background:** Managers may use early-summer controlled burns to control medusahead and other weedy species, but the effectiveness of these burns varies based on elevation and other factors. The effectiveness of controlled burns on low-elevation rangelands has not yet been studied, and additional research is needed to study the longevity of vegetation shifts postfire.

**Objectives:** The authors sought to determine the duration of effects to species composition and forage production postburn on low-elevation annual rangelands.

**Methods:** Before the burn in June 2011, the authors collected baseline data by establishing three permanent transects within the area to be burned and three permanent transects that would not be burned. Postfire, they returned to these six permanent transects annually in early June to collect plant cover and biomass measurements from 20 points evenly spaced along each transect. The authors ended data collection 3 years postburn when they were no longer observing differences between the control and study sites. They performed statistical analyses to determine which factors affected the management of weedy species through time.

**Location:** California

**Findings:** The authors determined that the burn significantly reduced medusahead cover and increased filaree and rose clover cover in the first year postburn. They also determined that native wildflower species cover and biomass were not significantly affected by the burn. The authors identified that within 3 years, medusahead cover was higher in the burned plots and filaree cover was similar between control and burn plots. They also identified that forage production in the burned plots was lower the 2 years after the burn.

**Implications:** The authors reported that the area was affected by drought, which could have affected their results because medusahead cover decreased across all sites and filaree is known to increase during drought. They stated that burning can provide good short-term management of medusahead, but those effects may quickly decrease without further treatments. The authors suggest that herbicide application, grazing treatments, and seeding of competitive species after a burn may slow the reestablishment of weedy species like medusahead.

**Topics:** survival; population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; grazing/herbivory; weather and climate patterns; drought; weed management; weed management subtopic: cultural control

## Davy, J.S., and Rinella, M.J., 2019, Targeted grazing for native forbs in annual grasslands: Rangeland Ecology and Management, v. 72, no. 3, p. 501–504.

**DOI:** https://www.doi.org/10.1016/j.rama.2019.01.003

**Background:** There are numerous ways to manage grasslands to increase beneficial forbs and suppress those that are unwanted, though many options are expensive and only give short-term success. Targeted grazing is one strategy that can increase certain desirable native forbs. On medusahead-invaded grasslands, even small numbers of forbs can support biodiversity and ecosystem services such as pollination.

**Objectives:** The authors sought to test how different targeted grazing strategies on an annual grassland affects the densities of two beneficial native forbs, Fitch's tarweed and vinegarweed.

**Methods:** The authors established four cattle grazing treatments: (1) grazing early in the growing season, (2) grazing late in the growing season, (3) grazing early and late, and (4) no grazing. They replicated each treatment three times and randomly assigned treatments to plots at the study site during the spring season annually from 2011 to 2013. Each year, the authors started early grazing treatments in early April and started late grazing treatments in late May. After grazing treatments were completed at the end of each growing season, the authors measured the density of tarweed and vinegarweed and estimated the cover of nonnative annual grasses (medusahead and soft brome), desirable nonnative annual forbs (filaree), and bare ground. The authors then performed statistical analysis to compare treatments.

**Location:** California

**Findings:** Tarweed and vinegarweed were only detected on plots during 2 years of the study. Tarweed and vinegarweed densities did not differ between early grazing and no grazing treatments in either year. Tarweed density was greater with late grazing and with repeated grazing in both years. In 2011, vinegarweed density was greater with repeated grazing compared to no grazing. Medusahead cover was reduced in all grazed treatments, though repeated grazing was most effective. Cover of the desirable forage grass soft brome was reduced most with early and repeated grazing treatments, whereas filaree sometimes benefitted from early and late grazing.

**Implications:** The authors suggest that grazing effects on forbs can be either positive or negative depending on when cows graze and that either effect may be beneficial depending on management goals.

**Topics:** population estimates or targets; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Davy, J.S., Roche, L.M., Robertson, A.V., Nay, D.E., and Tate, K.W., 2015, Introducing cattle grazing to a noxious weed-dominated rangeland shifts plant communities: California Agriculture, v. 69, no. 4, p. 230–236.

**DOI**: https://doi.org/10.3733/ca.v069n04p230

**Background:** California rangelands are dominated by nonnative annual species that are believed to have replaced native plant communities. Grazing livestock is a commonly used management tool to control invasive species, such as medusahead and yellow starthistle, and potentially enhance native plant diversity. However, less is understood about how grazing cattle affects annual invasive species on larger scales, such as the scale of a pasture.

**Objectives:** The authors sought to assess the effects of a prescribed grazing regime established by ranch personnel on (1) medusahead and (2) yellow starthistle populations.

**Methods:** In 2006, ranch managers reintroduced cattle grazing across 11 pastures that ranged between 80 to 600 acres. Pastures were generally grazed from January through May, with calves present through March. During the study, an average of 392 cows grazed for two grazing events of several days to 2 weeks in each pasture. The two grazing events occurred from November to February to reduce weed thatch, and March to June to target late-flowering plants. Between 2006 and 2011—during three observation periods in June 2006, 2009, and 2011—the researchers compared grazed and ungrazed plant cover and herbaceous species composition in 11 paired plots where one plot was grazed and the other was ungrazed. The researchers used statistical analyses to determine if community plant composition changed through time within the grazed and ungrazed pastures.

**Location:** California

**Findings:** Yellow starthistle cover did not differ across grazed or ungrazed treatments through time. Medusahead cover decreased with grazing midway through the study, but at the end of the study, medusahead cover was at the same level as the ungrazed treatment. During the years of lower medusahead cover during the study, medusahead was replaced with forage species in grazed treatments and with other nonnative, thatch-tolerating grasses in ungrazed treatments. Medusahead cover was only reduced (and replaced by other species) across treatments in years that did not have substantial late-spring rainfall.

**Implications:** The authors recommend adaptively timing the period of grazing to match rainfall and the growth stages of medusahead, emphasizing grazing in years with little late-spring rainfall to control medusahead. They also highlight the importance in recognizing differences in scale when applying small-scale research to larger landscapes.

**Topics:** site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## DiTomaso, J.M., and Smith, B.S., 2012, Linking ecological principles to tools and strategies in an EBIPM program: Rangelands, v. 34, no. 6, p. 30–34.

**DOI:** https://doi.org/10.2111/RANGELANDS-D-12-00060.1

**Background:** Herbicides and grazing are common strategies used to control invasive grasses in wildland and rangeland systems, partially because they can selectively target species. When considering a particular tool for managing invasive species, many factors should be considered, such as the seasonality of target and desired species and land use of the area.

**Objectives:** The authors' aim was to outline principles and strategies of the Ecologically Based Invasive Plant Management, or EBIPM, program that uses grazing and herbicides to control invasive plants.

**Methods:** In this review article, the authors discuss the Ecologically Based Invasive Plant Management program approach to invasive plant management of a few species such as medusahead and cheatgrass and some of the existing literature related to this management approach.

**Location:** Not specified

**Findings:** The authors report that existing literature provides evidence that certain grazing techniques can help areas resist invasion by nonnative plants. The authors provide specific guidance for using grazing and herbicides to treat invasive grasses based on findings from other studies, consisting of how to select, use, and apply herbicides. Specifically, they state that the herbicide imazapic is effective in controlling medusahead, cheatgrass, and other annual grasses. Additionally, they report that medusahead was controlled using low rates of imazapic when applied at the seedling stage and high rates of a different herbicide, aminopyralid, when applied before the plant emerged.

**Implications:** In using any management approach to control invasive plants, the authors state that the most successful efforts will be those linked to ecological principles. The authors suggest that timing of any management approach is important so that plants are treated during their most vulnerable development stage and before they can produce viable seed. Additionally, in using grazing to control invasive plants, the authors state that it is also important to maintain desirable vegetation as a competitor, that grazing should be of high intensity and short duration, and that annual grasses often return quickly once animals are removed.

**Topics:** nonnative invasive plants; habitat restoration or reclamation; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Dittel, J.W., Sanchez, D., Ellsworth, L.M., Morozumi, C.N., and Mata-Gonzalez, R., 2018, Vegetation response to juniper reduction and grazing exclusion in sagebrush-steppe habitat in eastern Oregon: Rangeland Ecology and Management, v. 71, no. 2, p. 213–219.

**DOI:** https://www.doi.org/10.1016/j.rama.2017.11.004

**Background:** Sagebrush ecosystems are negatively affected by overgrazing, invasive annual grasses, and juniper expansion. Juniper reduction, through mechanically removing established trees, is a management strategy used to support short-term recovery of desirable vegetation in sagebrush communities. However, less is known about the long-term, interacting effects of western juniper reduction and cattle grazing exclusion.

**Objectives:** The authors sought to (1) determine the plant community responses to livestock grazing exclusion and juniper removal, (2) assess fuel loads, and (3) quantify juniper recruitment.

**Methods:** In 2012, researchers established six 1-ha plots and divided each plot into four subplots. They installed fencing to exclude livestock on two subplots and mechanically cut juniper, leaving downed woody material on site, on two subplots for a total of four treatments (grazed cut, grazed uncut, ungrazed cut, ungrazed uncut). All grazing treatments were considered low intensity. For three summers (2014 to 2016), they collected data on herbaceous (nonnative and native species) and woody plant cover, shrub density, amount of downed woody material, and biomass. They measured litter and juniper seedling growth under downed trees.

**Location:** Oregon

**Findings:** Shrub cover, shrub abundance, percent cover, and biomass of any plant group did not differ between grazing and grazing-exclusion treatments across years. Exotic grass (cheatgrass, medusahead, and ventenata) cover and biomass initially increased after juniper removal but decreased by the end of the study and did not completely dominate cut plots. Removal also increased preferred forb plant cover and biomass in the second year, with no difference between preferred grasses across years. Preferred forbs and grasses included native species and nonnative forage species. Shrub cover was greater in cut plots the second year, but density did not differ. Grazing did not affect downed woody material or juniper seedlings. Juniper cutting increased downed woody biomass, but there was no difference in herbaceous litter biomass. Juniper seedling growth was highest under downed junipers.

**Implications:** The authors suggest that cutting juniper can increase short-term cover of herbaceous plants and shrubs but may be limited to early successional species. They also suggest that the grazing regime for their study site does not reduce herbaceous plants or shrubs. Because juniper recruitment was prolific under felled junipers, the authors suggest that managers focus on treating areas with downed junipers or burn-felled juniper piles to reduce new juniper growth.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; fuels and fuels management; nonnative invasive plants; conifer expansion; grazing/herbivory

## Dodson, E.K., and Root, H.T., 2015, Native and exotic plant cover vary inversely along a climate gradient 11 years following stand-replacing wildfire in a dry coniferous forest, Oregon, USA: Global Change Biology, v. 21, p. 666–675.

**DOI:** https://doi.org/10.1111/gcb.12775

**Background:** Temperature, moisture availability, and topographic position can affect postfire vegetation recovery and plant community composition. Exotic annual grasses, like cheatgrass and medusahead, may be more likely to succeed in warm, dry environments after stand-replacing wildfire. Therefore, climate change may exacerbate exotic species dominance after disturbance.

**Objectives:** Researchers sought to (1) understand postfire vegetation recovery patterns after stand-replacing fire across climate, moisture, and elevation gradients in a dry coniferous forest and (2) relate results to four future climate scenarios.

**Methods:** Eleven years after the Eyerly fire, researchers established 31 plots with 10 quadrats each in areas with complete overstory mortality across elevation gradients. They calculated heat load index using slope, aspect, and latitude. They estimated percent cover of all plant species and calculated relative cover of exotic species. They performed statistical analyses to understand the effect of heat load index and climatic moisture deficit—variables that account for slope, aspect, temperature, and moisture availability—on vegetation composition. They estimated future climatic moisture deficit in exact locations in the study area based on four global emission scenarios.

**Location:** Oregon

**Findings:** Researchers identified both native and exotic species in burned plots, where cheatgrass and medusahead constituted most of the exotic cover. Variation in vegetation composition correlated with variation in climatic moisture deficit across all plots. Increases in climatic moisture deficit and heat load index decreased native perennial cover and increased native short-lived cover and exotic cover. Projected climate scenarios were consistently associated with higher temperatures, but changes in precipitation varied. All four future climate scenarios had increases in climatic moisture deficit relative to baseline conditions.

**Implications:** The authors suggest that increased temperature and moisture stress after high-severity wildfire increases susceptibility to invasion by exotic grasses and that fine-scale variations, like slope and aspect, can affect vegetation recovery trends. In dry forest systems, they identify climate as a key driver of vegetation composition after fire. The authors note that projected climate scenarios suggest the recovery of native vegetation may be limited through time and that climate change could exacerbate exotic invasion to the point where exotics are dominant or codominant.

**Topics:** site-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; climate change; drought

## Dronova, I., Spotswood, E.N., and Suding, K.N., 2017, Opportunities and constraints in characterizing landscape distribution of an invasive grass from very high resolution multi-spectral imagery: Frontiers in Plant Science, v. 8, article 890, 17 p.

**DOI:** https://doi.org/10.3389/fpls.2017.00890

**Background:** Detecting and characterizing invasive plant invasions early on is critical to controlling infestations. Recent advances in unmanned vehicle sensing are a promising method, although its utility for many species, such as medusahead, is not yet known. Medusahead is well suited to remote sensing analysis because it has a unique phenology compared to other annual invasive grasses.

**Objectives:** The authors aimed to assess the feasibility of using high-resolution aerial imagery to characterize medusahead distribution by (1) using remotely sensed imagery to determine medusahead patch distribution, (2) comparing multiple object-based image analysis classification strategies, (3) assessing the benefit of including object texture in classification, and (4) identifying challenges of medusahead monitoring using this method.

**Methods:** The authors organized a field survey on a 36.8-ha grassland mid-May and early June 2013 and collected very high resolution (0.15 m) aerial imagery using an unmanned aerial vehicle. In the field, they surveyed 20 transects with varying medusahead infestations and determined dominant plant cover. The authors overlaid 300 location samples from the field with their remotely sensed data. Then, they used multiple classification methods to analyze the images and assess different strategies for determining medusahead cover from remote imagery. Additionally, they included texture variables to account for other grass species with similar phenology.

**Location:** California

**Findings:** The authors were able to use high-resolution aerial imagery to detect distribution of medusahead and determine general patch size. Different classification strategies provided varying degrees of accuracy, with most methods overpredicting extent of medusahead cover. The inclusion of object texture in models reduced error, although misclassification errors remained when barbed goatgrass was present with medusahead.

**Implications:** The authors assert that site-scale analyses like the one in this study are an important data source to inform management. Additionally, the ability to include object texture in classification allowed for more accurate medusahead detection when species with similar phenology were present. Finally, the authors state that the timing of imagery collection is important so that phenological contrast between medusahead and other grasses is maximized.

**Topics:** site-scale habitat characteristics; nonnative invasive plants; effect distances or spatial scale

## Eastburn, D.J., Roche, L.M., Doran, M.P., Blake, P.R., Bouril, C.S., Gamble, G., and Gornish, E.S., 2018, Seeding plants for long-term multiple ecosystem service goals: Journal of Environmental Management, v. 211, p. 191–197.

**DOI:** https://www.doi.org/10.1016/j.jenvman.2018.01.061

**Background:** California's annual rangelands are considered biodiversity hotspots and have experienced high levels of invasion. Seeding desirable species has not been widely practiced as a weed control method in these systems but could be an important management strategy to reduce invasive annual grasses and increase rangeland resistance.

**Objectives:** The authors established a long-term study to determine how different seeding mixes affect (1) invasive species reduction (2) native species diversity and richness, (3) forb diversity and legume abundance, and (4) forage tradeoffs.

**Methods:** Beginning in spring 1999, the authors treated the experimental site with herbicide (clopyralid), prescribed burning, and cattle rotation. Starting in fall 2004, the authors implemented and monitored five different seeding treatments (exotic annual, native perennial, exotic perennial, mixed native and exotic perennial, and unseeded) until 2015 to determine effect on invasive jointed goatgrass, yellow starthistle, and medusahead. They compared how treatments affected native, invasive, and forb species cover; forb and total diversity; forage quality and production; and nitrogen fixing plant cover. They also considered treatment costs.

**Location:** California

**Findings:** Jointed goatgrass frequency did not change across treatments. Yellow starthistle frequencies remained high across treatments except exotic and mixed perennial treatments. Medusahead cover decreased in all treatments throughout the experiment. Native perennial seeding plots had the highest levels of plant diversity and native plant cover. Forb diversity was greatest in annual and native perennial plots whereas nitrogen fixing plants were greatest in annual plots. Forage quality and production were similar across treatments. Costs were greatest in the native perennial seed mix treatment.

**Implications:** The authors suggest that including different seed mixes and increasing diversity of native species can allow for potential resistance to invasion. At a higher cost, perennial seeding (exotic and mixed) can be effective in competing against some invasive plants, such as yellow starthistle and medusahead, but may not be achievable for all invasive annual grasses. The authors recommend that managers consider strategies to optimize the overlap of desired species traits and increase plant diversity for pollination.

**Topics:** behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control

## Esposito, D.M., Rodhouse, T.J., Mata-Gonzalez, R., and Hovland, M., 2019, Differential species responses to aspects of resistance to invasion in two Columbia Plateau-protected areas: Rangeland Ecology and Management, v. 72, no. 5, p. 773–782.

**DOI:** https://www.doi.org/10.1016/j.rama.2019.05.006

**Background:** Abiotic conditions affect the spread and distribution of invasive plants, and understanding these abiotic factors in protected sagebrush ecosystems may be beneficial for management. Resistance mapping, which involves identifying landscape and ecological characteristics that support or deter exotic species, can be paired with distribution data to inform prioritization of conservation efforts in protected areas.

**Objectives:** Researchers sought to identify factors that may contribute to resistance of protected sagebrush ecosystems to invasion by invasive annual grasses.

**Methods:** At two field sites differing in topography, elevation, grazing legacies, soil type, and precipitation patterns, researchers visually estimated plant cover of native and exotic species in the summers of 2009 to 2013 at randomly selected, spatially balanced locations. They sampled from 3,671 plots across two protected areas. They characterized landscape differences and resistance patterns using digital data to map topography and elevation. They performed statistical analyses to understand the relationship between vegetation cover, landscape characteristics, and proximity to disturbance to derive the strongest drivers of cover.

**Location:** Idaho, Oregon

**Findings:** Researchers identified that invasive annual grasses were more prevalent at the Oregon site than the Idaho site and varied landscape characteristics determined species cover. In Oregon, nonnative grass cover decreased toward steep, north-facing slopes, but the cover of native perennial bunchgrasses and Wyoming big sagebrush increased. Cheatgrass favored dry conditions at both sites, whereas medusahead, which was only detected in Oregon, increased with more precipitation. Generally, across both protected areas, increases in elevation, precipitation, and distance to roads caused increased native species cover and decreased invasive species cover.

**Implications:** The authors suggest that understanding ecological resistance to plant invasion associated with physical landscape characteristics could support management of sagebrush steppe protected areas. They also acknowledge the importance of wildfire in shaping these communities. The authors state that landscape features linked to resistance do not ensure resistance but could be used as indicators of where to direct conservation efforts to effectively prevent invasion.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; effect distances or spatial scale; fire; nonnative invasive plants; weather and climate patterns; weed management; soils or geology; protected lands or areas

## Eviner, V., and Malmstrom, C., 2018, California's native perennial grasses provide strong suppression of goatgrass and medusahead: Grasslands, v. 28, no. 1, p. 3–6.

**URL:** https://www.cnga.org/resources/Documents/Bibliographies%20and%20Articles/Research%20articles%20from%20Grasslands/Eviner%20and%20%20Malmstrom_Grasslands%20Vol%2028%20No%201%20Winter%202018_reprint.pdf

**Background:** Exotic annual grasses dominate many grassland systems in California and inhibit native species. Additionally, they can cause reductions in plant diversity as well as quality and quantity of livestock forage. Native species have shown promise in outcompeting noxious invaders and may be effective in decreasing medusahead and barbed goatgrass.

**Objectives:** The authors' aim was to compare the ability of native perennial grasses and naturalized exotic annual grasses to suppress medusahead and barbed goatgrass.

**Methods:** In fall 2007, the authors established 36 treatments plots. All plots were planted with the annual invasive grasses medusahead and barbed goatgrass; half of the plots were also planted with eight native species and the other half were additionally planted with four naturalized exotic species. The authors recorded percent cover of all species twice yearly for 10 years to capture peak flowering of annual grasses (measured midspring) and perennial grasses and noxious grasses (measured late spring).

**Location:** California

**Findings:** Native grasses suppressed growth of medusahead and barbed goatgrass. Cover of both invasive species decreased during the course of the experiment and remained low for the last 6 years. Naturalized exotic species did not consistently suppress medusahead or barbed goatgrass. Suppression of both species fluctuated with drought when grown with naturalized exotics.

**Implications:** The authors suggest that planting native perennial grasses in restoration efforts may serve as a long-term control for barbed goatgrass and medusahead by preventing these annual invasive species from dominating. They note that it may take a few years for this approach to effectively suppress invasive species. Additionally, they suggest that use of native species in controlling annual invasive grasses may be even more effective when paired with aggressive weed management.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; drought; weed management; weed management subtopic: cultural control

## Fischer, A.P. and Charnley, S., 2012, Private forest owners and invasive plants—Risk perception and management: Invasive Plant Science and Management, v. 5, no. 3, p. 375–389.

**DOI:** https://www.doi.org/10.1614/IPSM-D-12-00005.1

**Background:** Private landowner engagement is necessary to mitigate the effects and spread of invasive plants. One predictor of mitigation behavior is risk perception. Studies on the risk perceptions and practices of private forest landowners regarding invasive plants are needed to improve access and usefulness of management information and resources.

**Objectives:** The authors sought to (1) understand private forest landowner risk perceptions and management motivations for invasive plants and (2) test if landowners' risk perception and management goals affect the likelihood of them treating invasive species.

**Methods:** The authors selected nine invasive plants (including cheatgrass and medusahead) in a ponderosa pine-dominated region and created a risk perception framework measuring landowners' (1) awareness and concern about invasive species on their property and (2) management intentions and values. They randomly surveyed 1,010 landowners in 2008 to determine risk perceptions and management goals. They received 505 responses and analyzed risk perception to compare with management actions and goals. Next, they performed interviews with 60 landowners to explore reasoning behind landowners' risk perceptions and management practices. The authors used qualitative and quantitative statistical methods to analyze results.

**Location:** Oregon

**Findings:** The authors determined that 52 percent of respondents were aware of at least one invasive species on their property; those respondents were twice as likely to treat invasive plants. The responses showed that 70 percent of respondents were concerned about at least one of the surveyed invasive species. These concerned landowners were more likely to treat invasive plants. Landowners who valued managing for wildlife were twice as likely to mitigate for invasive plants. Using interviews, the authors explored a spectrum of landowner beliefs on invasive plants and determined that awareness and concern were connected to landowners mitigating for invasive plants. However, few interview respondents could identify some of the common invasive species.

**Implications:** The authors suggest that landowner outreach programs about invasive plants should focus on raising awareness, generating concern, and providing education on the effects to wildlife habitat. They also recommend that more programs encourage and enable landowners to work together to stop invasions.

**Topics:** dispersal, spread, vectors, and pathways; habitat restoration or reclamation; fuels and fuels management; nonnative invasive plants; grazing/herbivory; agriculture; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; weed management subtopic: mechanical vegetation removal; forest management/timber harvest; human dimensions or economics

## Fusco, E.J., Finn, J.T., Balch, J.K., Nagy, R.C., and Bradley, B.A., 2019, Invasive grasses increase fire occurrence and frequency across US ecoregions: Proceedings of the National Academy of Sciences, v. 116, no. 47, p. 23594–23599.

**DOI:** https://doi.org/10.1073/pnas.1908253116

**Background:** Nonnative invasive grasses can alter fire regimes by increasing fuel loads in nongrassland systems, which can change fire occurrence, size, and frequency to a degree where native species are unable to recover. These species are widely present across the United States, but regional-scale studies of their potential effects have focused on cheatgrass.

**Objectives:** The authors sought to investigate associations between invasive grasses and fire regimes in (1) areas with and without invasive grasses and (2) using human-caused and ecological variables.

**Methods:** The authors identified 18 invasive grasses of interest based on a national invasive species database and if there was a reported fire effect based on a literature review. Twelve of those species were selected for study based on availability of sufficient abundance data. The authors then used fire data from 2000 to 2015 to assess fire regime effects by modelling fire occurrence, size, and frequency as a function of invaded and noninvaded areas and the effect of ecological (ecoregion and biophysical setting) and human-caused variables (distance to road and development percentage).

**Location:** United States

**Findings:** The authors identified invasive grasses present in 29 ecoregions and that cheatgrass had invaded the largest area. Medusahead and cheatgrass were associated with higher fire occurrence and more frequent fires compared to areas that were uninvaded. Human-caused and ecological variables were associated with fire occurrence and frequency for both species.

**Implications:** The authors suggest their results show annual invasive grasses affect fire regimes, specifically that these grasses have altered fuel load and continuity on the landscape, resulting in increased fire occurrence and frequency. They surmise that the decreased fire sizes that they observed for some species, including medusahead and cheatgrass, are the result of ecological and human-caused variables, such as fire suppression in invaded areas, and that annual invasive grasses are tightly tied with human activity.

**Topics:** broad-scale habitat characteristics; effect distances or spatial scale; fire; nonnative invasive plants

## Germino, M.J., and Lazarus, B.E., 2020, Synthesis of weed-suppressive bacteria studies in rangelands of the western United States—Special section of articles in *Rangeland Ecology and Management* provides little evidence of effectiveness: Rangeland Ecology and Management, v. 73, no. 6, p. 737–740.

**DOI:** https://www.doi.org/10.1016/j.rama.2020.02.007

**Background:** Controlling for exotic annual grass invasions in rangelands is a high priority for land managers and scientists. Although there are common practices to manage invasive annual grasses, such as cheatgrass and medusahead, it is unclear how using weed-suppressive bacteria as a bioherbicide reduces the root growth and establishment of those plants.

**Objectives:** The authors sought to provide a comprehensive review of the effectiveness of using weed-suppressive bacteria as a control technique through comparing previous study outcomes.

**Methods:** The authors synthesized 5 different studies with 214 total combined plots that were treated with weed-suppressive bacteria from 2015 to 2016 and monitored for 2 to 4 years. The studies ranged across several ecoregions and examined the effects of various treatments, consisting of herbicides, differing bacteria concentrations, and application methods on vegetation responses.

**Location:** Idaho, Montana, Washington, Wyoming

**Findings:** Only one of the five studies showed that weed-suppressive bacteria affected exotic annual grasses. The results of that experiment showed that use of a weed-suppressive bacteria available in a commercial product moderately decreased target invasive annual grasses for 1 year at two of three locations postfire. In contrast, they showed that herbicides were highly effective in reducing exotic annual grasses.

**Implications:** The authors emphasize the importance of negative results in using weed-suppressive bacteria to control invasive annual grasses. The authors warn that weed-suppressive bacteria reduced herbicide effectiveness when mixed and used across large areas of land and that herbicides alone significantly reduced exotic annuals. The authors suggest that although weed-suppressive bacteria may not be effective, the research has yet to include all types of available bacteria, herbicide combinations, and site conditions.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: biocontrol; weed management subtopic: herbicides; soils or geology

## Germino, M.J., and Lazarus, B.E., 2020, Weed-suppressive bacteria have no effect on exotic or native plants in sagebrush-steppe: Rangeland Ecology and Management, v. 73, no. 6, p. 756–759.

**DOI:** https://doi.org/10.1016/j.rama.2019.10.004

**Background:** Exotic annual grasses negatively affect the sagebrush steppe, decrease plant diversity, and increase wildfire intervals. Preemergent herbicides are used to manage annual grasses without affecting perennial grasses but are not effective long term. Biocontrol agents, such as weed-suppressing bacteria, have been shown to reduce cheatgrass and medusahead root growth in laboratory trials, but little is known about the effects of these bacteria on exotic grasses in the field.

**Objectives:** The authors sought to determine the effects of weed-suppressing bacteria at three sagebrush locations when combined with (1) herbicide application and (2) a soil treatment known as discing.

**Methods:** In fall 2016, researchers established three replicate plots at three sagebrush steppe locations that had undergone prescribed burning and been fenced to prevent livestock grazing prior to treatment. The researchers used two bacteria strains and established treatments to test the effectiveness of the bacteria with one of two herbicides (imazapic or rimsulfuron), with or without discing, and without any additional treatments. They applied herbicides first, followed by bacteria, and then completed discing using a rangeland drill. They measured and compared leaf cover across several plant groups pretreatment, during the peak growing season, and for the following three summers.

**Location:** Idaho

**Findings:** Neither bacteria strain decreased exotic annual grasses (medusahead and cheatgrass) or changed community cover across treatment combinations. There was a slight increase in native forbs with one bacterial strain; however, cover remained low. Both herbicide types reduced exotic annual grasses in the first year, but exotic annuals increased again after the second year. Discing reduced exotic annual grasses in the first year at one location.

**Implications:** The authors did not find that the application of weed-suppressive bacteria reduced exotic annual grasses. However, they suggest that these bacteria strains may not be infectious to certain species or do not grow in the sagebrush system. The authors note that the use of weed-suppressive bacteria should be applied experimentally and monitored carefully to determine the effects on the plant community. They do suggest herbicide application and increasing invasion resistance in perennial grass communities to decrease annual grass invasions.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: biocontrol; soils or geology

## Gornish, E.S., and Ambrozio dos Santos, P., 2016, Invasive species cover, soil type, and grazing interact to predict long-term grassland restoration success: Restoration Ecology, v. 24, no. 2, p. 222–229.

**DOI:** https://doi.org/10.1111/rec.12308

**Background:** Invasive species, in combination with land use and climate change, are degrading grasslands. Implementing effective restoration strategies is increasingly important, but revegetation is challenging due to low precipitation and productivity in these systems.

**Objectives:** The authors sought to identify biotic and abiotic factors that may affect long-term grassland restoration success.

**Methods:** The researchers monitored a restoration project across 12 fields. Restoration of these fields occurred between 2004 and 2007, when the authors applied broadleaf herbicide (triclopyr), seeded native perennial bunchgrass species, and later seeded native forb mixes between 2005 and 2011 on a subset of fields. In 2012, cattle grazed in several fields in the spring. The researchers applied herbicide approximately every 3 years to suppress weeds and mowed fields approximately every year to prevent fires. In May 2015, they established three or six transects in each field and measured plant species cover and richness; whether the species were invasive, native, or restored; and invasive species biomass. They also identified soil type using U.S. Department of Agriculture Natural Resources Conservation Service maps. They performed statistical analyses to assess differences between cover of restoration species and biotic and abiotic factors measured in the field.

**Location:** California

**Findings:** The researchers observed both seeded and unseeded native species in the restored agricultural fields, but they mostly observed invasive species. The dominant invasive species were wild oat, soft brome, and bur clover. Medusahead was not a dominant invasive species. The researchers determined that grazing and the presence of invasive cover negatively affected the

cover of restoration species. They also identified that soil type affected invasive plant cover and restoration success. They determined that the year a site was seeded and the species seeded did not determine restoration success, contrary to short-term studies that highlighted these factors as important for determining early restoration outcomes.

**Implications:** The authors suggest that grazing patterns, soil type, and invasive plant cover all play important roles in determining the long-term success of restoration projects in grasslands. The authors suggest collecting long-term data to distinguish between factors determining early versus ongoing restoration success. They also suggest minimizing grazing in drought years and prioritizing highly competitive species for restoration.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; soils or geology

## Gornish, E.S., Fierer, N., and Barberán, A., 2016, Associations between an invasive plant (*Taeniatherum caput-medusae*, medusahead) and soil microbial communities: PLOS ONE, v. 11, no. 9, 13 p.

**DOI:** https://www.doi.org/10.1371/journal.pone.0163930

**Background:** Invasive winter annual grasses, like medusahead, are negatively affecting plant diversity and soil carbon stocks and are altering fire frequency cycles in the western United States. Soil microbes, such as fungi and bacteria, can be altered by invasive plants near the root zone and subsequently alter soil conditions. However, little is known about the interaction between soil microbial communities and medusahead, particularly if these microorganisms enhance invasion.

**Objectives:** The authors sought to determine if soil microbial communities are (1) altered by medusahead invasion and (2) different between grasslands and oak woodland habitats.

**Methods:** In September 2013, researchers established four replicates of each plot in a grassland and oak woodland habitat, for a total of 40 plots. Sites were mowed, covered with plastic to enhance solar radiation, and sprayed with herbicide (glyphosate) prior to seeding. Five densities of medusahead seeds were applied and mixed with thatch. After medusahead seeding, annual rye, Blando brome, and a clover mix were seeded to simulate competition. In April 2014, the researchers simulated mowing or grazing through clipping vegetative biomass in half the plots. In the grassland sites, they added additional plots with shade cloth, oak litter, and a combination of both to simulate oak habitat characteristics and seeded medusahead at the highest density. In April 2015, they collected surface soil samples in each plot and used gene sequencing techniques to determine microbial diversity. They performed analyses to determine differences in soil microbes across treatments.

**Location:** California

**Findings:** Bacteria and fungi composition were different between the two habitats, with greater amounts of plant pathogens and arbuscular mycorrhizal fungi present in grasslands and greater amounts of ectomycorrhizal fungi present in oak woodlands. There were no effects of medusahead seed density or clipping treatments on microbial richness or composition. Fungal community richness was slightly higher in both the simulated oak habitat plots with litter additions and in the oak habitats themselves.

**Implications:** The authors suggest that open grasslands have higher abundances of fungal pathogens compared to oak woodlands. They did not find differences between soil communities with invasion; however, open grassland soil microbes may be more favorable for medusahead growth. They suggest that managers consider microbial interactions such as biocontrols and beneficial relations throughout relevant periods when considering management strategies.

**Topics:** genetics; site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Gornish, E.S., and James, J.J., 2016, Interactions among habitat, management, and demography for an invasive annual grass: Plant Ecology, v. 217, no. 10, p. 1247–1258.

**DOI:** https://www.doi.org/10.1007/s11258-016-0651-4

**Background:** Invasive grasses, like medusahead, are becoming more widespread with a changing climate, and biotic and abiotic factors may affect control efforts. Habitat characteristics and demography are important to study for effective management, but there is little research on how these factors interact with, and are affected by, management actions.

**Objectives:** The authors explored how (1) habitat characteristics, (2) demography, (3) management actions, and (4) the interactions of these factors affect medusahead.

**Methods:** The authors established 80 plots across 2 habitats: open grassland and oak woodland. In October 2014, the authors seeded plots with five densities of medusahead and a constant density of mixed native plant seeds. They defoliated half of the plots in April 2015, simulating mowing and grazing, and organized two substudies on additional plots in October 2014 and April 2015. One examined the effect of oak litter and shading, and the other applied two defoliation treatments. The authors measured medusahead germination, establishment, persistence, seed production, and density and statistically compared results across plots.

**Location:** California

**Findings:** Medusahead germination was unaffected by treatments, but seedling establishment was higher in open grasslands than in oak woodlands. Medusahead persistence was higher in woodlands with defoliation than without, although defoliation had no effect on shoot persistence in grasslands. Medusahead density was higher in grasslands than woodlands and was highest in grassland plots without defoliation. Oak litter and shade treatments reduced establishment and persistence of germinated medusahead seeds. Defoliated plots had decreased medusahead density; however, density decreased most with two defoliation treatments. Additionally, plots that were only defoliated once had increased medusahead seed production.

**Implications:** The authors emphasize that defoliation has important management implications and recommend at least two defoliation treatments within a season to target seeds that germinate later; this may limit seed production and reduce medusahead density. They propose that timing of management actions, in other words, timing the two defoliations during the growing season that they recommend, may interact with the reproductive cycle of medusahead and affect how populations respond to management. Because medusahead was lower in woodlands, the authors suggest oak corridors may be useful for isolating areas invaded by medusahead. They also indicate oak litter may be a physical and chemical barrier to medusahead establishment.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; weed management subtopic: mechanical vegetation removal; forest management/timber harvest

## Gornish E.S., James, J.J., and Laca, E.A., 2015, The value of oak woodland habitats as control for medusahead (*Taeniatherum caput-medusae*), *in* Standiford, R.B., and Purcell, K.L., tech. cords., Managing oak woodlands in a dynamic world—Proceedings of the seventh California oak symposium, Visalia, Calif., November 3–6, 2014: Berkeley, Calif., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-251, p. 131–143.

**URL:** https://www.fs.usda.gov/treesearch/pubs/49978

**Background:** Habitat type and seed bank dynamics could be critical for determining the dominance of medusahead. Understanding factors that support the spread of medusahead could inform future control efforts.

**Objectives:** Researchers sought to investigate the role of (1) seeding density, as a proxy for the seed bank, and (2) habitat type on medusahead density and recruitment.

**Methods:** Researchers established paired plots in fall 2013 in open grasslands and oak woodlands. They cleared the study site, seeded medusahead at five densities across plots, and seeded common grass and clover species. They measured plant density during life cycle stages, from germination to seed production. In June 2014, they counted flowering spikes, collected spikes from 10 plants at each plot to determine seed production, and germinated seeds in petri dishes to assess percent germination. They performed statistical analyses to understand the relationship between habitat type, seeding density, and medusahead density and recruitment.

**Location:** California

**Findings:** Medusahead density was much lower in oak woodlands than open grasslands. The density of annual competitors was initially lower in oak woodlands as well. Medusahead produced significantly more flowering spikes in open grasslands. Seeding rate also caused an increase in spike production. However, seeding rate caused a slight decrease in the number of seeds produced per spike. Neither habitat nor seeding rate affected percent germination. Habitat type and seeding rate did not individually determine recruitment, but the interaction of these factors drove reproductive output.

**Implications:** The authors suggest that oak woodlands are associated with reduced medusahead density and recruitment. High seeding rates in oak woodlands increased reproductive output of medusahead, pointing to the importance of the seed bank in determining dispersal trends. They recommend that identifying information relating seeding density and environmental factors to medusahead dominance can help managers identify potential control techniques. The authors suggest that oak woodlands play an important role in managing medusahead and should, thus, be conserved.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; nonnative invasive plants; weed management

## Gray, A.N., Baer, K.C., and Witt, C., 2021, Invasive plants, chap. 8 *of* Barrett, T.M., and Robertson, G.C., eds., Disturbance and sustainability in forests of the western United States: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-992, 231 p.

**URL:** https://www.fs.usda.gov/treesearch/pubs/62126

**Background:** This report evaluates forest disturbance in the western United States, with this summary focusing on the invasive plant chapter. Small-scale invasive plant populations can be difficult to find and eradicate using broad-scale strategic forest monitoring. However, monitoring may be used to determine locations and extents of established invasive populations, driving management actions.

**Objectives:** The authors sought to quantify abundance of nonnative plants within forests of the western United States and evaluate monitoring options.

**Methods:** The authors used data collected from 2001 to 2016 by the Forest Inventory and Analysis program to estimate abundance and distribution of nonnative plants. This program samples one point per 2,400 ha using two protocols, repeating measurements every 10 years. For protocol 1, crews document presence of invasives and record cover values for the four most abundant plant types on each plot. For protocol 2, botanists sample all plants within a subset of plots during the peak flowering period; however, protocol 2 was only implemented across a subset of States from 2001 to 2010. The authors quantified nonnative species cover and estimated cover change. They also compared the two protocols' estimates of nonnative abundance.

**Location:** Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming

**Findings:** Cheatgrass was the most abundant species within forests in contiguous States. Medusahead was one of the most abundant species within Pacific Coast States. In Hawaii and Alaska, strawberry guava and common dandelion were the most abundant nonnatives, respectively. Nonstocked forests (forests where tree stocking was less than 10 percent) had higher cover of nonnatives in the Rocky Mountains and Alaska. Rocky Mountain and Pacific Coast forests had higher nonnative cover in hardwood and dry conifer forest types and within forest stands 0 to 50 years old than high elevation and moist conifer types. Invasive plant cover appeared to increase significantly throughout 10 years. Protocol comparison indicated more nonnatives were detected with botanist sampling.

**Implications:** The authors state that effects on forests from nonnative plants are likely to increase through time and suggest needs for effective monitoring and early detection. They note that botanist surveys provided the most accurate assessments of nonnative species composition and suggest implementing a protocol where nonbotanist crews undergo training to identify a targeted set of relevant nonnatives.

**Topics:** population estimates or targets; broad-scale habitat characteristics; habitat selection; fire; nonnative invasive plants; infrastructure; includes new geospatial data

## Hamilton, T., Burritt, E.A., and Villalba, J.J., 2015, Assessing the impact of supplements, food aversions, and silica on medusahead (*Taeniatherum caput-medusae* (L.) Nevski) use by sheep: Small Ruminant Research, v. 124, p. 45–54.

**DOI:** https://doi.org/10.1016/j.smallrumres.2015.01.014

**Background:** Grazing may help control annual grasses. However, grazers avoid medusahead because of low palatability, nutritional value, and antiherbivory defenses. Feeding grazers nutritional supplements may increase willingness to consume medusahead.

**Objectives:** The authors examined (1) how nutritional content of medusahead affects intake and preference, (2) if medusahead consumption causes food aversion, and (3) if silica limits medusahead consumption.

**Methods:** The authors organized five feeding trials, four from May to August 2012, and one in May 2013. During trials 1 through 3, they split 32 lambs into four nutritional supplement treatment groups: (1) no supplements, (2) high energy, (3) high protein, and (4) both supplements. In each trial, the authors fed lambs medusahead in either early reproductive (trial 1), late reproductive (trial 2), or thatch (trial 3) stages and measured intake. During trial 4, they fed 30 lambs a novel food and tested food aversion by splitting lambs into three treatment groups, feeding them (1) nontoxic mixtures, (2) toxic mixtures, or (3) medusahead, and measured intake of the novel food after treatment. In trial 5, they tested if silica reduces food intake by splitting 30 lambs into three groups, feeding them (1) 2.5 percent silica, (2) 4.5 percent silica, and (3) no silica, and measuring hay consumption. The authors analyzed chemical makeup of the food given relative to consumption.

**Location:** Utah

**Findings:** Medusahead quality declined as it matured. In trials 1 and 2, lambs fed high-energy supplements ate slightly more medusahead; however, medusahead intake was low for both groups. In trial 3, lambs that received supplements ate and preferred medusahead more than controls (no supplements). In trial 4, lambs that received the toxic mixture ate less of the novel food type, but nontoxic and medusahead mixtures had no effect. In trial 5, lambs that were fed 2.5 percent silica had the lowest alfalfa hay intake, but both silica-fed groups ate more tall fescue hay than controls on most days of the trial.

**Implications:** The authors state that nutritional supplements have a small effect on medusahead intake. However, because supplements increased intake of medusahead thatch, they suggest grazing thatch during spring may help manage medusahead. They also suggest that silica and low nutrition contributes to low palatability of medusahead more than food aversion.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Homer, C., Rigge, M., Shi, H., Meyer, D., Bunde, B., Granneman, B., Postma, K., Danielson, P., Case, A., and Xian, G., 2020, Remote sensing shrub/grass National Land Cover Database (NLCD) back-in-time (BIT) products for the western U.S., 1985–2018: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9C9O66W

**Background:** For an updated version of this dataset, see Rigge and others (2021; https://doi.org/10.5066/P95IQ4BT). There is a critical need to monitor ecosystem health in sagebrush steppe communities due to changes caused by management, fire, and climate change. Remote sensing is a method that can be used to monitor ecosystem changes and ascribe change to specific drivers.

**Objective:** The authors sought to provide a time-series dataset of land cover types derived from satellite imagery across the western United States.

**Methods:** The authors used Landsat satellite imagery from 1985 to 2018 and created an automated modeling method to map and measure change across six land cover types: bare ground, shrub, sagebrush, litter, herbaceous, and annual herbaceous. The authors removed all satellite images from 2012 due to poor quality. They included several other variables in their models, consisting of topographic features, water, climate, and indices related to land cover types. After creating and training the models, the authors applied two model validation approaches and calculated temporal changes to each land cover type.

**Location:** Arizona, California, Colorado, Idaho, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The authors determined that bare ground increased while shrub cover declined across their study period. Most pixels in the satellite imagery had some cover change. Precipitation and temperature significantly affected all cover components across all years. During the 30 years studied, shrubs and sagebrush responded positively to increasing minimum temperatures but negatively to increasing maximum temperatures.

**Implications:** The authors suggest that their dataset may improve monitoring of changing land cover types and can help evaluate climate change effects and determine management actions.

**Topics:** broad-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; drought; water; soils or geology; includes new geospatial data

## Irvine, K.M., Wright, W.J., Shanahan, E.K., and Rodhouse, T.J., 2019, Cohesive framework for modelling plant cover class data: Methods in Ecology and Evolution, v. 10, no. 10, p. 1749–1760.

**DOI:** https://www.doi.org/10.1111/2041-210X.13262

**Background:** Modern methods for quantifying plant cover can result in inaccurate estimates of occurrence and abundance and do not offer a streamlined statistical process for data interpretation. A modeling technique, Bayesian hierarchical modeling, could account for complexities that other statistical methods exclude. This approach involves interpreting continuous mean cover proportions rather than categorical cover data, and accounting for variables that affect accuracy.

**Objectives:** The authors sought to expand statistical methods for analyzing plant cover data.

**Methods:** Researchers analyzed observation records from two study sites in sagebrush steppe ecosystems. At one site, they analyzed multiple records of percent cover estimates for bare ground and four species of conservation concern, including cheatgrass, medusahead, Sandberg bluegrass, and bluebunch wheatgrass from 220 plots. At a second location, they analyzed cover estimates for big sagebrush from 156 plots across three areas of interest. They developed a Bayesian hierarchical model that links the ordinal plant cover classes to the latent percent cover value.

**Location:** United States

**Findings:** Researchers determined that bare ground cover estimates had the most observer discrepancies and that cheatgrass cover had the most cover estimation errors. They determined high probability of detection across species, and most discrepancies in cover class observations were off by a single cover class category. They identified that medusahead, Sandberg bluegrass, and bluebunch wheatgrass detection error and cover class discrepancies were low, and observers tended to agree upon cover class categories for these species. They detected few observation errors for big sagebrush. They determined that statistical models that did not account for observation errors tended to overestimate abundance and underestimate occurrence. However, they detected few measurement errors and determined that relying on cover class categories did not negatively affect statistical accuracy for the empirical datasets.

**Implications:** The authors suggest that accurate cover estimates are important for guiding management in sagebrush steppe ecosystems. The authors also suggest that using advanced statistical techniques that consider detection probability and observation error could improve ecological inference across studies. Their paper provides a comprehensive statistical modeling framework for analyzing ordinal cover classes.

**Topics:** population estimates or targets; site-scale habitat characteristics; nonnative invasive plants; protected lands or areas

## James, J.J., Davy, J., Doran, M.P., Becchetti, T., Brownsey, P., and Laca, E.A., 2017, Targeted grazing impacts on invasive and native plant abundance change with grazing duration and stocking density: Rangeland Ecology and Management, v. 70, no. 4, p. 465–468.

**DOI:** https://dx.doi.org/10.1016/j.rama.2017.01.006

**Background:** Targeted grazing can be a useful tool for managing invasive grasses in rangeland ecosystems. However, it can be challenging for ranchers to achieve the high-density, short-duration grazing strategies explored in previous studies because of the low palatability of invasive grasses. Therefore, studying the tradeoffs between stocking density and grazing duration is important for rangeland management.

**Objectives:** The authors sought to determine how (1) stocking density and (2) grazing duration affects the composition of native plants, desirable forage species, and medusahead on rangelands.

**Methods:** In April 2008, the authors performed grazing trials at two study locations dominated by medusahead. At one location, the authors grazed cattle on 12 pastures, assigning 6 pastures to a low-density and long-duration treatment (fewer cattle for 21 days) and 6 pastures to a high-density and short-duration treatment (more cattle for 14 days). At the other location, they grazed sheep on 8 pastures, assigning 4 to the low-density and long-duration treatment (fewer sheep for 30 days) and 4 to the high-density and short-duration treatment (more sheep for 16 days). At both locations, they established two areas with no grazing as controls. They clipped vegetation in each pasture before the trials began and again after 1 year. They identified clippings as medusahead, desirable forage species, or native plants; quantified vegetative differences between treatments; and used statistics to compare the results.

**Location:** California

**Findings:** In the cattle grazing trials, both grazing treatments increased native plant abundance, although the high-density and short-duration treatment increased native plants more. Both treatments reduced medusahead abundance, but neither treatment had an effect on desirable forage species. In the sheep grazing trial, the high-density and short-duration treatment increased native plant abundance and decreased medusahead more than the low-density and long-duration treatment, which overall did not affect plant composition. In both trials, forage utilization was higher in low-density and long-duration treatments.

**Implications:** The authors suggest that their findings indicate logistically feasible grazing densities and durations can reduce medusahead and increase native species. Because high-density/short-duration treatments were most effective, they propose that duration of grazing rather than forage use is the most important driver for vegetation restoration. The authors state that a 1- to 2-week difference in grazing duration can alter outcomes.

**Topics:** habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## James, J.J., Drenovsky, R.E., Monaco, T.A., and Rinella, M.J., 2011, Managing soil nitrogen to restore annual grass-infested plant communities—Effective strategy or incomplete framework?: Ecological Applications, v. 21, no. 2, p. 490–502.

**DOI:** https://doi.org/10.1890/10-0280.1

**Background:** Invasive annual grasses are threatening perennial grass-dominated ecosystems worldwide. Previous work has attributed annual grass invasion to increased soil nitrogen availability and uptake after disturbances, and conversely, there have not been conclusive results that decreased soil nitrogen increases perennial grass establishment. Understanding how nitrogen management affects perennial grass germination and growth may be important for restoration practices.

**Objectives:** The authors sought to determine how soil nitrogen management affects the (1) growth and (2) competitive ability of invasive annual and native perennial grasses.

**Methods:** The authors performed a meta-analysis of studies that experimentally altered nitrogen availability for annual and perennial grass species. Using an online database and conference abstracts, the authors evaluated 25 studies, with a total of 35 datasets providing information about the variables of interest. The authors used statistical methods to synthesize and analyze data across the studies about the effects of nitrogen availability on plant density and biomass at the seedling stage, relative growth rates, and competitive interactions between annual and perennial species.

**Location:** Not specified

**Findings:** The meta-analysis showed that decreased soil nitrogen availability reduced annual grass biomass and tiller production at a greater rate than for perennial grasses. Faster growing species, such as annual grasses, had higher growth rates than perennial grasses under low nitrogen availability. Perennial biomass was greater when competing against annual grasses in high-nitrogen soils. Low soil nitrogen did not affect the competitive advantage of annual grasses over perennial grasses.

**Implications:** The authors suggest that if grasses are seeded for restoration, lower soil nitrogen availability may not affect differences in growth rates or initial competition dynamics between invasive and native plants. Instead, invasive plants may succeed based on earlier germination times and faster growth rates. They recommend that if invasive grasses can be controlled the first year, then soil nitrogen management may be beneficial in restoration throughout the long term.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; weed management; soils or geology

## James, J.J., Gornish, E.S., DiTomaso, J.M., Davy, J., Doran, M.P., Becchetti, T., Lile, D., Brownsey, P., and Laca, E.A., 2015, Managing medusahead (*Taeniatherum caput-medusae*) on rangeland—A meta-analysis of control effects and assessment of stakeholder needs: Rangeland Ecology and Management, v. 68, no. 3, p. 215–223.

**DOI:** https://www.doi.org/10.1016/j.rama.2015.03.006

**Background:** Evidence-based science on rangeland invasions is important for managers and stakeholders, but determining the most useful information for controlling invasive species can often be difficult. Providing a quantitatively synthesized literature review allows for managers to review relevant information about common medusahead control methods and understand knowledge gaps and implementation barriers.

**Objectives:** The authors sought to (1) identify the distribution of effects for medusahead control techniques and (2) evaluate stakeholder experiences and information needs.

**Methods:** The authors performed a meta-analysis of the literature and a stakeholder survey. The authors searched databases for articles published between 1960 and 2013 that experimentally assessed medusahead management treatments, consisting of herbicides, grazing, burning, seeding, and several combinations of each. Using data from 22 studies, they compared changes in medusahead cover, biomass, and density and how these differed across annual and perennial grasslands through time. In fall 2013, they surveyed 93 stakeholders across several groups about relevant management strategies to control medusahead and costs and barriers to implementation.

**Location:** California, Idaho, Nevada, Oregon, Utah

**Findings:** The meta-analysis showed that on annual rangelands, herbicides, burning, seeding, and grazing treatment combinations initially reduced medusahead. Past the first year, herbicides and herbicides plus seeding had persistent effects on medusahead in annual rangelands, whereas grazing did not. On perennial rangelands, all treatment combinations were effective in reducing medusahead the first year, but the effects disappeared after the second year except for herbicides. No studies looked at the grazing effects on perennial rangelands. The most common stakeholder goals included increasing plant diversity, forage production and quality, and wildlife habitat. The most common needs included an understanding of costs, risks, and outcomes on larger time and management scales. They determined that stakeholders viewed common management strategies as equally effective in controlling medusahead but were more likely to use grazing regimes.

**Implications:** The authors suggest that there are several challenges in managing invasive species, but they highlighted targeted livestock grazing as the most successful and least expensive strategy among managers to control medusahead. They identified research needs, including improving understanding of seed bank responses to control treatments and optimizing grazing regimes. They also suggest a need to understand the risks and benefits of treatment methods and how adaptive management strategies can be implemented over various spatial and temporal scales.

**Topics:** fire; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; human dimensions or economics

## James, J.J., Ziegenhagen, L. and Aanderud, Z.T., 2010, Exploitation of nutrient-rich soil patches by invasive annual and native perennial grasses: Invasive Plant Science and Management, v. 3, no. 2, p. 169–177.

**DOI:** https://www.doi.org/10.1614/IPSM-D-09-00033.1

**Background:** Understanding plant traits can be important when characterizing invasion strategies. Plant traits that may affect invasion can relate to a plant's ability to access soil nutrients, known as root foraging ability, and can be determined by root growth and morphology. However, more research is needed to determine how plant traits and the tradeoffs between them can affect plant growth.

**Objectives:** The authors sought to compare how (1) invasive annual and (2) native perennial grasses differ in their ability to uptake nutrients from soils.

**Methods:** In spring 2006, researchers selected four annual grasses and four perennial grasses and then planted 3-week-old seedlings into pots within seven study blocks. Within each block, researchers assigned four plants of each species to one of two nutrient treatments: (1) uniform, nutrients mixed into soil or (2) patchy, soil nutrients constrained to two core locations. They assigned these plants to one of two harvest options (common time, 47 days after planting or developmental stage, peak vegetative biomass) for 224 total plants. The researchers measured factors consisting of root length density, specific root length, root foraging precision, relative growth rate, and nitrogen uptake. They used statistics to compare species and treatments.

**Location:** Oregon

**Findings:** Six species demonstrated root foraging precision in at least one harvest option. Annual grasses had greater root foraging precision than perennials, but the size of this difference did not vary between harvest stages. Annual grasses also had greater root length density, specific root length, root-to-weight ratio, and relative growth rate compared to perennials, but these factors did not differ between harvest stages. Two species of perennial grasses (bluebunch wheatgrass and squirreltail) had higher values of root nitrogen uptake than two of the annual grasses (cheatgrass and medusahead). When averaged across nutrient treatments, annuals had greater nitrogen and phosphorous uptake, and higher biomass than perennials.

**Implications:** The authors state that although invasive grass roots may have greater foraging precision, noninvasive and native species in the study also demonstrated similar root responses. They suggest that other factors, such as germination and emergence timing, may contribute more to invasive grass success than root placement.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat selection; nonnative invasive plants; soils or geology

## Jarnevich, C.S., LaRoe, J., Engelstad, P., and Sullivan, J., 2021, INHABIT species potential distribution across the contiguous United States (ver. 1.0): U.S. Geological Survey data release. [Superseded in 2023 by version 3.0, which is available at the same DOI.]

**DOI:** https://doi.org/10.5066/P9V54H5K

**Background:** Department of Interior land management agencies have expressed a need for habitat suitability models for invasive plant species.

**Objectives:** The authors aimed to provide a habitat suitability model that maps the potential distributions of various invasive plant species.

**Methods:** The authors used remotely sensed imagery and spatial data with known invasive plant occurrences and a range of environmental variables to create habitat suitability models. They used modeling techniques developed by Young and others (2020; https://doi.org/10.1371/journal.pone.0229253) to create maps that estimate potential invasive species distribution.

**Location:** United States

**Findings:** They developed a mapping tool with numerical information to show potential distribution of many invasive plant species, such as medusahead, across the United States biophysical landscape and climate.

**Implications:** The authors suggest that resource managers can use these models to help inform invasive plant management decisions at multiple spatial scales.

**Topics:** nonnative invasive plants; site-scale habitat characteristics; includes new geospatial data

## Jarnevich, C.S., Sofaer, H.R., and Engelstad, P., 2021, Modelling presence versus abundance for invasive species risk assessment: Diversity and Distributions, v. 27, no. 12, p. 2454–2464.

**DOI:** https://doi.org/10.1111/ddi.13414

**Background:** Efforts to model the distribution of invasive plants have typically focused on species presence rather than abundance because of the meager availability of abundance data. However, species abundance can provide valuable information about the magnitude of an invasion. Improving understanding of alignment between presence and abundance models could facilitate use of these models in management.

**Objectives:** The authors sought to (1) compare species presence and abundance in environmental space, (2) explore how presence and abundance models predict species distribution in geographic space, and (3) assess invasion risk.

**Methods:** The authors created an ensemble of distribution models based on online and Federal databases of presence and cover for three invasive annual grasses and one invasive forb. The authors selected 26 predictors based on life history and measures of correlation. They used the top predictor variables, consisting of measures of drought stress and temperature, to define environmental space for species comparisons. They also compared invasion risk in 305 Federal land management units based on the proportion of the unit modeled as suitable for presence or abundance.

**Location:** Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming

**Findings:** In environmental space, red brome was abundant in a discrete portion of the areas in which it was present. In contrast, areas of medusahead abundance almost completely overlapped areas of presence. Ventenata and bur buttercup abundances were clustered, but with additional points of abundance scattered throughout the areas of presence. In geographic space, the presence and abundance models generally correlated well but predicted relatively large areas of presence relative to abundance for red brome and medusahead. Presence and abundance models largely agreed in their predictions of invasion risk for land management units.

**Implications:** The authors noted that the results of model comparisons showed that presence modeling may provide sufficient information to guide management decisions. The authors also stated that environmental space plotting showed how management for species like red brome can be targeted in areas with discrete environmental conditions that favor abundance whereas other species might be expected to become abundant wherever they are present, like medusahead.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat selection; nonnative invasive plants; weather and climate patterns; drought; weed management; water

## Jarnevich, C.S., Sofaer, H.R., and Engelstad, P.S., 2021, Presence and abundance data and models for four invasive plant species: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9MVEPP4

**Background:** Invasive species management can be strengthened by spatial data that highlight potential invasion risk, such as data on potential distribution and potential area of abundance.

**Objectives:** The authors sought to model the (1) potential distribution and (2) potential area of abundance of four invasive plant species in the western United States.

**Methods:** The authors developed habitat suitability models considering species distribution and abundance of four invasive species, including red brome, bur buttercup, medusahead, and ventenata based on techniques developed by Young and others (2020; (https://doi.org/10.1371/journal.pone.0229253). They used five formulas to develop habitat models and accounted for sampling bias by using two sources of background samples for each species, which resulted in 10 models per species. They merged presence and abundance data to construct models for four different habitat suitability thresholds. They used environmental predictors in their habitat models, consisting of climate, soil characteristics, topography, and tree cover, among other factors.

**Location:** United States

**Findings:** The authors developed habitat suitability models, based on presence and abundance, for four invasive species. They produced a data bundle, consisting of spatial data files associated with presence and abundance for each species and data summaries divided by management unit.

**Implications:** The authors suggest that the spatial data and habitat suitability models will support management efforts related to invasive species of concern.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat selection; nonnative invasive plants; weather and climate patterns; drought; weed management; water; includes new geospatial data

## Johnson, D.D., and Davies, K.W., 2012, Medusahead management in sagebrush-steppe rangelands—Prevention, control, and revegetation: Rangelands, v. 34, no. 1, p. 32–38.

**DOI:** https://www.doi.org/10.2111/1551-501X-34.1.32

**Background:** Medusahead is an exotic annual grass that reduces forage species and native plant diversity and increases wildfire frequency and severity. A few management strategies have been developed to control and limit the future spread of medusahead.

**Objectives:** The authors sought to synthesize management approaches based on up-to-date information on (1) preventing the spread of medusahead, (2) controlling existing medusahead populations, and (3) revegetating perennial grasses in sagebrush rangelands.

**Methods:** The authors present management methods to control medusahead based on the literature. They review strategies for limiting the establishment and dispersal of medusahead, reducing resource availability, and eradicating new or existing populations.

**Location:** California, Colorado, Idaho, Nevada, Oregon, Utah, Washington

**Findings:** Medusahead prevention includes limiting seed dispersal by using vegetation barriers in noninvaded areas. For example, planting desert wheatgrass near an infestation edge limited medusahead density during a 2-year period. Excluding livestock grazing in invaded areas during certain seasons may also limit long-distance seed dispersal. Maintaining a competitive plant community may reduce resources available to medusahead. Fire prevention can also be used to limit medusahead spread but may lead to other unintended consequences, such as conifer expansion in susceptible areas. If fire prevention is not possible, seeding competitive perennial bunchgrasses after a wildfire may limit dispersal. Early detection and control of new infestations of medusahead are crucial for preventing reproduction and the development of soil seed banks. Prescribed burning followed by the appropriate timing of preemergent herbicides can be effective in reducing established medusahead. Revegetation of perennial bunchgrasses can be paired with control methods to further limit the spread of medusahead.

**Implications:** The authors suggest that managers should focus on prevention of medusahead infestations because this approach is cost effective and more achievable than restoration of invaded areas. However, if medusahead populations are established, they suggest implementing multiple control methods, such as prescribed burning, herbicide application, and subsequent fall seeding.

**Topics:** dispersal, spread, vectors, and pathways; fire; fuels and fuels management; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Johnson, D.D., Davies, K.W., Schreder, P.T., and Chamberlain, A.M., 2011, Perceptions of ranchers about medusahead (*Taeniatherum caput-medusae* (L.) Nevski) management on sagebrush steppe rangelands: Environmental Management, v. 48, no. 3, p. 400–417.

**DOI:** https://www.doi.org/10.1007/s00267-011-9703-7

**Background:** Ranchers in sagebrush ecosystems can suffer economic losses caused by medusahead invasion that degrades livestock forage and alters the natural ecosystem. However, little is known about ranchers' behaviors and perceptions regarding medusahead management.

**Objectives:** The authors sought to determine if medusahead presence affected a rancher's behaviors and perceptions regarding land management.

**Methods:** In July 2008, the authors mailed a survey to ranchers in the Oregon sagebrush ecosystem using addresses from local Cooperative Extension offices. They sent several reminders by phone and mail. The survey asked about ranchers' perceptions and weed management practices during 2007. The authors used statistical tests to compare responses between ranchers reporting medusahead presence and absence.

**Location:** Oregon

**Findings:** Of the 111 ranchers who responded, about half indicated that medusahead was present on their grazing land and was more problematic than Dalmatian toadflax, cheatgrass, knapweeds, leafy spurge, and ventenata. Compared with ranchers on noninvaded land, those with medusahead present were nearly seven times more likely see it as a problem. Overall, ranchers perceived that operating costs were more concerning than invasive plants. Respondents indicated that invasive plants were as concerning as livestock prices, public land regulations, and adverse weather, but more of a concern than grazing land availability, predators, or private land regulations. Ranchers with medusahead invasion were more concerned about public land regulation, more likely to do preventive weed control and monitoring, more likely to indicate a lack of return on investment of invasive weed treatments, and more likely to personally treat and insist on local treatment of invaded areas. Most ranchers indicated an interest in receiving information about treatments and preferred paper or in-person sharing over web based.

**Implications:** The authors determined that ranchers on medusahead-invaded rangelands seem to have a higher awareness and aversion to invasive grasses such as medusahead. They state that invasive plants may not be a top concern because ranchers have to prioritize the costs of other needs. The authors suggest that it is important to raise awareness in the ranching community about the negative effects of medusahead to motivate prevention, monitoring, and treatment.

**Topics:** nonnative invasive plants; weed management; human dimensions or economics

## Jones, L.C., Davis, C., and Prather, T.S., 2020, Consequences of *Ventenata dubia* 30 years postinvasion to bunchgrass communities in the Pacific Northwest: Invasive Plant Science and Management, v. 13, no. 4, p. 226–238.

**DOI:** https://www.doi.org/10.1017/inp.2020.29

**Background:** Invasive annual grasses, such as ventenata, can alter species diversity, species interactions, and community dynamics. In the Pacific Northwest, it is unclear how ventenata has affected community composition long term, particularly the interaction with indigenous and invasive species and associated abiotic features.

**Objectives:** The authors sought to determine (1) the distribution and abundance of ventenata, (2) changes in plant diversity with increasing ventenata cover, (3) associated abiotic and biotic factors, and (4) and invasion patterns.

**Methods:** From May to July 2012 to 2013 and May to August 2018, researchers surveyed three habitat types (bluebunch wheatgrass, Idaho fescue, low shrub) among two grassland ecoregions. They sampled percent cover of plants, biological soil crust, bare ground, rock, and litter on 15 transects in each habitat. They measured soil depth and collected soil samples for texture, phosphorous, and potassium concentrations. They used statistical analyses to compare species composition for three ventenata cover classes (none, low, high) across each habitat type and ventenata cover with associated soil characteristics.

**Location:** Idaho, Washington

**Findings:** Ventenata was abundant in more than half of the plots in both grassland ecoregions and was greatest in the bluebunch wheatgrass habitat. High ventenata cover was associated with low indigenous species richness and overall diversity. In one grassland, high ventenata cover correlated with high cover of other nonindigenous species, especially bald brome and cheatgrass. In the second grassland, high ventenata cover correlated with high cover of the nonindigenous species Japanese brome and medusahead. Shallow soils and south and west aspects correlated with increased ventenata cover; however, the authors did not find associations between soil texture, phosphorous, or potassium. Invasion patterns indicate that ventenata has moved from seasonally wet areas to drier areas through time.

**Implications:** The authors identified that areas dominated by cheatgrass and medusahead are susceptible to ventenata invasion, indicating it can spread in both dry and moist areas. The authors caution managers to prevent and control new invasions, and that they should anticipate that ventenata can spread to areas with similar abiotic and biotic characteristics present in this study.

**Topics:** behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; weed management; soils or geology

## Jones, L.C., Norton, N., and Prather, T.S., 2018, Indicators of ventenata (*Ventenata dubia*) invasion in sagebrush steppe rangelands: Invasive Plant Science and Management, v. 11, no. 1, p. 1–9.

**DOI:** https://www.doi.org/10.1017/inp.2018.7

The summary for this article was previously published in Poor and others (2021, p. 18–19; https://doi.org/10.3133/ofr20211031).

## Kennedy, A.C., 2017, Weed-suppressive soil bacteria to reduce cheatgrass and improve vegetation diversity on ITD rights-of-way (RP 258): Idaho Transportation Department.

**URL:** https://rosap.ntl.bts.gov/view/dot/34952

**Background:** Controlling invasive annual grasses, such as cheatgrass and medusahead, is challenging for transportation departments because recently disturbed areas like roadsides are susceptible to invasion. Naturally occurring bacteria from soils can stunt roots and reduce competitiveness in invasive annual grasses throughout several years. Traditional weed treatments have been minimally successful along roadsides, so investigating the effectiveness of weed-suppressive bacteria in this setting is warranted.

**Objectives:** The author sought to (1) study the effects of using weed-suppressive soil bacteria on roadsides invaded with cheatgrass and medusahead and (2) determine optimal uses and recommendations for using weed-suppressive bacteria.

**Methods:** The researchers sprayed weed-suppressive bacteria on eleven 1-acre plots at seven sites with moderate cheatgrass and possible medusahead invasion along highways during the falls of 2014, 2015, and 2016. Each spring, they measured the survival of the weed-suppressive bacteria, plant density, and plant growth along 10-m transects. Additionally, they collected field data from eight subplots within each plot. The researchers captured digital images of the subplots during the fall and spring. They analyzed the images using a software designed to estimate percent cover of vegetation, bare soil, litter, rock, and biological soil crusts. They also studied the effectiveness of the treatment in relation to location, landscape conditions, soil, and climate. They evaluated bacterial success using statistical methods.

**Location:** Idaho

**Findings:** The author determined that cheatgrass declined 30 to 97 percent in all plots 1 year after the application of the weed-suppressive bacteria. They identified that medusahead was absent in all test plots after the application of the bacteria. At one site, the authors identified that broadleaf weed species increased in areas where the invasive grasses were reduced. During the course of the study, they determined that cheatgrass was reduced 70 percent in the test plots compared to the control sites.

**Implications:** The author suggests that weed-suppressive bacteria treatments are effective for managing medusahead and cheatgrass along roadsides. They state that the competitiveness of native plants increases after invasive annual grasses are reduced using weed-suppressive bacteria. They also provided recommendations for weed-suppressive bacteria treatments. The author recommends continued monitoring of their sites to determine the long-term treatment effects.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; infrastructure; weed management; weed management subtopic: biocontrol; weed management subtopic: herbicides; soils or geology

## Kennedy, A.C., 2018, Selective soil bacteria to manage downy brome, jointed goatgrass, and medusahead and do no harm to other biota: Biological Control, v. 123, p. 18–27.

**DOI:** https://www.doi.org/10.1016/j.biocontrol.2018.05.002

**Background:** Invasive annual grasses, such as cheatgrass, jointed goatgrass, and medusahead, pose threats to croplands and rangelands. Weed-suppressive bacteria, present in the soil, could limit root development and reduce invasive species in the seed bank.

**Objectives:** The author sought to (1) identify bacteria capable of controlling target species without harming other organisms and (2) evaluate efficacy in different management contexts.

**Methods:** The author derived three bacterial strains from soil samples collected in early spring. To narrow selective strains, the author excluded isolates that negatively affected nontarget organisms. The author tested bacterial candidates in small-plot field trials in 28 plots across 4 treatment types (3 bacterial strains and 1 treatment lacking bacteria). The author then performed large-plot field trials across four ecotypes, including croplands, pastures, mixed rangelands, and monoculture weed rangelands. The author established 20 plots at 6 sites and sprayed bacteria in late fall. The author studied cheatgrass across all ecotypes, jointed goatgrass in two cropland sites, and medusahead across five mixed and monoculture rangeland sites. The author collected data annually for 7 years, measuring plant density, number of plants, plant diversity, percent cover, number of reproductive tillers, plant height, soil temperature, and soil moisture.. The author performed statistical analyses to understand the effect of different isolates on three invasive species across separate ecotypes.

**Location:** Washington

**Findings:** Bacteria had different effects on invasive species depending on the context. Effects of bacterial isolates on weed suppression did not become apparent until several years after application. After 7 years, the author determined that soil bacteria effectively suppressed cheatgrass in all ecotypes except monoculture rangelands, reduced jointed goatgrass in croplands, and effectively reduced medusahead in mixed rangelands but not monoculture rangeland sites. The author reports that native perennial plants persisted where they were present before application of bacteria. The author did not detect bacteria in the soil 5 to 6 years after application.

**Implications:** The author suggests that weed-suppressive bacteria offer a longer-term solution to weed management and this method of biological control can be paired with other weed management techniques. The author also suggests that application timing is critical and that a delay between initial application and eventual suppression is probable.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; agriculture; weed management; weed management subtopic: biocontrol; soils or geology

## Kerns, B.K., and Day, M.A., 2014, Fuel reduction, seeding, and vegetation in a juniper woodland: Rangeland Ecology and Management, v. 67, no. 6, p. 667–679.

**DOI:** https://www.doi.org/10.2111/REM-D-13-00149.1

**Background:** Western juniper has expanded across the sagebrush ecosystem, affecting plant communities and wildlife habitat. Removing juniper, through cutting and burning, may reduce native vegetation and increase invasive species cover. Postdisturbance seeding can limit the spread of invasive species, and evaluating the effectiveness of different seed mixes could support the recovery of perennial plants after juniper removal.

**Objectives:** The authors sought to determine the effects of (1) fuel reduction treatments and (2) planting two different seed mixes on slash piles and skid trails.

**Methods:** In 2008, managers cut and removed juniper trees and researchers established slash pile locations. In winter 2009, the researchers burned slash piles and established plots on skid trails and burned slash piles. They seeded all plots in spring 2009 using three randomly assigned seed treatments (cultivar, local, or no seed) and used uncut controls as a fourth treatment comparison. The slash pile experiment included 20 replicates. The skid trail experiment included 15 replicates for seeding with 20 uncut plots. The cultivar seed mix contained commercially available native seeds, and the local seed mix contained native seeds sourced from an ecologically similar area. They sampled tree and stump diameters precutting and postcutting and estimated plant canopy cover posttreatment. Statistical analyses compared the effects of each treatment on plant responses.

**Location:** Oregon

**Findings:** Juniper basal area was reduced to 1.3 $m^2$/ha after cutting. Two years after seeding, species composition was altered for both disturbance types. Seeding was somewhat successful in establishing native plant cover but was less successful in skid trail areas. Exotic species increased across all treatments during the study and sometimes increased more in the fuel reduction treatments than in the controls. Neither seed mix lowered exotic grass cover, which was largely composed of cheatgrass. Areas close to former juniper trees appeared to have some resistance to invasion. There was weak evidence that the cultivar mix outperformed the locally sourced mix.

**Implications:** The authors suggest that fuel reduction treatments can increase short-term exotic grass cover and should be integrated with invasive species management, seeding native or fast-growing species, and evaluating long-term effectiveness. They also suggest that managers should consider invasive species control, disturbance type, and vegetation composition more than seed sources when implementing restoration treatments.

**Topics:** site-scale habitat characteristics; fuels and fuels management; nonnative invasive plants; conifer expansion; weed management; weed management subtopic: cultural control

## Kerns, B.K., Day, M.A., and Ikeda, D., 2020, Long-term seeding outcomes in slash piles and skid trails after conifer removal: Forests, v. 11, no. 8, article 839, 14 p.

**DOI:** https://doi.org/10.3390/f11080839

**Background:** Conifer encroachment is an issue in the western United States. Canopy removal and disturbances, like skid trails and slash burning, can negatively affect vegetation, creating susceptibility to exotic invasion. Seeding can help plant communities recover, but seed sources and species can affect restoration success.

**Objectives:** The authors studied how different seeding treatments can affect the long-term restoration of (1) skid trails and (2) slash burn piles by examining native species cover, exotic weed suppression, and native plant diversity.

**Methods:** The authors resampled two experiments designed in 2008 to examine seeding in slash piles and skid trails associated with juniper removal. They examined two seed mixes (locally collected and purchased cultivar seeds) consisting of bottlebrush squirreltail, bluebunch wheatgrass, and western yarrow. In spring 2009, during the initial experiment, researchers randomly assigned seed treatments (no seed, local, cultivar) to plots and used uncut controls as a fourth treatment comparison. The slash pile experiment included 20 replicates. The skid trail experiment included 15 replicates for seeding with 20 uncut plots. Eight years after seeding in spring 2017, researchers collected ground cover and plant diversity data, grouped species into functional groups, and compared treatments.

**Location:** Oregon

**Findings:** Within slash piles, both seed mixes increased seeded species cover but not total cover. Most native perennials had lower cover within treatments. Exotic grass cover was lower in seeded plots compared to unseeded but was lowest in areas not cut. Seeding increased perennial bunchgrasses diversity. Within skid trails, seed species response was driven largely by squirreltail cover in locally seeded plots whereas bluebunch wheatgrass cover was similar across treatments. Western yarrow cover was greater in locally seeded plots in areas with high precut juniper cover. Perennial bunchgrass cover was lower in seeded plots, whereas native annual forb cover was higher across treatments. Exotic grass cover increased within skid trails and was highest in cultivar treatments. Seeding had varied effects on plant diversity.

**Implications:** The authors suggest that seeding skid trails or slash piles may not increase recovery of broader vegetation communities but can lead to long-term persistence of seeded species. They suggest that seeding may suppress exotic grasses and note that local seeds may outperform cultivars. They advise caution when interpreting short-term recovery results because they may not represent long-term outcomes.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; fuels and fuels management; nonnative invasive plants; conifer expansion; weed management; weed management subtopic: cultural control

## Kettenring, K.M., and Adams, C.R., 2011, Lessons learned from invasive plant control experiments—A systematic review and meta-analysis: Journal of Applied Ecology, v. 48, p. 970–979.

**DOI:** https://www.doi.org/10.1111/j.1365-2664.2011.01979.x

**Background:** Synthesizing existing research on controlling invasive plants and restoring invaded landscapes can affect future restoration success. Effectively translating research to management relies on further examination of existing knowledge.

**Objectives:** The authors performed a systematic review and meta-analysis to (1) understand the most effective approaches for controlling invasive species and (2) assess how control methods are evaluated to inform restoration applications.

**Methods:** The authors searched a variety of databases for publications through 2009 using search terms related to invasive species and restoration. They included articles that presented quantitative data, occurred in a field context, and addressed revegetation of native species. The authors determined 355 papers that aligned with their inclusion criteria. They collected data on several questions and performed a meta-analysis to compare control methods with invasive and native plant responses.

**Location:** North America

**Findings:** The authors determined that most studies occurred in North America, focused on temperate grasslands, and took place during a period of less than 1 year. Studies predominantly focused on herbicide as a control method, as well as cutting and burning. About one-third of the studies included revegetation of native plant species. The authors determined that herbicides effectively reduced invasive plants whereas burning generally promoted the return of invasive plants and reduced native species biomass. They identified that most studies excluded considerations of cost or feasibility regarding large-scale application of control methods.

**Implications:** The authors suggest that controlling invasive species may lead to undesired consequences like reducing native species. They also suggest that existing studies are limited in scope and do not account for cost or feasibility and may not be transferable to management settings. They advocate for native revegetation as a method to break the invasion cycle and increase the efficacy of controlling invasive species. They also advocate for an adaptive management approach that would incorporate the perspectives of restoration practitioners in the research process.

**Topics:** habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; weed management subtopic: mechanical vegetation removal; human dimensions or economics

## Kyser, G.B., Creech, J.E., Zhang, J., and DiTomaso, J.M., 2012, Selective control of medusahead (*Taeniatherum caput-medusae*) in California sagebrush scrub using low rates of glyphosate: Invasive Plant Science and Management, v. 5, no. 1, p. 1–8.

**DOI:** https://doi.org/10.1614/IPSM-D-11-00032.1

**Background:** Existing methods for controlling medusahead may not be effective or feasible in semiarid sagebrush systems across the Great Basin. Exploring glyphosate herbicide as a control method could provide an alternative approach for managing medusahead in sensitive sagebrush systems.

**Objectives:** The researchers sought to assess the effectiveness of glyphosate in reducing medusahead cover and seed production when applied at (1) different rates and (2) during different times of the year.

**Methods:** The researchers organized glyphosate trials at two adjacent sites in 2009 and 2010. They established 120 plots at each site with 3 different treatment timings (mid-March, late April to early May, late May to early June), 10 rates of glyphosate application, and 4 replicates of each treatment combination. They visually estimated plant cover and assessed big sagebrush vigor based on new growth. The researchers collected biomass, dried samples, and counted medusahead stems. They collected seedheads in summer 2009 to assess seed viability. They performed statistical analyses to evaluate the relationship between application treatments and medusahead cover, stem density, and seed production, as well as cover of other species and sagebrush vigor.

**Location:** California

**Findings:** Researchers identified that increasing glyphosate application rate caused corresponding declines in medusahead cover at all application times. They also determined that application timing affected medusahead cover and midseason application most effectively reduced cover in both study years. They determined that early application extended the growing season of medusahead by reducing competition and caused increased seed production. Late-season treatments effectively reduced medusahead cover but left more standing dead, presenting a potential fire risk. Midseason and late-season glyphosate application reduced seed production more than early-season treatments. Midseason application reduced big sagebrush vigor during the second year.

**Implications:** The authors suggest that applying low rates of glyphosate midseason could effectively reduce medusahead cover and seed production in sagebrush systems. They suggest that this approach could be more cost effective given the reduced quantity of glyphosate needed. They note that treatments would likely be most effective throughout multiple years. They also note that glyphosate treatment can cause a slight reduction in big sagebrush vigor, but this effect is not long term.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; fire; fuels and fuels management; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Kyser, G.B., Peterson, V.F., Davy, J.S., and DiTomaso, J.M., 2012, Preemergent control of medusahead on California annual rangelands with aminopyralid: Rangeland Ecology and Management, v. 65, no. 4, p. 418–425.

**DOI:** https://www.doi.org/10.2111/REM-D-12-00003.1

**Background:** Medusahead is a highly invasive grass throughout California rangelands and is poor grazing forage due to its high silica content. Although prescribed burning, intensive grazing, and some herbicides can be used to control medusahead, these methods may not be viable in all situations There are several preemergent herbicides that can be applied to control medusahead; however, it is unclear how each herbicide affects medusahead and desirable forage species.

**Objectives:** The authors sought to determine the effects of using different preemergent herbicides on (1) medusahead and (2) forage species.

**Methods:** In 2009, the researchers established treatment plots in three annual grassland locations with four replications per site. They compared different application rates of three herbicides (four rates of aminopyralid, two rates of rimsulfuron, and one rate of imazapic) and an untreated control. They applied herbicides using backpack sprayers and spray booms in fall 2009. In the following spring, they estimated plant species cover and biomass, as well as medusahead height. They evaluated medusahead seed production, seed fill, and seed germination. The researchers performed statistical analyses to compare treatment effects on each measured variable.

**Location:** California

**Findings:** Across infested plots, species richness was low and included mostly nonnative species. Aminopyralid applications reduced medusahead cover at all sites, and higher application rates caused greater reductions in cover. The other two herbicides did not consistently reduce medusahead. Medusahead height, seed production, fill, and germination did not differ across treatments. Cover of nonnative forage annual grass species increased with the highest concentration of aminopyralid application at all locations, whereas broadleaf plant cover decreased across all sites.

**Implications:** The researchers suggest that high rates of aminopyralid applied in the fall can control medusahead and other invasive plants in similar sites if these species are targeted specifically with spot application of the herbicide. They additionally suggest that applying aminopyralid at high rates may be particularly useful in small invasions or revegetation projects, while noting that use depends on medusahead density and other species in the area. They also suggest that these treatments may be short lived and need to be monitored regularly.

**Topics:** behavior or demographics; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Kyser, G.B., Wilson, R.G., Zhang, J., and DiTomaso, J.M., 2013, Herbicide-assisted restoration of Great Basin sagebrush steppe infested with medusahead and downy brome: Rangeland Ecology and Management, v. 66, no. 5, p. 588–596.

**DOI:** https://doi.org/10.2111/REM-D-12-00184.1

**Background:** Medusahead and cheatgrass are two of the most harmful invasive grasses in the United States. A critical component of restoring invaded landscapes is reestablishing desired species. Using herbicides to manage invasive species before seeding has had positive short-term effects; however, herbicide effectiveness can be affected by temporal and ecological factors.

**Objectives:** The authors sought to (1) determine the long-term effects of four different herbicide treatments on medusahead, cheatgrass, and native vegetation and (2) evaluate how seeding affects revegetation strategies.

**Methods:** The authors established 20 plots at 2 experimental sites. They applied five herbicide treatments: three in October 2008 (rimsulfuron, imazapic, and sulfometuron plus chlorsulfuron), one in April 2009 (glyphosate), and one untreated control. In September 2010, they applied five seeding treatments to each herbicide treatment by factorially combining two different seed mixes applied with two different seeding methods and an unseeded control. The authors measured plant cover, seedheads, and biomass in June 2009 to 2011 and used statistics to determine treatment effects.

**Location:** California

**Findings:** In June 2009, herbicide treatments had removed most medusahead and cheatgrass cover at both sites. One year after treatment, one site's cheatgrass cover increased across treatments but remained lower on treated plots, and cheatgrass cover was only lower on plots treated with imazapic and glyphosate 2 years after treatment. One year after treatment at the

second site in this study, medusahead cover was only lower on imazapic treated plots, whereas cheatgrass cover remained low across treatments. Two years after treatment, medusahead did not differ across treated and untreated plots and increased within sulfometuron+chlorsulfuron plots, whereas cheatgrass cover remained lower on all treated plots than control plots, except glyphosate-treated plots. Perennial grasses did not respond to treatments at either site, imazapic treatments increased native forb cover within treatments, and seeding did not affect cover of native plant species.

**Implications:** The authors state that all four herbicides are good options for short-term control of medusahead and cheatgrass. However, because they determined imazapic controlled invasives more consistently throughout longer timeframes, they suggest that it may be the best option of the tested herbicides for restoring sites. They suggest poor vegetation establishment from seeding could be due to low rainfall and that unpredictable precipitation may be a barrier for successful revegetation.

**Topics:** population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: herbicides

## Lacroix, C., Jolles, A., Seabloom, E.W., Power, A.G., Mitchell, C.E., and Borer, E.T., 2014, Non-random biodiversity loss underlies predictable increases in viral disease prevalence: Journal of the Royal Society Interface, v. 11, no. 92, p. 1–10.

**DOI:** https://doi.org/10.1098/rsif.2013.0947

**Background:** Biodiversity loss could lead to an increase in disease prevalence. Research on this topic is timely because climate change has increased biodiversity loss and the spread of pathogens.

**Objectives:** The authors sought to (1) assess plant virus prevalence in soft brome grass as it related to site-level plant diversity, (2) understand the likelihood of host species to become infected and transmit infection, (3) evaluate the connection between host abundance and transmission, and (4) link host species with aphid reproduction and preference.

**Methods:** The researchers surveyed 31 plant communities across 10 locations in 2006. To test for viruses, they collected leaf tissue at the end of the growing season from up to 20 individuals of soft brome in each of the plant communities, resulting in 609 samples. They calculated infection prevalence for soft brome and estimated percent cover, abundance, and richness at each location. In the greenhouse, they tested infection susceptibility of 20 grass species (8 perennial native, 1 annual native, 3 perennial native, and 8 annual exotic—including medusahead), and the ability of infected plants from these species to transmit the infection to susceptible barley hosts. To assess aphid fecundity and host preference, they used existing data. First, they placed aphids on 10 individuals from 8 grass species and recorded adult survival and young aphid count. Second, they tested aphid feeding preference by placing aphids in the center of various equidistant plant species and later counting aphids.

**Location:** California, Oregon, British Columbia

**Findings:** The authors determined that virus prevalence decreased as plant diversity increased. Virus prevalence increased as soft brome percent cover increased, but mean cover of soft brome was not affected by plant diversity. Aphid fecundity and preference varied depending on the host species. The most widespread hosts were also associated with more aphids. Soft brome had high rates of viral transmission, high aphid fecundity and preference, and was moderately susceptible to infection. Annual grass species (both exotic and native) were more susceptible to disease than perennials, associated with higher transmission, and had greater aphid fecundity and preference. Exotic species (such as medusahead) were not more susceptible to infection than native species but had higher counts of aphids.

**Implications:** The authors suggest that the entire plant community plays a role in predicting disease prevalence, and in particular highlight that the most common plant species they included in their study were also the most likely to host diseases spread by aphids. They also suggest that environmental changes that affect community composition could determine future disease dynamics.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; other: species and population characteristics; nonnative invasive plants; climate change

## LaForgia, M.L., 2021, Impacts of invasive annual grasses and their litter vary by native functional strategy: Biological Invasions, v. 23, p. 2621–2633.

**DOI:** https://doi.org/10.1007/s10530-021-02527-2

**Background:** Native plants grow using different functional strategies. Resource-acquisitive natives grow quickly when scarce resources are abundant, whereas resource-conservative natives grow slowly to tolerate stress. Previous research indicates that invasives affect native plants differently depending on functional strategy, but there is paltry research on how invasive plant litter affects native plants that vary in functional strategy.

**Objective:** The author examined the effects of invasive grass litter on all life stages of native annual forbs with different functional strategies.

**Methods:** The author established 10 plots, each containing 3 subplots with one of three treatments: (1) no live grass or litter, (2) live grass, and (3) live grass with litter. All grasses and litter were invasive grass species already present at the site. Medusahead was one of four dominant grasses within the subplots. In October 2016, they seeded each subplot with six native annual forb species (three resource-conservative species and three resource-acquisitive species) and then monitored each population for germination, survival, and seed set. To test belowground seed survival, the author buried mesh bags with seed of the same native species in September 2016. In August 2017, they dug up seed bags and counted viable seeds. The author used statistical modeling to assess population growth rate, germination, mortality, and seeds per individual for each species.

**Location:** California

**Findings:** The author determined that live grass and live grass with litter decreased growth rates of acquisitive forbs. Growth rate of conservative forbs was only affected by live grass with litter. Live grass with litter reduced germination of all forb species but had a stronger effect on resource-acquisitive species. The number of seeds per individual decreased with live grass and more greatly in live grass with litter treatments in resource-acquisitive forbs. Live grass with litter treatments increased mortality for all forbs, with higher mortality in acquisitive species.

**Implications:** The author suggests that effects from invasive annual grasses may differ between native forbs with different functional strategies. However, because litter affected all annual forbs in this study, they suggest that litter, rather than competition, may be the primary effect of invasive plants and that invasive plant litter may shift the functional composition of plant communities.

**Topics:** survival; behavior or demographics; population estimates or targets, site-scale habitat characteristics; nonnative invasive plants

## LaForgia, M.L., Kang, H., and Ettinger, C.L., 2021, Invasive grass dominance over native forbs is linked to shifts in the bacterial rhizosphere microbiome: Microbial Ecology, v. 84, p. 496–508.

**DOI:** https://doi.org/10.1007/s00248-021-01853-1

**Background:** Soil microbial communities can differ depending on plant community and may affect plant competition. The role of invasive annual grasses in disrupting bacterial and fungal microbiomes and subsequently altering plant community composition is not well understood.

**Objectives:** The authors sought to assess (1) differences in microbiomes between invasive grasses and native forbs' root zones, (2) the potential role of competition in defining microbiomes, (3) the relative effect of plant group on microbiomes, and (4) the identity and abundance of microbial families relative to plant performance.

**Methods:** In spring and summer of 2017, the authors collected local soil and seeds of six native annual forbs and three invasive annual grasses (such as medusahead) in a serpentine grassland. They seeded five replicates of each forb species paired with each grass species and five replicates of each species seeded alone. Ultimately, the experiment maintained 84 grass-forb pair pots, 27 forb pots, and 15 grass pots. All plant treatments grew in an open-air greenhouse from December 2017 to April 2018, when the authors weighed aboveground biomass and collected soil samples. The authors extracted and sequenced DNA from soil samples and performed statistical analyses to compare bacterial and fungal microbiomes and plant performance across treatments.

**Location:** California

**Findings:** The authors determined that the fungal microbiome did not vary between grasses and forbs, but the bacterial microbiome did. Bacterial diversity was higher in forb microbiomes. Differences in bacterial and fungal communities were more evident between plant groups than species. Grass-forb pairs had different microbiomes than unpaired groups and had higher diversity than grass microbiomes, which may have affected biomass of these two plant functional types when grown together. Grasses had greater biomass than forbs when grown together, but there was no direct relationship between the biomass of grasses and forbs when they were grown together. A small proportion of bacterial families and one fungal family differed between treatments.

**Implications:** The authors suggest that annual grass invasions are likely correlated with microbial shifts across the plant community and that bacteria may be more important than fungi in determining outcomes. They also suggest that certain microbial associations could promote grass growth or suppress forb growth, selectively benefiting invasive annual grasses over native forbs.

**Topics:** genetics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Lazarus, B.E., Feris, K., and Germino, M.J., 2021, Weed-suppressive bacteria effects differ in culture compared to in soils and with or without microbial competition and separation of active ingredient: Biological Control, v. 152, article 104422.

**DOI:** https://doi.org/10.1016/j.biocontrol.2020.104422

**Background:** New strategies for managing invasive annual grasses are needed. Weed-suppressive bacteria reduced root growth of exotic annual grasses in laboratory studies but have shown mixed effectiveness in reducing populations of exotic invasive annual grasses in field settings, possibly due to competition from native soil bacteria.

**Objectives:** The authors sought to (1) reproduce results where weed-suppressive bacteria inhibited medusahead and cheatgrass without harming nontarget species at three bacteria densities, (2) test how presence of other microbes on the seed surface affects bacterial effectiveness, and (3) test bacterial efficacy against medusahead in soils with or without native microbes.

**Methods:** The authors placed surface-sterilized or unsterilized seeds on agar in petri dishes that had been treated with one of two bacterial strains (*Pseudomonas fluorescens* D7, ACK55) at one of three concentrations (high, low, or cell-free filtrate) or a control (sterile media). They tested five plant species: two annual invasive grasses (cheatgrass and medusahead) and three nontarget perennial bunchgrasses (crested wheatgrass, bluebunch wheatgrass, and Sandberg bluegrass). The authors also planted medusahead seeds in soil treated with one of the two bacteria strains or an untreated control. They sterilized soils and seed prior in the bacterial strain experimental treatment to eliminate native microbes. The authors measured germination, root length, and shoot length and ran statistical models to determine the effectiveness of each treatment.

**Location:** Idaho

**Findings:** Neither bacterial treatment reduced medusahead germination or growth in soil with or without native microbes. However, both bacteria strains reduced germination and growth on agar plates. At high bacteria concentrations, reduced germination and growth occurred for both the target annual grasses and the nontarget perennials, and the bacteria effect was stronger when competing microbes were removed by seed surface sterilization. At low concentrations, bacteria inhibited germination and root growth of annual grasses without also inhibiting nontarget perennials but still inhibited shoot growth of all species. Cell-free filtrate did not affect germination or growth of any species.

**Implications:** The authors determined that weed-suppressive bacteria applied at high concentrations were not as selective in this study as previously reported. They suggest that the idea that competition from native microbes may explain the mixed field success of weed-suppressive bacteria was only partially supported by the results of this study.

**Topics:** behavior or demographics; nonnative invasive plants; weed management; weed management subtopic: biocontrol; soils or geology

# Lazarus, B.E., and Germino, M.J., 2019, An experimental test of weed-suppressive bacteria effectiveness in rangelands in southwestern Idaho, 2016–18: U.S. Geological Survey Open-File Report 2019–1050, 19 p.

**DOI:** https://www.doi.org/10.3133/ofr20191050

**Background:** Exotic annual grasses are increasingly threatening rangelands and, once established, are difficult to eradicate. Management treatments include applying herbicides and weed-suppressive bacteria, which are used as biocontrol agents to reduce exotic grass root growth. However, it is unclear if applying weed-suppressive bacteria independently or in combination with herbicides is effective in controlling invasive grasses such as medusahead and cheatgrass.

**Objectives:** The authors sought to determine the effectiveness of weed-suppressive bacteria in controlling invasive annual grasses independently or combined with (1) two different herbicides and (2) two application methods.

**Methods:** In 2016, researchers established burned plots in three locations across a range of climatic conditions. They fenced and preburned the sites in fall 2016 and applied 10 treatments, randomly replicated three times at each location. The treatments included application of two strains of a commercially available weed-suppressive bacterium (*Pseudomonas fluorescens* strains D7 and MB906) in combination with two herbicides (imazapic and rimsulfuron) and two application methods (surface spraying or discing). Discing treatments followed bacterial application with a rangeland drill. Researchers measured vegetation cover pretreatment and for 2 years after application. They used statistical analyses to compare the effects of each treatment on total vegetation cover and annual and perennial grass cover for each site across the study period.

**Location:** Idaho

**Findings:** Across all locations in both study years, the two bacterial strains did not affect vegetation cover when applied independently or in combination with herbicides or for each application method. In both years, the herbicide imazapic decreased annual grass cover but did not result in increased perennial grass cover. The herbicide rimsulfuron reduced total vegetative cover and invasive annual grass cover at all locations in the first year but had varying results in the second year.

**Implications:** The authors suggest that the weed-suppressive bacteria used in this study were not effective in reducing invasive annual grasses. They note that the bacterial populations may not have grown enough to become toxic to invasive annual grasses during the 2-year study. The authors also suggest that imazapic is more effective short term at controlling invasive annual grasses than rimsulfuron or the weed-suppressive bacteria.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: biocontrol; weed management subtopic: herbicides

## Lazarus, B.E., and Germino, M.J., 2021, A chemical and bio-herbicide mixture increased exotic invaders, both targeted and non-targeted, across a diversely invaded landscape after fire: Applied Vegetation Science, v. 24, no. 2, article e12574, 13 p.

**DOI:** https://doi.org/10.1111/avsc.12574

**Background:** Invasive species can cause changes in sagebrush steppe ecosystem characteristics that facilitate establishment of secondary invasive plants. Management tools such as herbicides and weed-suppressive bacteria to control invasive species can have unintended effects on native and nonnative plant species composition and plant pathogens.

**Objectives:** The authors sought to explore how postfire herbicidal and bacterial treatment affected (1) plant functional groups, (2) plant species diversity, and (3) a plant pathogen across landscape characteristics and time.

**Methods:** In November 2016, after summer wildfires, land managers treated 486 ha with a tank mixture of a preemergent herbicide, imazapic, and a bacterium designed to suppress cheatgrass and medusahead (*Pseudomonas fluorescens* strain MB906). The authors identified 41 pairs of comparable sprayed and unsprayed plots within burned areas. In each plot, they sampled vegetation and soil characteristics and the presence of a cheatgrass pathogen 2 and 3 years posttreatment. They determined topographic characteristics using digital models. They used statistical analysis to identify the effects of spraying on vegetation functional groups through time and across landscape characteristics.

**Location:** Idaho

**Findings:** Spraying reduced cover of cheatgrass and medusahead 2 years but not 3 years after treatment and was more effective in flat bottomlands. Invasive perennial forb cover was greater in treated areas both years and in warmer, drier sites. Exotic annual forb cover increased after spraying on cooler, wetter sites and decreased after spraying on warmer, drier sites. Native perennial forbs increased marginally after spraying, and native shrubs increased after spraying on less gravelly soils. Spraying reduced native annual forb cover where these plants were more likely to occur. Overall, cover of nontarget invasive annual grasses and perennial grasses was not significantly different between sprayed and untreated areas and spraying reduced invasive species diversity only in the second year after treatment. The presence of the cheatgrass pathogen varied with cheatgrass density.

**Implications:** The authors suggest that one-time herbicide-bacteria treatment temporarily reduced target species cover postfire, did not substantially increase desirable species, and resulted in increases in undesirable exotic forbs. The authors speculate that increases in nontarget invasive species inhibited growth of desirable species. They concluded that invasive species treatment plans should account for all species present because undesirable results are possible.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: biocontrol; weed management subtopic: herbicides; water; soils or geology

## Lazarus, B.E., and Germino, M.J., 2021, Post-fire vegetation cover, plant species diversity, and *Ustilago bullata* infection rates at Boise River Wildlife Management Area 2018–2019: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9CB7C62

**Background:** Exotic annual grasses increase wildfires and pose risks to native perennial plant communities. Landscapes are often invaded concurrently with a diverse number of exotic plant species, but methods for controlling invasive species mostly focus on a small subset of target species. Therefore, exploring treatment effects on controlling a wider variety of exotic invasive species could be beneficial for managing complex landscapes.

**Objectives:** The authors sought to assess responses of (1) exotic annual grasses, such as cheatgrass and medusahead, and (2) nontarget species to a mixture of an herbicide and a weed-suppressive bacterium applied over large landscapes after wildfire.

**Methods:** The researchers assessed responses of the plant community and a natural cheatgrass pathogen to spray treatment across different wildfire sites within a Wildlife Management Area. After the postfire aerial application of a mixture of pre-emergent herbicide (imazapic) and a weed-suppressive bacterium (*Pseudomonas fluorescens* strain MB906) to 486 ha in November 2016, researchers monitored plant cover and diversity in 41 paired plots inside and outside treated areas in the summers of 2018 and 2019. They also collected soil cores to assess soil texture and organic-matter content and used spatial data to determine physical properties of sites, consisting of elevation, slope, and aspect. They identified more than 90 species that they grouped into different functional groups for cover analyses.

**Location:** Idaho

**Findings:** The authors developed datasets containing plot-level landscape variables related to slope, elevation, climate, and soil characteristics; plant cover by vegetation group; and species diversity and cheatgrass pathogen infection rates in treated and untreated areas.

**Implications:** The authors suggest that these data can provide insight into vegetation responses to invasive species control methods across large, topographically complex landscapes after wildfire.

**Topics:** site-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: herbicides; weed management subtopic: biocontrol; soils or geology

## Lazarus, B.E., Germino, M.J., Brabec, M., Peterson, L., Walker, R.N., and Moser, A., 2020, Post-fire management-scale trials of bacterial soil amendment MB906 show inconsistent control of invasive annual grasses: Rangeland Ecology and Management, v. 73, no. 6, p. 741–748.

**DOI:** https://doi.org/10.1016/j.rama.2020.03.005

**Background:** Invasive annual grasses can replace perennial grasses and shrubs in western rangelands after wildfires. Along with herbicide application, a type of soil bacteria has been used as a biopesticide to target invasive grasses. However, previous studies coapplied bacteria and herbicides, and researchers were unable to determine what treatment caused the vegetation response.

**Objectives:** The authors sought to determine how (1) invasive grasses and (2) native grasses responded to applications of a type of soil bacteria across landscapes through time.

**Methods:** In fall 2016, researchers implemented four treatments: (1) bacteria only, (2) herbicide only (imazapic), (3) combined bacteria and herbicide, and (4) untreated plots across three different locations postfire. They measured plant cover on all treatments for three vegetation groups: (1) all invasive annual grasses, (2) target invasive annual grasses (medusahead and cheatgrass), and (3) perennial grasses for 3 consecutive years. Treatment areas and vegetative plots varied in size for each location. The researchers tested for differences across treatment effects on vegetation groups through time and across locations.

**Location:** Idaho

**Findings:** Across all locations, the bacteria-only treatment did not reduce total invasive grass cover in any year but did reduce target invasive grass cover in the second year. The herbicide-only treatment reduced all invasive and target invasive grass cover in the first 2 years, but not in the third year. The treatment combination of bacteria and herbicide reduced invasive grasses less than the herbicide-only treatment, but this difference was not statistically significant. Perennial grass cover increased with the herbicide-only treatment at one location. Perennial grass cover was lowest in the first year and highest in the second year, although this pattern differed slightly by location.

**Implications:** Overall, the authors did not find that applying the bacteria reduced invasive grasses across landscapes, except for reducing target invasives in year 2, which may warrant further study. The authors suggest that mixing the herbicide and bacteria may have decreased the herbicide's toxicity toward invasive grasses and that the differences seen between locations could have been due to varied environmental conditions.

**Topics:** population estimates or targets; site-scale habitat characteristics; fire; nonnative invasive plants; weed management; weed management subtopic: biocontrol; weed management subtopic: herbicides

## Leffler, A.J., James, J.J., and Monaco, T.A., 2013, Temperature and functional traits influence differences in nitrogen uptake capacity between native and invasive grasses: Oecologia, v. 171, no. 1, p. 51–60.

**DOI:** https://www.doi.org/10.1007/s00442-012-2399-4

**Background:** The Great Basin Region is heavily invaded by exotic annual grasses. Studying the effects of temperature and plant traits on nitrogen uptake in native and invasive species can provide insights into invasion dynamics.

**Objectives:** The authors sought to (1) assess the effect of temperature on nitrogen uptake in native and nonnative perennial species and invasive annual grass species, (2) determine which traits predict nitrogen uptake, and (3) understand the relationship between temperature and predictive traits.

**Methods:** Researchers grew plants from two native perennials (bottlebrush squirreltail and bluebunch wheatgrass), one nonnative perennial (crested wheatgrass), and two annual invasive grasses (cheatgrass and medusahead) individually in pots with three to five seeds of each species. They placed 20 individuals of each species in growth chambers at one of four temperatures 10 days after plants emerged. Starting 5 weeks after germination, they randomly removed 10 pots of each species and measured nitrogen absorption, nitrogen uptake, leaf mass, leaf surface area, leaf nitrogen, root length, root mass, root surface area, and root nitrogen. They used statistical analyses to examine differences in nitrogen uptake for different species at different temperatures.

**Location:** Utah

**Findings:** The authors determined that nitrogen uptake differed by species and that differences were temperature dependent. Nitrogen absorption rate related to plant biomass was the best predictor of plant nitrogen uptake across species. All species had similar absorption rates at low temperatures but different rates at higher temperatures. Medusahead nitrogen uptake increased at higher temperatures. Root mass and leaf mass were the strongest morphological predictors of nitrogen uptake. Nitrogen uptake greatly differed between annuals and perennials. The authors identified that at low temperatures, leaf traits predicted nitrogen uptake for both annuals and perennials, but at high temperatures, leaf traits predicted uptake for annuals and both leaf and root traits were predictive of uptake for perennials.

**Implications:** The authors suggest that, at higher temperatures, annual invasive grasses may face fewer constraints than perennials and more readily acquire nitrogen, signaling an additional competitive advantage under predicted climate scenarios. They suggest that their findings support a more comprehensive understanding of exotic annual grasses in the Great Basin.

**Topics:** behavior or demographics; nonnative invasive plants; climate change; soils or geology

## Leffler, A.J., Monaco, T.A., and James, J.J., 2011, Nitrogen acquisition by annual and perennial grass seedlings—Testing the roles of performance and plasticity to explain plant invasion: Plant Ecology, v. 212, p. 1601–1611.

**DOI:** https://www.doi.org/10.1007/s11258-011-9933-z

**Background:** Successful species invasion occurs when species disperse to disturbed areas, tolerate harsh conditions, or grow quickly compared to native plants. Invasive seedlings may outperform native species after emergence, but performance differences can depend on environmental conditions.

**Objectives:** The authors sought to determine how different temperatures during the growing season affects (1) tissue production, (2) nitrogen uptake, and (3) if changes in tissue production and uptake are different for invasive and native grasses species.

**Methods:** The authors planted 100 seeds per species, each into 10 boxes, which were grown in 4 different temperatures. Species included two native perennial grasses (bottlebrush squirreltail, bluebunch wheatgrass), one nonnative perennial grass (crested wheatgrass), and two nonnative annual grasses (cheatgrass and medusahead). The authors measured shoot length, nitrogen uptake, and biomass up to 10 days after germination.

**Location:** Utah

**Findings:** Initial medusahead height growth after emergence was faster than any other species regardless of temperature, but perennial grasses had similar heights to medusahead after the first week. Medusahead had the highest root-to-shoot ratio, whereas cheatgrass had the lowest. Cheatgrass had the highest nitrogen uptake at the highest temperature compared to the other species. Cheatgrass had the highest absorption rate and whole plant nitrogen uptake, whereas medusahead was similar to the other perennial grasses. Low temperatures reduced nitrogen absorption in all species, and as temperatures increased, cheatgrass ultimately grew faster and was able to uptake more nitrogen than any other species in the trial.

**Implications:** The authors suggest that exotic annual grasses and perennial vegetation have similar nitrogen uptake at low temperatures but that exotic annual grasses have higher nitrogen uptake rates at high temperatures. Because warmer temperatures are expected in the coming decades, the authors suggest managers focus on maintaining perennial vegetation to prevent further invasion of plant communities.

**Topics:** behavior or demographics; nonnative invasive plants; soils or geology

## Li, D., Miller, J.E.D., and Harrison, S., 2019, Climate drives loss of phylogenetic diversity in a grassland community: Proceedings of the National Academy of Sciences, v. 116, no. 40, p. 19989–19994.

**DOI:** https://doi.org/10.1073/pnas.1912247116

**Background:** Climate change may cause shifts in the genetic diversity of plant communities, which may lead to a loss of certain traits. Plants that are not tolerant to drought or heat may die off, resulting in a plant community with lower resilience to water and temperature variability. Although many studies have documented the effects of climate change on biodiversity, few have looked at how climate change can cause community-wide genetic shifts in grasslands.

**Objectives:** The authors sought to analyze (1) how changes in climate through time affected the genetic diversity of a grassland community, (2) if changes to diversity related to precipitation levels, and (3) if changes in diversity were associated with certain plant types.

**Methods:** From 2000 to 2018, the authors collected data on plant community composition at 80 sites within a large grassland. At each location, the authors established five quadrats to examine species composition at within-site (each quadrat), site (all five quadrats within a site), and regional (all quadrats at all sites) scales. Within the grassland, the authors identified plant groups including exotic annual grasses (medusahead, wild oat, and soft brome) and native and nonnative forbs. They also regularly collected data on local precipitation levels. After data collection, they created statistical models to determine if the community's genetic diversity was shifting during the study period and which plant groups were changing.

**Location:** California

**Findings:** The genetic diversity in this community declined at within-site and site scales but was stable regionally. Site-level genetic diversity was positively associated with winter rainfall, and this critical winter rainfall generally decreased during the study period. Because of their connection to winter rainfall amount, native forbs were disproportionately lost at site levels in comparison to other plant groups. This loss of native forbs largely contributed to the site-level declines in genetic diversity.

**Implications:** The authors state that the directional change toward hotter and drier climates may cause a decrease in genetic diversity, which could decrease the resilience of plant communities to further environmental change. The authors suggest that maintaining several species with similar traits through climatic extremes can help to stabilize communities and that preserving higher levels of genetic diversity across larger spatial scales can help to mitigate losses of genetic diversity at smaller scales. In management terms, preserving plant diversity at the landscape scale can help buffer the effects of climate change, even if plant diversity only persists in heterogenous communities across landscape units.

**Topics:** population estimates or targets; genetics; broad-scale habitat characteristics; site-scale habitat characteristics; nonnative invasive plants; weather and climate patterns; climate change; drought; water

## Li, Y.M., Roche, L.M., and Gornish, E.S., 2020, Bridging the research-implementation gap in weed management on California rangelands: Rangeland Ecology and Management, v. 73, no. 3, p. 348–357.

**DOI:** https://doi.org/10.1016/j.rama.2020.01.007

**Background:** Invasive plants negatively affect natural resources, and more effective control measures are needed. However, there is often a "research-implementation gap" where science-based research is perceived as inaccessible, unaffordable, or irrelevant to the managers who would use it.

**Objectives:** The authors sought to gather information from weed management practitioners related to (1) weed management costs, (2) high-priority weeds, and (3) spatial and temporal variation in weed management.

**Methods:** The authors developed and distributed a survey to 309 weed management practitioners at 7 university co-op workshops between 2016 and 2018. They analyzed responses to eight survey questions about respondents' professional affiliation and region of focus, weed management perspectives, and management practices. The authors analyzed results using qualitative and quantitative methods.

**Location:** California

**Findings:** The authors received 259 survey responses. The average annual weed management cost was around $5 per hectare regardless of location across the region. As the size of weed management areas increased, per-unit cost of management decreased. The respondents identified thistles (particularly yellow star thistle) and medusahead as the most problematic weeds.

Medusahead was identified as one of the most problematic weeds across all ecoregions and organizations. Most respondents reported changes in rangeland weeds in the past 5 to 10 years related to increases in weed abundance and coverage and shifts in weed species. Most respondents indicated that drought negatively affected weed management and that these effects were related to lowered treatment efficiency, more competitive or prevalent weeds, and increased complexity in treatment timing.

**Implications:** The authors suggest that because respondents indicated increases in weeds in recent years, modern spending on weed management may be ineffective and particularly inadequate in drought conditions. However, because smaller management operations and budgets can limit weed management, they propose a need for more effective communication and collaboration between researchers and practitioners to create cost-effective weed management strategies. They also state that although medusahead was identified as one of the top three high-priority weed species, it is not one of the top researched species, indicating potential to fill a scientific gap as well as a practitioner need.

**Topics:** nonnative invasive plants; weather and climate patterns; climate change; drought; weed management; human dimensions or economics

## Litt, A.R., and Pearson, D.E., 2013, Non-native plants and wildlife in the Intermountain West: Wildlife Society Bulletin, v. 37, no. 3, p. 517–526.

**DOI:** https://www.doi.org/10.1002/wsb.306

**Background:** Invasive plants can alter ecosystem dynamics, such as native plant diversity, water runoff, and nutrient uptake. Although the effects of invasive plants on native plants have been widely studied, less is known about the effects of nonnative plant species on wildlife.

**Objectives:** The authors sought to review the interactions between nonnative plants and wildlife species.

**Methods:** The authors reviewed and synthesized literature about invasive or nonnative plants and the effects on wildlife, differentiating between food resources and habitat.

**Location:** Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** Cheatgrass and medusahead invasions have led to a decreased abundance of specialist rodents and breeding birds, whereas generalist wildlife species either increase or are less affected by invasions. Vegetation changes can alter food resources, change forage quality, and modify predator-prey dynamics. Nonnative grass invasions can alter habitat structure and cause vegetation to become more homogenous with less open space between plants. A homogenous invasive landscape can decrease native shrub cover, which may shift bird communities and decrease populations of native rodents. Dense stands of cheatgrass may also hinder some terrestrial species' ability to avoid predators and forage for food, which may ultimately affect survival, growth, and reproduction. Vegetation structure changes may favor some wildlife species through the creation of beneficial characteristics that were scanty with previous plant compositions. Wildlife may also facilitate invasions by dispersing medusahead seeds caught on animal fur, creating soil disturbances, or through seed predation. Weed management strategies have been implemented for many invasive species, but it is unknown if treatments effectively mitigate effects to wildlife.

**Implications:** The authors suggest that the effects of invasive plants on wildlife are species specific depending on dietary and habitat structure needs. Vegetation changes can affect food availability or habitat quality through altering vegetation structures for nesting or predation cover.

**Topics:** dispersal, spread, vectors, and pathways; habitat selection; predators or predator control; fire; nonnative invasive plants; grazing/herbivory; weed management; sensitive/rare wildlife

## Lohr, K., Yensen, E., Munger, J.C., and Novak, S.J., 2013, Relationship between habitat characteristics and densities of southern Idaho ground squirrels: Journal of Wildlife Management, v. 77, no. 5, p. 983–993.

**DOI:** https://doi.org/10.1002/jwmg.541

**Background:** The southern Idaho ground squirrel is a candidate species under the Endangered Species Act due to habitat loss and range reduction. More information about the ground squirrel's habitat preference is needed to inform potential restoration or translocation efforts to effectively conserve this species.

**Objectives:** Researchers aimed to assess the role of (1) soil texture, (2) topography, and (3) vegetation in determining the density of ground squirrel burrows.

**Methods:** The researchers randomly selected 21 study sites from a range of occupied habitat. They established 79 plots across the study sites, with a mix of low-density and high-density plots based on the number of burrows observed in the early summers of 2004 and 2005. They collected soil samples in April of 2004 and 2005 to analyze soil texture and calculated slope and aspect using digital spatial analysis tools. The researchers visually estimated plant cover at 29 plots in 2004 and 50 plots in 2005. They assigned 78 species to 19 plant functional groups and performed statistical analyses to assess the relations between plant functional groups, soil texture, topography, and squirrel burrow entrance density.

**Location:** Idaho

**Findings:** The researchers identified that plots with high-density burrows were associated with soils containing greater proportions of silt. High-density plots were mostly on north- and east-facing aspects, but slope did not affect burrow density. Lastly, plots with high-density burrows were associated with higher proportions of native perennial grasses and forbs and greater plant diversity. Soil texture and aspect had the greatest effect on burrow density, but vegetation composition also played an important role. Plots with low-density burrows were associated with sandy soils, south-facing aspects, lower plant diversity, and exotic annual grasses (such as cheatgrass and medusahead).

**Implications:** The authors suggest that restoration and translocation efforts to conserve the southern Idaho ground squirrel should primarily focus on habitats with silty soils, east-facing aspects, and high native plant diversity. They also suggest that restoration seed mixes should include diverse combinations of species dominated by native perennial forbs.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat selection; habitat restoration or reclamation; nonnative invasive plants; soils or geology; sensitive/rare wildlife

## Louhaichi, M., Carpinelli, M.F., Richman, L.M., and Johnson, D.E., 2012, Native forb response to sulfometuron methyl on medusahead-invaded rangeland in eastern Oregon: The Rangeland Journal, v. 34, no. 1, p. 47–53.

**DOI:** https://www.doi.org/10.1071/RJ11021

**Background:** Medusahead invasion in the western United States is negatively affecting both domestic livestock and wildlife. Sulfomenturon methyl is an herbicide commonly used to control medusahead on rangelands and, when applied at low rates, has been shown to control medusahead without affecting native perennial species. However, there is little information about how this herbicide may affect native forbs.

**Objectives:** The authors sought to assess how application of the herbicide sulfomenturon methyl affects native forb density.

**Methods:** The authors selected three study sites, randomly selected plots at each site, and paired plots with similar ecological conditions, establishing a total of 65 paired plots across the three sites. In autumn 2001, they applied herbicide to one randomly selected plot from each pair, leaving the other as a control. The authors organized sampling in each plot, recorded forb species composition and species density, and took photographs to analyze green leaf cover in May 2001 before treatments and after treatments in May 2002 to 2004. They also took soil samples to identify potential differences between the sites. They used statistical models to compare the effects of the treatment on each forb species.

**Location:** Oregon

**Findings:** The authors evaluated 11 native forb species within plots at their field sites. Three years after herbicide application, six species had significantly reduced density in plots with herbicide application compared to control plots. After 3 years, there was also significantly less vegetation cover in herbicide-treated plots compared to the controls. Statistical modeling showed the effect of the herbicide differed greatly depending on the forb species and the year since treatment. Soil attributes did not differ between the three sites.

**Implications:** The authors state that when using sulfomenturon methyl to control medusahead, managers should also consider the potential for the herbicide to negatively affect nontarget species. They suggest that reductions in forb density may have secondary consequences because forb reduction may open areas to invasion by new species. The authors suggest that low-herbicide rates paired with appropriate site preparation may minimize effects on nontarget species.

**Topics:** population estimates or targets; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: herbicides; soils or geology

## Maestas, J.D., Porter, M., Cahill, M., and Twidwell, D., 2022, Defend the core—Maintaining intact rangelands by reducing vulnerability to invasive annual grasses: Rangelands, v. 44, no. 3, p. 181–186.

**DOI:** https://doi.org/10.1016/j.rala.2021.12.008

**Background:** Proactively minimizing threats to intact rangelands could reduce vulnerability to annual grass invasion. The vulnerability of a landscape depends on ecological risk factors and the ability of human communities to manage and adapt to invasions. Preventative management can be effective and cost efficient because it addresses invasions before they become widespread.

**Objectives:** The authors sought to highlight a broad-scale, crossboundary framework for invasive annual grass management in shrubland and grassland ecosystems in the western United States.

**Methods:** The authors reviewed literature about invasive annual grass management to support a conceptual framework for broad-scale, proactive management of invasive plants. They considered landscape context and scale in risk assessments to understand whether management should focus on protection and prevention or mitigation and rehabilitation. They outlined three avenues for minimizing vulnerability of intact rangelands, which include reducing exposure to invasive seed sources, improving resilience by promoting perennial plants, and building capacity to adapt to change.

**Location:** Not specified

**Findings:** The authors stated that landscape context and scale are important for understanding vulnerability and identifying appropriate management approaches. They also stated that limiting invasive seed dispersal by managing access to invaded areas, monitoring travel corridors, regulating agricultural seed contamination, and depleting invasive seeds in the seed bank using selective herbicides could collectively reduce exposure to invasive seed sources. Promoting the health of perennial native plants through restoration seeding, treating invasive competitors, and limiting ground-disturbing activities could improve resilience. Viewing invasive species management through a socioecological lens and incorporating flexibility, long-term funding, community involvement, and knowledge-sharing strategies could contribute to building capacity to adapt to changing conditions.

**Implications:** The authors propose integrating proactive approaches to mitigate vulnerability of intact rangelands with monitoring and adaptive management responses. They recommend focusing on mechanisms of invasion and prioritizing protection of intact rangelands rather than strictly managing landscapes that have already been invaded.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; nonnative invasive plants; weed management; human dimensions or economics

## Malmstrom, C.M., Butterfield, H.S., Planck, L., Long, C.W., and Eviner, V.T., 2017, Novel fine-scale aerial mapping approach quantifies grassland weed cover dynamics and response to management: PLOS ONE, v. 12, no. 10, article e0181665, 28 p.

**DOI:** https://www.doi.org/10.1371/journal.pone.0181665

**Background:** Early detection of invasive species infestations includes using remotely sensed imagery to distinguish landscape-scale differences in vegetation composition. Medusahead and barbed goatgrass growing seasons overlap with important forage plants, which makes them challenging to differentiate and detect using satellite imagery. However, it is possible to use aerial imagery to remotely detect invasions based on differing growth stages associated with variations in peak greenness.

**Objectives:** The authors sought to (1) determine medusahead and barbed goatgrass invasions using aerial imagery and (2) evaluate the persistence of forage and weed-dominated patches relative to management efforts.

**Methods:** Researchers surveyed four management units on three private properties, ranging in grazing intensities. In spring and summer of 2008 to 2009, they used a mapping camera to collect aerial imagery during peak growth and at the end of the growing season. They used 1-m-scale imagery and ground-truth points to differentiate between weed-dominated versus forage-dominated patches based on changes in greenness through time. They compared differences in cover for vegetation types across months, years, and properties to determine the persistence of weed patch distributions in ungrazed and grazed units.

**Location:** California

**Findings:** Spring images with forage dominance appeared greener than weed patches, and the opposite was true at the end of the growing season. Annual grasses could be detected separately from forage species during the growing season. Weed-dominated cover was more persistent in ungrazed properties and was associated with thatch layers, whereas grazed properties had more forage cover.

**Implications:** The authors suggest that land managers can use aerial imagery as a simple and cost-effective method to determine invasive weed distributions and persistence through time to inform adaptive management strategies. This technique can support early detection of new invasions and allow for early prevention efforts.

**Topics:** broad-scale habitat characteristics; site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; includes new geospatial data

## Mangla, S., Sheley, R.L., and James, J.J., 2011, Field growth comparisons of invasive alien annual and native perennial grasses in monocultures: Journal of Arid Environments, v. 75, no. 2, p. 206–210.

**DOI:** https://www.doi.org/10.1016/j.jaridenv.2010.09.015

**Background:** Medusahead is invading grasslands across the western United States that are dominated by native grasses or other invasive grasses such as cheatgrass. However, no previous field experiment has compared the growth characteristics of medusahead with species already present in the ecosystems it invades.

**Objectives:** The authors sought to compare growth characteristics of medusahead, bluebunch wheatgrass, and cheatgrass.

**Methods:** The authors organized a field experiment across the 2008 and 2009 growing seasons. In 2008, they applied herbicide (glyphosate), removed all vegetation, and established five test plots for each species. In both years, they randomly assigned and spread each of the three seed types among different plots and harvested sample plants in all plots throughout the growing season to dry and weigh biomass. The authors used statistical analyses to compare the relative growth rate, period of growth, and resulting total biomass of the three plant species.

**Location:** Oregon

**Findings:** 2008 was a historically dry year, whereas 2009 had close to average precipitation. In 2008, medusahead had a longer growing period and higher biomass than cheatgrass but lower total biomass than bluebunch wheatgrass. In 2009, medusahead grew longer and had more biomass than bluebunch wheatgrass or cheatgrass. In both years, averaged across sampling days, medusahead had a higher growth rate than cheatgrass.

**Implications:** The authors suggest that species biomass may vary depending on the amount and timing of precipitation, as seen in this study with higher biomass of bluebunch wheatgrass in the dry 2008 season versus higher medusahead biomass in the average 2009 season. Climatic conditions under which bluebunch outperformed medusahead in this experiment are less common historically than those that favor medusahead. The authors also indicate that medusahead may replace cheatgrass through time in an ecosystem because medusahead grows later into the season, producing more biomass overall.

**Topics:** behavior or demographics; nonnative invasive plants; weather and climate patterns; drought

## Mangla, S., Sheley, R.L., James, J.J., and Radosevich, S.R., 2011, Intra and interspecific competition among invasive and native species during early stages of plant growth: Plant Ecology, v. 212, p. 531–542.

**DOI:** https://doi.org/10.1007/s11258-011-9909-z

**Background:** Annual invasive grasses are a threat to semiarid ecosystems. To effectively manage these species, resource managers must understand their ecological processes. Specifically, understanding competition between different species and between individuals of the same species will be important to restoration efforts, which may vary at different levels of nutrient availability and life history stages.

**Objective:** The authors sought to understand how type and intensity of competition affects growth of native and nonnative grass species with or without nitrogen application.

**Methods:** The authors performed a greenhouse experiment from June to November 2008 in which they grew two native perennial grasses—bluebunch wheatgrass and Sandberg bluegrass—and two invasive annual grasses—medusahead and cheatgrass—from field-collected seeds and soil. They applied a combination of three treatments: one of 14 combinations of the 4 grass species (species alone, species with itself, and species with each of the 3 other species), application of nitrogen, or a harvest date of 15, 30, 60, or 90 days after planting, for a total of 1,120 experimental units. The authors measured total biomass for each seedling and ran statistical analyses to determine the effect of their treatments on final biomass and competitive effects.

**Location:** Oregon

**Findings:** The authors observed competition between different species and between individuals of the same species particularly during early growth stages. Competition within species varied across time and was greatest for native species at earlier harvest dates. Annual invasive grasses were more competitive when nitrogen was applied than native species. Bluebunch wheatgrass was competitive with medusahead and cheatgrass at the two early harvest dates.

**Implications:** The authors suggest that managers should consider reducing the seeding rate of native species in restoration to account for within-species competition at early growth stages. They also suggest that bluebunch wheatgrass may be a better native competitor to annual invasive grasses than Sandberg bluegrass but that its competitive advantage is short lived. Finally, the authors state that increased nitrogen may cause annual invasive grasses to be more competitive.

**Topics:** behavior or demographics; nonnative invasive plants; weed management; weed management subtopic: cultural control; soils or geology

## Mangla, S., Sheley, R.L., James, J.J., and Radosevich, S.R., 2011, Role of competition in restoring resource poor arid systems dominated by invasive grasses: Journal of Arid Environments, v. 75, no. 5, p. 487–493.

**DOI:** https://www.doi.org/10.1016/j.jaridenv.2011.01.002

**Background:** Invasive plant competition may be one factor contributing to native vegetative failure, but abiotic factors may also play a role, particularly in resource-poor environments. A greater understanding of the competitive traits of invasive grasses is important to determine restoration priorities.

**Objectives:** The authors sought to determine (1) the competition intensity between native and invasive grasses and (2) the importance of how competition could affect plant biomass and survivorship in a resource-poor system.

**Methods:** In spring 2008, researchers applied herbicide (glyphosate) to remove existing vegetation followed by rototilling the soil. In May of 2008, they seeded four grass species (cheatgrass, medusahead, bluebunch wheatgrass, and Sandberg bluegrass) either alone, or in a mixture with five seeding densities for each possible species combination. Each treatment was replicated three times for 1,875 total plots. Four weeks after seeding and 1 year after seeding, they measured emergence and density. The researchers measured biomass in August 2008 and July 2009. They performed statistical analyses to quantify the competitive effects of invasive species on plant biomass and survivorship.

**Location:** Oregon

**Findings:** Cheatgrass, medusahead, and bluebunch wheatgrass biomass, density, or survivorship did not change when planted alone or with other species, indicating no effects of competition. Invasive grass biomass increased through time. Sandberg bluegrass plants did not survive through time.

**Implications:** The authors suggest that to improve restoration success through plant establishment in resource-poor environments, determining strategies to overcome abiotic factors (for example, drought or cold stress) may be more beneficial than focusing on competitive plant interactions.

**Topics:** survival; behavior or demographics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control

## Marchetto, K.M., Wolf, T.M., and Larkin, D.J., 2021, The effectiveness of using targeted grazing for vegetation management—A meta-analysis: Restoration Ecology, v. 29, no. 5, article e13422, 12 p.

**DOI:** https://doi.org/10.1111/rec.13422

**Background:** Targeted grazing is a low-cost, versatile method for invasive plant control achieved by carefully controlling the density, duration, and timing of livestock grazing. Recent increased use of targeted grazing has raised the need for investigation into its effectiveness.

**Objectives:** This study evaluated existing evidence for the effectiveness of targeted grazing to (1) control undesired plant species, (2) increase plant community richness and diversity, and (3) affect general plant abundance.

**Methods:** The authors performed a review of experimental studies that isolated the effect of targeted grazing on plants. The authors sampled the literature using systematic searches of online literature databases, which yielded 70 studies meeting the criteria for inclusion. The systematic review consisted of a statistical method for combining data from the sampled studies, which allowed for exploration of patterns across studies. The authors used the combined data to examine the effects of livestock species, years of grazing, and control methods on undesired plant species and community characteristics. Undesired plant species in the sampled studies included 45 invasive, toxic, or fuel-loading species. The most frequently studied species were leafy spurge, medusahead, yellow star thistle, and cheatgrass.

**Location:** North America

**Findings:** Targeted cattle, sheep, and goat grazing resulted in current-year reduction of undesired plant species relative to control plots; however, undesirable plant species grew back in the year after grazing. Duration of grazing did not have a significant effect on control of undesired plant species. Targeted grazing had an overall positive effect on plant community richness, and increased grazing duration had a small positive effect on richness. There was no significant overall effect of targeted grazing on general plant abundance.

**Implications:** The authors suggest that, across habitats and livestock species, targeted grazing could be used for current-year control of undesired plant species and achieving increases in plant community richness, indicating the applicability of targeted grazing as a tool in ecological restoration. However, the authors believe their findings also demonstrate a need for more research into the effects of grazing treatments during posttreatment years and to what extent increases in community richness are due to native or exotic plant species.

**Topics:** population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Marini, F., Weyl, P., Vidović, B., Petanović, R., Littlefield, J., Simoni, S., de Lillo, E., Cristofaro, M., and Smith, L., 2021, Eriophyid mites in classical biological control of weeds—Progress and challenges: Insects, v. 12, no. 6, article 513, 25 p.

**DOI:** https://doi.org/10.3390/insects12060513

**Background:** Treating invasive species with methods such as biocontrols can be a viable option to target infestations long term at a lower cost. Recent research has shown that mites can be used to control invasive plants; however, there is a need to further explore their effects.

**Objectives:** The authors sought to describe the effectiveness of using mites as a biocontrol method by understanding the (1) species biology, (2) limitations, and (3) release process to control invasive species.

**Methods:** The authors reviewed and synthesized literature to describe mite characteristics, consisting of host specificity, risks involved during release, and effects on weed species. They also summarized the effects of mite release and the monitoring process.

**Location:** North America

**Findings:** The authors identified that for mites to be an effective biocontrol, mites may need to reach certain density levels, mites need access to certain plant tissues, and target plants need to be at a development stage when they are vulnerable to mites. There are many factors that may limit mite effects, considering that local adaptations may be highly specific. Additionally, identifying the effects of mites on plants may be difficult to detect due to their size. The authors determined that different mite species may be adapted to the same plant and that morphologically similar species may be distinct species, as was identified on medusahead and cheatgrass. Mites that have coevolved with hosts may be ineffective in controlling populations. To release mites, managers need to be able to identify species, transfer mites to invasive plants, and ensure mites can effectively disperse to other plants. After release, managers should monitor the effects on invasive and nontarget species.

**Implications:** The authors suggest that for mites to be useful as a biocontrol, managers need to understand mite and plant biology, potential effects on target and nontarget species, and the utility of genetic analyses to discern differences in species. They also suggest that biocontrol programs should understand the release steps and the postrelease monitoring to understand the effects of mites on plant communities.

**Topics:** survival; nonnative invasive plants; weed management; weed management subtopic: biocontrol

## Mariotte, P., Spotswood, E.N., Farrer, E.C., and Suding, K.N., 2017, Positive litter feedbacks of an introduced species reduce native diversity and promote invasion in Californian grasslands: Applied Vegetation Science, v. 20, no. 1, p. 28–39.

**DOI:** https://www.doi.org/10.1111/avsc.12291

**Background:** Invasive species that produce large quantities of litter with low decomposability could generate feedbacks that intensify the dominance of invasive species. Litter accumulation poses risks to the establishment and growth of native plants because litter can alter physical and chemical characteristics at the soil surface.

**Objectives:** The authors sought to (1) compare the effects of litter type and depth on plant performance of wild oat, medusahead, and a mixture of native species, (2) assess which plant life stages were most affected by litter accumulation, and (3) determine effects of litter accumulation on native species recruitment and diversity.

**Methods:** In November 2014, the researchers established 90 randomized plots with 3 randomly assigned litter types (oat, medusahead, or a combination of both) and 4 litter depths. They maintained six control plots. They applied seeds to plots from wild oat, medusahead, and a mixture of native species and added litter to the plots after seeding. In November 2014 and March 2015, they measured litter depth and light availability above and below the litter. They recorded germination in February 2015. In May 2015, they recorded the number of stems of focal species, counted flowering stems to estimate seed production of nonnative plants, and collected biomass. They also measured soil moisture, soil microbial biomass, and nitrogen availability. They performed statistical analyses to compare the effects of litter type and depth on light availability, soil nutrients and moisture, and the growth and reproduction of native and nonnative species.

**Location:** California

**Findings:** The authors detected that litter depth significantly affected plant performance, but litter type had no effect. Litter depth reduced light availability, marginally reduced soil available nitrogen and soil microbial biomass, and had no effect on soil moisture. With increased litter depth, wild oat had greater recruitment and growth and medusahead produced more flowers and seeds, but litter depth decreased native species' recruitment, growth, and diversity.

**Implications:** The authors suggest that litter accumulation supports a positive feedback loop that exacerbates the spread of invasive species and adversely affects native species. They recommend removing litter, through burning or grazing, to manage invasive species.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; weed management; soils or geology

## Markova, D.N., and Mason-Gamer, R.J., 2015, Diversity, abundance, and evolutionary dynamics of Pong-like transposable elements in Triticeae: Molecular Phylogenetics and Evolution, v. 93, p. 318–330.

**DOI:** https://www.doi.org/10.1016/j.ympev.2015.07.008

**Background:** Transposable elements are DNA fragments that can move from one location in the genome to another. The activity of transposable elements, such as movement of DNA fragments between species, has helped shape the genome of almost all organisms. Species of wheat from the Triticeae tribe have a high number of transposable elements in their genome, and thus, the study of these DNA fragments is important to understand the evolution of wheat.

**Objectives:** The authors sought to study one particular type of transposable element, Pong-like transposable elements, in Triticeae.

**Methods:** The authors performed phylogenetic analysis on DNA fragments from the genetic material of 21 species (such as medusahead) from the tribe Triticeae for their study.

**Location:** Not specified

**Findings:** The authors determined that the evolutionary history of Pong-like transposable elements in wheat was complex and may have been driven by multiple versions of these DNA fragments in ancestors, different evolutionary success of these DNA fragments, and occasional horizontal transfer.

**Implications:** Understanding the evolutionary history of medusahead can help advance broad efforts to control and manage this species. Often, this evolutionary history is best understood at higher levels of biological hierarchy, as this study has addressed.

**Topics:** genetics; nonnative invasive plants

## Marty, J., 2015, Fire effects on plant biodiversity across multiple sites in California vernal pool grasslands: Ecological Restoration, v. 33, no. 3, p. 266–273.

**DOI:** https://doi.org/10.3368/er.33.3.266

**Background:** Fire is a common tool used to control invasive species; however, there has been little study of large-scale and long-term fire effects on plant diversity. Fire effects are often site specific, creating a need for studies to look at fire effects at a larger scale. There has also been no research into how fire may affect vegetation in native-species-dominated vernal pools.

**Objectives:** The author's aim was to assess the effect of prescribed fire in heavily invaded uplands and native-dominated vernal pools (1) on native and exotic species and (2) as a management tool to control invasive species.

**Methods:** The author established four treatment locations at sites with active grazing and where fire was an existing management tool. They implemented three 10- to 30-ha prescribed burns at each site in May or June of 2001 to 2003 where they burned 95 percent of standing fine fuels. Within each site, they sampled three burned and three unburned plots and five vernal pools within each plot. The author sampled plant composition in nine quadrats in, alongside, and surrounding dried vernal pools the year before treatment and for 3 years after treatment. They used statistics to compare treatment effects.

**Location:** California

**Findings:** Exotic annual grass cover was less in burned plots than unburned plots at all sites the first year after the burn; however, exotic annual grass cover returned to pretreatment levels by the second year. Exotic annual forb cover only increased in plots surrounding vernal pools and was greater at burned plots 1 year postburn. Native forb richness was greater in burned plots the first year postburn; however, native forb cover did not increase. At one site, fire increased native species cover and richness; this increase remained for 3 years postburn.

**Implications:** The author asserts that this study shows that fire is an effective treatment to increase native species in vernal pool grasslands based on the results from the one site mentioned, and that increased native cover may be the result of indirect fire effects to nutrient and water availability. They additionally suggest that the increase in native forbs resulting from fire may be beneficial to livestock because it increases early-season forage. Finally, the author states that fire alone is not an effective treatment option for controlling invasive species long term and that other management tools will continue to be important.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; water

## McKay, S., Morris, L.R., Morris, C.E., and Leger, E.A., 2017, Examining the potential competitive effects of *Ventenata dubia* on annual and perennial grasses: The Prairie Naturalist, v. 49, p. 19–22.

**URL:** https://digitalcommons.unl.edu/tpn/177/'

The summary for this article was previously published in Poor and others (2021, p. 20–21; https://doi.org/10.3133/ofr20211031).

## McMahon, D.E., Urza, A.K., Brown, J.L., Phelan, C., and Chambers, J.C., 2021, Invasive plant probability prediction outputs and code for paper "Modelling species distributions and environmental suitability highlights risk of plant invasions in western United States": Fort Collins, Colo., Forest Service Research Data Archive.

**DOI:** https://doi.org/10.2737/RDS-2020-0078

**Background:** Data on the presence of invasive species is important to inform effective land management decisions.

**Objectives:** The authors sought to share methods and results from McMahon and others (2021; https://doi.org/10.1111/ddi.13232) to (1) describe the distributions of 15 invasive species, such as cheatgrass and medusahead, and (2) predict their risk of invasion within the arid and semiarid western United States.

**Methods:** In McMahon and others (2021), the authors used publicly available presence and absence data for 15 invasive species from more than 148,000 survey plots spanning from 1940 to 2020. They modeled predictions of species distributions based on the probability of species presence and associated variables of climate, soil, topography, and records of disturbance. This data repository shares code from the modeling process and downloadable rasters of model predictions across the study region.

**Location:** Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming

**Findings:** The authors created two spatial datafiles of predicted probability of species occurrence for all 15 invasive species. One spatial datafile shows areas of known species presence and the other file shows predicted occurrences of species using their model of habitat suitability.

**Implications:** These models can be used to prioritize monitoring and management at a range of spatial scales. The authors note that these models should be used in addition to field data. For instance, the species presence predictions are estimates for where new invasions may occur.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; habitat selection; nonnative invasive plants; weather and climate patterns; soils or geology; includes new geospatial data

## McMahon, D.E., Urza, A.K., Brown, J.L., Phelan, C., and Chambers, J.C., 2021, Modelling species distributions and environmental suitability highlights risk of plant invasions in western United States: Diversity and Distributions, v. 27, no. 4, p. 710–728.

**DOI:** https://doi.org/10.1111/ddi.13232

**Background:** Models of species distribution are an important tool to predict future invasions; however, there are a range of challenges associated with such models. A flexible modelling approach can avoid some of these issues using data of both species' occurrence and absence.

**Objectives:** The authors' aim was to determine (1) distributions, (2) environmental suitability, and (3) invasion risk of 15 invasive plants.

**Methods:** The authors used existing presence and absence data of 15 invasive plants, such as medusahead and cheatgrass, from publicly available data from 148,404 plots from the USGS Landfire Reference Database and BLM Assessment, Inventory, and Monitoring database. They used species occurrence data and correlated it with 13 other variables, consisting of several climate, soil, and topographical variables and distance to road, overlap with past wildfires, and day of sampling (a proxy for phenology) to create a species distribution model for each species. Their models mapped distribution and estimated invasion risk of all 15 species across 28 ecoregions in the western United States using predictions of environmental suitability.

**Location:** Arizona, California, Colorado, Idaho, Nebraska, New Mexico, North Dakota, Montana, Nevada, Oregon, South Dakota, Utah, Washington, Wyoming

**Findings:** The authors determined that minimum temperature and climatic water deficit were important for predicting the presence of most species. They determined that warm desert grasses are expanding into cold deserts, cold desert herbaceous species are expanding in nearly all directions, and disturbance driven forbs are primarily moving east. Day of sampling was the most important predictor of medusahead and it was associated with clayey soils and winter-dominant precipitation. Cheatgrass was associated with a range of conditions, particularly in areas with higher climatic water deficit, lower summer precipitation, and in burned areas. Cheatgrass is already ubiquitous in the region, but medusahead was predicted to expand within and outside of its invasion range.

**Implications:** The authors suggest that their species-specific results can inform adaptive management at a landscape scale. Specifically, managers can use this information to target areas for monitoring and control efforts based on predictions of invasion. They suggest that their areas of predicted invasion match ecoregional boundaries and known species traits. Additionally, they suggest that suitable habitat may change substantially as the climate changes.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; habitat selection; effect distances or spatial scale; fire; nonnative invasive plants; weather and climate patterns; climate change; water; soils or geology; includes new geospatial data

## Miller, R.F., Chambers, J.C., Pyke, D.A., Pierson, F.B., and Williams, C.J., 2013, A review of fire effects on vegetation and soils in the Great Basin Region—Response and ecological site characteristics: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-308, 126 p.

**DOI:** https://doi.org/10.2737/RMRS-GTR-308

**Background:** Soil characteristics and vegetation composition play a role in determining resilience to disturbance, resistance to invasion, and successional trajectories after fire. Understanding the relationship between ecological site characteristics and fire effects can inform management decisions in the Great Basin Region.

**Objectives:** The authors sought to (1) provide information related to fire effects on vegetation and soils in the Great Basin, (2) understand fire effects in relation to ecological site components, (3) inform selection of ecological sites for fire treatment, (4) inform predictions of environmental responses to fire, and (5) identify knowledge gaps based on the existing literature.

**Methods:** The authors reviewed literature to summarize fire effects on plants and soils to inform management decisions in the Great Basin Region. They synthesized findings in a report and developed a management framework to guide the evaluation of ecological site components and appropriate treatments for managing invasive plants.

**Location:** California, Idaho, Nevada, Oregon, Utah, Washington

**Findings:** The authors determined that soil temperature, moisture regimes, and vegetation composition strongly affected resilience to disturbance and resistance to invasion. They determined that warm, dry soils were less resilient, which has implications for sagebrush systems as the climate warms. Aside from soil and climate characteristics, factors like litter accumulation and biological soil crusts affected fire dynamics and the spread of invasive species. Plant succession trajectories depended on many interacting factors, consisting of fire severity, residual perennial plants, proximity to seed sources, and postfire disturbance. The authors identified that relying on other treatments besides fire may be more appropriate in certain areas where abiotic and biotic conditions support the return of invasive species.

**Implications:** The authors suggest that factors influencing resilience and resistance are dynamic, vary across environmental gradients, and shift with climate change. They suggest that managers account for these complexities and guide treatment approaches with a series of questions (examples provided) to evaluate ecological site characteristics and potential succession trajectories after fire.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat restoration or reclamation; fire; fuels and fuels management; nonnative invasive plants; grazing/herbivory; weather and climate patterns; climate change; drought; weed management; weed management subtopic: cultural control; weed management subtopic: mechanical vegetation removal; water; soils or geology; human dimensions or economics

## Montes-Sanchez, J.J., Van Miegroet, H., and Villalba, J.J., 2017, Effects energy supplementation and time on use of medusahead by grazing ewes and their lambs: Rangeland Ecology and Management, v. 70, no. 3, p. 380–387.

**DOI:** https://www.doi.org/10.1016/j.rama.2016.11.005

**Background:** Livestock grazing may offer an alternative for managing annual invasive grasses. Medusahead has high silica content, which is undesirable for ruminants, but mother ewes may influence their lambs to consume this invasive plant. Supplements with high fiber content, like beet pulp, could also increase medusahead intake by sheep.

**Objectives:** The researchers sought to (1) analyze the effect of an energy supplement on medusahead consumption and (2) understand the influence of mother ewes on the forage preferences of their offspring.

**Methods:** Researchers established six blocks containing two treatment plots each and three control plots between blocks. Within each block, three ewes and lambs consumed the beet pulp supplement and grazed in one plot, and another three ewes and lambs without supplementation grazed in an adjacent plot for 15 days. Researchers observed their behavior and recorded their grazing preferences—explicitly noting if they grazed medusahead—and repeated these observations for lambs alone after they were weaned. Researchers visually estimated pregrazing and postgrazing plant biomass in 25 randomly distributed squares, and they harvested biomass in four squares. They visually estimated cover, assessed defoliation, and calculated the biomass of defoliated stems. They analyzed nutrient levels and fiber content of different plant groups, consisting of medusahead, other annual grasses, bunchgrasses, and forbs. Through statistical analyses, they calculated the relative abundance of medusahead, the proportion of medusahead grazing events, the difference in medusahead consumption before and after weaning, and the relationship between grazing proportions of ewes and their lambs.

**Location:** Utah

**Findings:** The authors determined that supplementation did not significantly affect consumption of different plant groups, quantity of biomass removed, or defoliation of medusahead stems. They identified a strong correlation between mothers and their offspring for grazing preferences related to medusahead consumption. Ewes and lambs consumed more medusahead later in the grazing period. The authors also determined that grazing caused an increase in the relative abundance of medusahead.

**Implications:** The authors suggest that using grazing to manage weeds in moderately invaded areas could be effective. They also suggest that managers could select flocks with females that prefer medusahead because ewes can affect the preference of their offspring for consuming medusahead.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Montes-Sanchez, J.J., and Villalba, J.J., 2017, Effects of early experience and alternative feeds on medusahead (*Taeniatherum caput-medusae* ssp. *asperum*) intake by sheep: Applied Animal Behaviour Science, v. 188, p. 9–16.

**DOI:** https://www.doi.org/10.1016/j.applanim.2016.12.014

**Background:** Medusahead is an invasive annual grass with poor nutritional value that can negatively affect rangelands. Sheep grazing is a management strategy used to control medusahead. Grazing behavior of lambs can be influenced by their mothers or by supplementing unpalatable foods with nutritional feed; the forage preferences of experienced lambs that have been influenced by their mothers and inexperienced lambs may differ.

**Objectives:** The authors sought to assess the intake of medusahead and alternative forage for (1) inexperienced and (2) experienced sheep.

**Methods:** In June 2013, researchers exposed mother sheep and their lambs to a medusahead-invaded pasture and later selected 15 lambs that were considered experienced. The researchers grazed the lambs in an orchardgrass pasture and fed them alfalfa hay, followed by tall fescue hay. Researchers also grazed 15 inexperienced lambs originally exposed to high-quality feed in the same orchardgrass pasture with the same feeding regimen. They tested four treatments for each group (medusahead with alfalfa, medusahead without alfalfa, no medusahead with alfalfa, no medusahead without alfalfa). Researchers recorded foraging activities, plant heights, plant cover, and biomass pregrazing and postgrazing. They performed chemical analyses of each diet and compared treatments across groups.

**Location:** Utah

**Findings:** Medusahead intake did not differ between experienced and inexperienced lambs and was not affected by alfalfa hay availability or intake. Inexperienced sheep consumed more medusahead the first day and the last 2 days, whereas experienced sheep did not differ in medusahead intake across days. There were no differences in grazing events between treatment groups or vegetation types. Medusahead had the greatest crude protein and silica content, whereas bunchgrasses had the lowest.

**Implications:** The authors suggest that managers can use yearling sheep to graze in medusahead-invaded patches for a short period of time and recommend moving sheep to diverse vegetation patches for a few days between medusahead exposure. They recommend grazing experienced animals because they may consume medusahead more evenly than inexperienced animals. They also recommend avoiding grazing when medusahead is seeding to reduce dispersal.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Montes-Sanchez, J.J., and Villalba, J.J., 2017, Understanding medusahead low intake and palatability through in vitro digestibility and fermentation kinetics: Animal, v. 11, no. 11, p. 1930–1938.

**DOI:** https://doi.org/10.1017/S1751731117000866

**Background:** Sheep grazing has been unsuccessful at controlling medusahead invasion. Lack of success is attributed to medusahead's high silica content, which lowers its nutritional value and limits intake. However, additional variables may affect medusahead's low palatability.

**Objectives:** The authors examined apparent digestibility and fermentation rates of medusahead in comparison to more palatable feeds related to (1) plant maturity stage, (2) particle size, and (3) association with supplemental nutrients.

**Methods:** The authors harvested medusahead samples in June 2013 for use in three experiments. First, they tested digestibility of medusahead at seven phenological stages, using two palatable feeds (alfalfa and tall fescue hay) in comparison to two energy concentrate mixtures. Second, they tested digestibility at different particle sizes by cutting medusahead and two hay types into 1- to 20-millimeter (mm) pieces. Third, they mixed medusahead with high-quality feeds to determine if there were associated effects with medusahead digestibility. The authors collected stomach liquid from two sheep and used a laboratory gas production technique to test the digestibility of medusahead. They prepared solutions for each treatment from the three experiments and mixed them with stomach liquid. Each experimental treatment was tested six times during two different days. They measured digestibility and fermentation per treatment by calculating gas produced and used statistics to determine differences between treatments.

**Location:** Utah

**Findings:** Medusahead from late vegetative through late reproductive stages had similar digestibility as energy concentrates and tall fescue hay. Medusahead in thatch stage had the lowest digestibility. All medusahead stages, except thatch, had greater digestibility than alfalfa hay. However, alfalfa hay had faster fermentation rates than medusahead, and fermentation rates for medusahead slowed as the plant matured. Smaller particles of medusahead had greater digestibility than larger particles and fermentation slowed as particle size increased, a pattern that was not observed in alfalfa or tall fescue hay. Mixing medusahead with high-quality feeds had no effect on digestibility.

**Implications:** The authors suggest that rather than silica content, particle size and slow fermentation rates in comparison to more palatable feeds are the greatest factors affecting low palatability and limited use of medusahead by sheep.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Nafus, A.M., and Davies, K.W., 2014, Medusahead ecology and management—California annual grasslands to the Intermountain West: Invasive Plant Science and Management, v. 7, no. 2, p. 210–221.

**DOI:** https://www.doi.org/10.1614/IPSM-D-13-00077.1

**Background:** Medusahead invasions are threatening western rangelands by spreading rapidly and becoming the dominant species. Because of medusahead's widespread infestation, it has been difficult to discern a uniform set of management strategies across the invaded range.

**Objectives:** The authors sought to summarize medusahead (1) ecology and (2) management, focusing on the Intermountain West and California annual grasslands.

**Methods:** The authors reviewed literature that describes existing knowledge of medusahead ecology and management, consisting of prevention and maintaining native plant resistance. They also discussed early detection and methods of control.

**Location:** California, Idaho, Nevada, Oregon, Utah, Washington

**Findings:** Medusahead seeds disperse most commonly by wind, animals, and vehicles, and tend to establish more when perennial bunchgrasses are absent. Preventing and reducing dispersal through early detection and eradication is essential to limit further spread. Medusahead can be managed by applying herbicides in adjacent infestations, increasing resistance of native

vegetation to medusahead, and recognizing which areas are more at risk to invasion. However, once invaded, control strategies should be used and may be integrated with other treatments, such as revegetation with desirable species. Prescribed fire can be used to control medusahead before seedheads mature and by using slow burns at a higher heat intensity. Applying certain herbicides in the fall can control medusahead without negatively affecting nontarget vegetation, but they may need to be reapplied yearly. Mechanical treatments can reduce medusahead but may not be effective alone and may have negative effects on native plants and soils. Grazing can also reduce medusahead cover and seed production, particularly in midspring, resulting in higher forb richness.

**Implications:** The authors suggest that managers need to prioritize controlling large-scale infestations of medusahead before implementing restoration treatments, specifically through prevention, early detection, and eradication efforts. They recommend that managers consider the timing of control treatments and focus on areas that have intact native vegetation. In California grasslands, burning or grazing can reduce seed production. In the Intermountain West, preemergent herbicides may be more effective in reducing medusahead. The authors suggest that management approaches are not interchangeable between the two focal regions; however, seeding desirable species may be important across infested areas.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: biocontrol; weed management subtopic: cultural control; weed management subtopic: herbicides; weed management subtopic: mechanical vegetation removal

## Naupari, J.A., Vierling, L.A., and Eitel, J.U.H., 2013, Delineating native and invasive plant functional groups in shrub-steppe vegetation using bidirectional reflectance: Journal of Applied Remote Sensing, v. 7, no. 1, p. 1–19.

**DOI:** https://doi.org/10.1117/1.JRS.7.073563

**Background:** Determining the presence and abundance of invasive grasses is a priority in the western United States. Remote sensing using satellite and aircraft imagery to measure surface reflectance has emerged as an important tool for monitoring invasives; however, most methods only capture images at one standard downward angle, which can complicate analysis. Different methods that allow for multiangle analysis may provide additional information about invasive grasses.

**Objectives:** The authors sought to (1) measure reflectance factors during the growing season for four rangeland vegetation groups and (2) examine and compare remote sensing identification of invasive plants using multi-angle and single-angle methods.

**Methods:** From May to July 2007 and from July to August 2008, the authors used a light measurement tool at multiple angles to quantify the reflectance of target vegetation groups (native shrub, native grasses, invasive annual grasses, and forbs) on four study sites with similar ecological conditions. They identified medusahead and cheatgrass as the main invasive annuals represented in the study area. The authors calculated and estimated reflectance values and indices and used statistics to compare the differentiation of vegetation groups as estimated by different monitoring techniques.

**Location:** Idaho

**Findings:** Using the single downward viewing angle, the authors were unable to differentiate invasive grasses using one type of reflectance value, but they could differentiate invasive grasses from bare ground using a different reflectance index during the first 3 weeks in July. Neither value nor index was able to differentiate between the other vegetation groups using the single downward angle. Using multiple viewing angles, the authors identified that invasive grass reflectance values greatly differed from all other vegetation groups, and this difference was the biggest during late July to early August. Shrub reflectance values were more dependent on viewing angle than any other group.

**Implications:** The authors state that a potential reason for high reflectance values in medusahead during midsummer to late summer is due to changes in canopy structure and leaf orientation as medusahead plants age. The authors suggest that their results indicate certain satellite products and spatial imagery may be used to identify invasives and map medusahead if specific reflectance values are used and when images are taken at certain times of the year.

**Topics:** nonnative invasive plants

## Pastick, N.J., Dahal, D., Wylie, B.K., Parajuli, S., Boyte, S.P., and Wu, Z., 2020, Characterizing land surface phenology and exotic annual grasses in dryland ecosystems using Landsat and Sentinel-2 data in harmony: Remote Sensing, v. 12, no. 4, article 725, 17 p.

**DOI:** https://doi.org/10.3390/rs12040725

**Background:** Mapping and monitoring are important components of invasive annual grass management. Remote sensing yields abundant data for mapping vegetation, but existing techniques for identifying proportional cover of invasive annual grasses provide information at resolutions too coarse or infrequent for effective management.

**Objectives:** The authors sought to develop a fully automated remote sensing method for accurately mapping invasive annual grass cover at fine spatial and temporal resolutions.

**Methods:** The authors modeled invasive annual grass cover from 2016 to 2018 using a set of remotely sensed imagery synthesized from two satellites, called Harmonized Landsat and Sentinel-2 (HLS) data. To prepare satellite data, the authors developed an algorithm to automatically remove nonvegetation pixels from the images. To address data gaps, they estimated weekly images of vegetation cover based on the available data. They then developed estimates of exotic annual grass cover based on the greenness of each pixel in the HLS imagery and other factors such as aspect, elevation, and soils. They derived information about growing season duration from the satellite images to distinguish invasive annual grasses from native vegetation based on life cycle timing differences. They compared the vegetation cover values derived from HLS data to those derived from lower-resolution weekly satellite images. They validated their model using field data previously collected from 1,885 points.

**Location:** California, Idaho, Nevada, Oregon

**Findings:** The automated method for removing nonvegetation pixels was significantly more accurate than standard methods. Statistically derived estimates of vegetation cover using HLS data in combination with topographic and soils factors were more strongly correlated with coarser-resolution satellite images than the estimated weekly vegetation cover data alone. The resultant annual maps of percent exotic annual grass cover had lower or similar errors compared to previous remote sensing mapping efforts.

**Implications:** The authors suggested that their method demonstrated the utility of HLS data in combination with Landsat data for mapping exotic annual grasses at resolutions pertinent to land managers. They attributed their model's success to the frequency of HLS data, which captured the high interannual variability in growing conditions and timing, and their method for preparing the imagery, which produced a series of cloud-free images for the growing season.

**Topics:** population estimates or targets; nonnative invasive plants

## Pastick, N.J., Wylie, B.K., Rigge, M.B., Dahal, D., Boyte, S.P., Jones, M.O., Allred, B.W., Parajuli, S., and Wu, Z., 2021, Historic and future trends in exotic annual grass (%) cover in the western US (1985 to 2019 and 2025 to 2040): U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9Z85VET

**Background:** Exotic annual grasses have stressed sagebrush ecosystem dynamics in western North America. Monitoring exotic annual grass distribution and spread can facilitate effective vegetation management and ecosystem conservation efforts.

**Objectives:** The authors sought to model long-term historical and future changes in exotic annual grass cover in sagebrush ecosystems.

**Methods:** The authors synthesized prior estimates of exotic annual grass cover to model changes in percent exotic annual grass cover. They used observed changes from 1985 to 2019 to train and validate their model of future changes for the years 2025 to 2040. They excluded agricultural and urban areas, water bodies, and forests with greater than 40 percent tree canopy. The authors used climate change projections under low and high human-caused emissions scenarios to drive estimates of future changes in exotic annual grass cover.

**Location:** California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The authors provided geospatial data for the rate of change in exotic annual grass cover for the periods 1985 to 2019 and 2025 to 2040 at a 30-m spatial resolution. The data differentiate future changes in cover according to whether the outputs are based on projections of low or high atmospheric greenhouse gas concentrations. The data also include bounds for uncertainty derived from each emissions scenario.

**Implications:** The authors suggest that data about exotic annual grass occurrence can be used to guide management activities.

**Topics:** population estimates or targets; nonnative invasive plants; climate change; includes new geospatial data

## Pastick, N.J., Wylie, B.K., Rigge, M.B., Dahal, D., Boyte, S.P., Jones, M.O., Allred, B.W., Parajuli, S., and Wu, Z., 2021, Rapid monitoring of the abundance and spread of exotic annual grasses in the western United States using remote sensing and machine learning: AGU Advances, v. 2, no. 2, 22 p.

**DOI:** https://doi.org/10.1029/2020AV000298

**Background:** Remote sensing can provide landscape-scale data for mapping exotic annual grasses. Recent work has yielded datasets at high spatial and temporal resolutions. Automated modeling techniques can use these datasets to provide timely information about invasions to assist fire and vegetation management.

**Objectives:** The authors sought to (1) map past, present, and future exotic annual grass abundance, (2) quantify factors influencing invasions, and (3) identify invasion and wildfire risk in priority landscapes for conservation, such as greater sage-grouse habitat.

**Methods:** The authors used satellite imagery and existing vegetation and topographic datasets to model exotic annual grass cover, primarily brome species and medusahead, for 2016 to 2019, and to produce near-real-time estimates for early 2020. They obtained previously collected field data for approximately 220,000 points from 2004 to 2019 for training and validating models. They then combined their 2016 to 2019 model with two existing models to create a model for 1985 to 2019. To identify drivers of change, they assessed model outputs in relation to climate, topography, soils, vegetation composition, wildfire, historical treatments, and distance to roads. They used climate change scenarios to predict exotic grass cover for 2025 to 2040 and assess fire risk in sage-grouse habitat.

**Location:** California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The combined model showed increased exotic annual grass cover since 1985. Disturbances, proximity to roads, lower elevation, higher temperatures, and drier soils were associated with increased cover of exotic grasses. Increases in exotic grass cover were higher in already invaded areas and lower in locations with high shrub cover. Fire facilitated invasion, whereas weed management reduced exotic grass cover. Rapid estimates for 2020 showed similar distribution of exotic grasses to the prior-year maps. Projections indicated an upward elevation shift and eastward expansion of invasions and sustained and new invasions in sage-grouse habitat, with exotic grasses causing increases in fire risk.

**Implications:** The authors suggest managers should consider a threshold of approximately 10 percent exotic annual grass cover for increased invasion rate and wildfire risk. They indicate their rapid model can facilitate quick response to invasions and enhance fire prediction. They also discuss the implications of new invasions and fire risk for sage-grouse conservation.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; fire; fuels and fuels management; fuel breaks; nonnative invasive plants; infrastructure; weather and climate patterns; climate change; weed management; soils or geology; includes new geospatial data

## Perkins, L.B., and Hatfield, G., 2014, Competition, legacy, and priority and the success of three invasive species: Biological Invasions, v. 16, p. 2543–2550.

**DOI:** https://www.doi.org/10.1007/s10530-014-0684-3

**Background:** Species invasion can be unpredictable; however, understanding traits that contribute to invasion patterns can inform management decisions. Three aspects that contribute to invasion include competitive ability, plant-soil feedbacks, and the timing of growth. However, it is unclear which traits contribute to the success of crested wheatgrass, cheatgrass, and medusahead.

**Objectives:** The authors sought to determine the importance of (1) competitive ability, (2) plant-soil feedbacks, and (3) the timing of growth for determining the success of three invasive species.

**Methods:** In spring 2011, researchers planted four restoration species in pots in a greenhouse: common yarrow, big squirreltail, rubber rabbitbrush, and Sandberg bluegrass. They grew restoration species individually or alongside invasive species (crested wheatgrass, cheatgrass, and medusahead) to examine competition dynamics. To determine plant-soil feedbacks, they collected soil from invaded (legacy) and noninvaded areas for each species. To determine effects related to the timing of growth, they planted restoration species before, after, or concurrently with invasive grasses. For each invasive species, they planted 8 pots per treatment, resulting in 24 pots total. They collected aboveground biomass and calculated a response index to determine restoration species performance with or without invasive grasses.

**Location:** Nevada

**Findings:** The authors determined that all three invasive grasses benefited from competitive ability and planting timing, whereas only crested wheatgrass benefited from legacy soil. Restoration plant biomass was highest when grown in legacy soil without crested wheatgrass and lowest when crested wheatgrass was planted first in legacy soil. Restoration plant biomass was highest when grown without cheatgrass or medusahead in noninvaded soil and lowest when cheatgrass and medusahead were planted first in legacy soil and noninvaded soil, respectively.

**Implications:** The authors suggest that competitive ability is the dominant trait affecting invasiveness for all three study species. The authors recommend that understanding invasion traits across similar site conditions may allow managers to improve invasion control strategies.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; nonnative invasive plants; soils or geology

## Perkins, L.B., Hatfield, G., and Espeland, E.K., 2016, Invasive grasses consistently create similar plant-soil feedback types in soils collected from geographically distant locations: Journal of Plant Ecology, v. 9, no. 2, p. 180–186.

**DOI:** https://www.doi.org/10.1093/jpe/rtv040

**Background:** Plant-soil feedbacks alter soil nutrients and the soil microbial community, and subsequently affect plant performance. The same species can have different plant-soil feedbacks depending on the associated soil characteristics. These feedbacks can affect invasion dynamics.

**Objectives:** The researchers sought to (1) analyze the plant-soil feedbacks of four invasive species paired with three distinct soil types and (2) distinguish between the effect of species and soil source on plant-soil feedbacks.

**Methods:** The researchers collected soil samples from three distinct locations to conduct their study in a greenhouse. They planted four invasive species (crested wheatgrass, yellow star thistle, smooth meadow-grass, and medusahead) into each of the three soil types, with six replicates of each treatment, to condition the soil. After 80 days, researchers removed the aboveground plant biomass and homogenized the soil based on treatment type. Then, during the response phase, they planted the same species and a native species, junegrass, in the conditioned soil and unconditioned soil to compare performance. They harvested, dried, and weighed biomass of plants grown during the response phase. They calculated plant-soil feedback responses based on differences in biomass between conditioned and unconditioned soils. They performed statistical analyses to compare plant-soil feedback responses and understand the relationship between soils and species in determining responses.

**Location:** Montana, Nevada

**Findings:** The authors determined that, regardless of soil source location, crested wheatgrass and medusahead had consistent plant-soil feedbacks, favoring their growth over the growth of a native species. Smooth meadow-grass had neutral feedbacks across soil types, and yellow star thistle had varied responses depending on the soil type. Soil characteristics, species identity, and the combination of soil and conditioning species affected native and invasive species biomass, as well as plant-soil feedback responses.

**Implications:** The authors suggest that invasive species can affect the soil to favor their performance, which can pose threats to native vegetation communities. They also suggest that both soil characteristics and species identity determine invasive plant-soil feedbacks. Lastly, they indicate that understanding these feedbacks can improve knowledge and predictions surrounding invasion ecology.

**Topics:** dispersal, spread, vectors, and pathways; nonnative invasive plants; soils or geology

## Perkins, L.B., Johnson, D.W., and Nowak, R.S., 2011, Plant-induced changes in soil nutrient dynamics by native and invasive grass species: Plant and Soil, v. 345, p. 365–374.

**DOI:** https://www.doi.org/10.1007/s11104-011-0788-9

**Background:** Previous research has demonstrated how soil nutrients can affect both native and invasive plants, which uptake and use nutrients to grow. In turn, plants may affect soil nutrients by using mechanisms that increase their ability to uptake nutrients. However, more research is needed to determine how plants alter soil nutrients and if invasive plants alter nutrients differently than native plants.

**Objectives:** The researchers sought to determine (1) how plants affect soil nutrients and (2) if invasive grasses affect soil nutrients differently than native grasses.

**Methods:** In January 2009, researchers planted five replicates of four exotic grasses (medusahead, cheatgrass, barbed goatgrass, and crested wheatgrass) and three native grasses (squirreltail, bluebunch wheatgrass, and small sixweeks grass) into two different soil types (sandy loam and clay soil) and allowed them to grow for 80 days. Their experimental design also included unplanted controls. Researchers sampled soils preplanting and postplanting and measured nutrient concentrations in both the soil and plant tissues. They performed statistical analyses to determine differences in plant tissue and soil nutrients.

**Location:** Nevada

**Findings:** Researchers identified plant group-induced changes in soil nutrients and species-specific differences in plant and soil nutrients. In clay soil, plant nutrient content, specifically calcium content, differed between native and invasive grasses. Plant nutrient content in native grasses was similar in squirreltail and bluebunch wheatgrass, but small sixweeks grass had higher levels of several different nutrients. Exotic grass species also varied in their plant nutrient content. Medusahead had low concentrations of potassium and phosphorous, whereas cheatgrass had high concentrations of calcium, magnesium, iron, and manganese. Soil nutrient content also differed between species and within groups, but patterns were not consistent. Invasives in particular had contrasting effects on a few different types of soil nutrients, with some species increasing and others decreasing available soil nutrients.

**Implications:** The authors found that, as a group, exotic species did not alter nutrients differently than native species. However, they suggest that although not all exotic grasses modified nutrients in the same way, nutrient alteration may be a pathway in which certain species increase invasion ability.

**Topics:** site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Perkins, L.B., and Nowak, R.S., 2013, Native and non-native grasses generate common types of plant-soil feedbacks by altering soil nutrients and microbial communities: Oikos, v. 122, no. 2, p. 199–208.

**DOI:** https://www.doi.org/10.1111/j.1600-0706.2012.20592.x

**Background:** Plant-soil feedbacks are defined by plants altering soil nutrients and the soil microbial community in such a way that either inhibits or favors subsequent plant growth. These feedbacks may provide insight into plant coexistence and invasion dynamics.

**Objectives:** The researchers sought to (1) assess plant-soil feedbacks based on soil nutrients and the soil microbial community and (2) compare plant-soil feedbacks across native and nonnative grass species.

**Methods:** The researchers designed a greenhouse experiment with two phases to first condition two soil types (sandy loam and clay) and then assess plant growth on the conditioned soil. They studied three native species (bottlebrush squirreltail, bluebunch wheatgrass, and small fescue) and four nonnative species (cheatgrass, medusahead, crested wheatgrass, and barbed goatgrass). They grew plants in 640 pots with replicates of all grass species in both soil types in a greenhouse for 80 days, then removed aboveground biomass, homogenized soils from each treatment combination, and sampled for nutrients and soil microbial diversity. Then, they repotted soils and replanted grass species to measure aboveground biomass to assess growth of different species in response to soil conditioning. They performed statistical analyses to assess the effect of soil conditioning on subsequent plant growth, considering changes to soil nutrients and microbial diversity.

**Location:** Nevada

**Findings:** Soil conditioning, soil type, and plant-soil feedbacks affected soil nutrients, soil microbial communities, and plant growth. Native species were generally associated with plant-soil feedbacks that suppressed their subsequent growth. Crested wheatgrass and medusahead produced plant-soil feedbacks that supported their growth and suppressed others. Cheatgrass and barbed goatgrass had neutral plant-soil feedbacks.

**Implications:** The authors suggest that it is important to consider both soil nutrients and soil microbial composition in relation to dynamics of plant invasion. Additionally, they suggest that some nonnative species may produce plant-soil feedbacks that benefit their own performance. They also note the importance of soil texture and suggest that medusahead may be more invasive in clay soils.

**Topics:** dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Prado-Tarango, D.E., Mata-González, R., Hovland, M., and Schreiner, R.P., 2021, Assessing commercial and early-seral arbuscular mycorrhizal fungi inoculation to aid in restoring sagebrush steppe shrubs: Rangeland Ecology and Management, v. 79, p. 87–90.

**DOI:** https://doi.org/10.1016/j.rama.2021.08.001

**Background:** The presence of arbuscular mycorrhizal fungi in soils can affect plant growth. Arbuscular mycorrhizal fungi are symbiotic microorganisms that exist within plant roots and can facilitate nutrient absorption by host plants in exchange for carbon. Their role in ecosystem function warrants exploration of these fungi as tools for ecosystem restoration.

**Objectives:** The authors investigated the effects of a commercial arbuscular mycorrhizal fungus on (1) mycorrhizal establishment and (2) plant biomass of native sagebrush steppe shrubs and an invasive annual grass.

**Methods:** The authors first verified the viability of the commercial fungus using crimson clover, a generalist mycorrhizal species. Then, in a greenhouse, the authors grew three sagebrush species and medusahead in sterilized soil or field soil gathered from a sagebrush steppe ecosystem. The authors treated half of each soil type with the commercial fungus. Fifteen weeks after planting, the authors measured characteristics of mycorrhizal activity, plant root and shoot biomass, and total dry plant biomass. The authors used statistical methods to compare effects of the treatments.

**Location:** Oregon

**Findings:** No mycorrhizal activity occurred in sterilized soil. For Wyoming big sagebrush and medusahead, treatment with the fungus did not affect mycorrhizal activity in field soil. For black sagebrush, treatment resulted in some increased mycorrhizal activity. In contrast, treatment decreased overall mycorrhizal colonization for low sagebrush. Sterilized soils produced greater biomass for all Wyoming big sagebrush and medusahead biomass variables and greater total and shoot biomass for black sagebrush and low sagebrush. Treatment did not affect biomass except that root biomass was lower on treated sterilized soils for Wyoming big sagebrush and treated field soils for low sagebrush.

**Implications:** The authors determined that a mycorrhizal fungal treatment did not generally increase mycorrhizal activity or plant biomass for sagebrush species and medusahead. The authors suggest that the lower plant growth in field soils with mycorrhizal activity may indicate that the fungus was parasitic in their experiment, possibly because of the reduced-stress environment of the greenhouse or because of variation in the mycorrhizal relationship across species. The authors conclude that managers should test specific mycorrhizal fungi prior to application to avoid unexpected outcomes.

**Topics:** behavior or demographics; habitat restoration or reclamation; nonnative invasive plants; soils or geology

## Pyke, D.A., and Wirth, T.A., 2017, Compilation of BLM monitoring reports assessing post wildfire seeding of rangelands, 2001–2009: U.S. Geological Survey data release.

**DOI:** https://www.doi.org/10.5066/F7445JPQ

**Background:** Reports from monitoring efforts associated with postfire rehabilitation can provide details on if seeding treatments effectively reduce soil erosion, suppress invasive species, and increase preferred plant species.

**Objectives:** The researchers sought to compile postfire rehabilitation reports from 2001 to 2009 to assess if seeding efforts, performed from 2001 to 2006, successfully prevented soil erosion or reduced invasion of nonnative annual plants.

**Methods:** The researchers compiled and evaluated 220 closeout reports describing postfire rehabilitation seeding efforts across rangelands in the Intermountain West. They included 214 reports of aerial seeding and 113 reports of drill seeding. These reports provided a summary of seeding success based on 3 years of monitoring. Reports described success based on qualitative ratings of good, fair, poor, or failure. The researchers performed statistical analyses to compare seeding success ratings with elevation, long-term average precipitation, and annual precipitation data.

**Location:** California, Colorado, Idaho, Nevada, Oregon, Utah, Washington, Wyoming

**Findings:** The researchers determined that aerial seedings were generally more likely to fail than succeed, whereas drill seedings succeeded slightly more often than they failed. They identified that aerial seeding success could be explained by increasing elevation, long-term average precipitation, and precipitation in years 1 and 3 after seeding. In contrast, they determined that elevation was the only driver of drill seeding success.

**Implications:** The researchers suggest that the success of drill seeding may be less affected by precipitation patterns. They also suggest that additional quantitative information, such as maps and prefire vegetation data, could support spatial assessments and aid in the development of a decision analysis tool to inform prioritization of postfire rehabilitation efforts.

**Topics:** broad-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control; soils or geology

## Pyke, D.A., and Wirth, T.A., 2017, Compilation of studies assessing post wildfire seeding of rangelands worldwide, 1965–2010: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/F7MW2F9B

**Background:** Mitigation after wildfire involves efforts to reduce soil erosion and the spread of invasive plants. Reviewing results from postfire seeding efforts across rangelands worldwide can provide information on the effectiveness of restoration efforts on a broad scale.

**Objectives:** The researchers aimed to compile literature from 1965 to 2010 pertaining to postfire rehabilitation to assess if seeding reduces (1) soil erosion and (2) the prevalence of invasive species.

**Methods:** The researchers compiled literature from a variety of databases, using search terms related to fire, restoration, seeding, and invasive species, such as medusahead and cheatgrass. They initially identified 1,519 articles that met their search criteria and reviewed all associated abstracts. They excluded irrelevant articles and refined their sample to 126 articles, which they reviewed further. Their final sample of products examining the effectiveness of postfire seeding included 53 articles with 8 products examining soil erosion and 19 examining postfire rehabilitation in relation to invasive species. They created a dataset with summaries detailing methods, results, conclusions, and other useful information from the studies included in their sample.

**Location:** North America

**Findings:** The researchers compiled literature pertaining to postfire rehabilitation efforts and evaluated the results of a wide variety of studies to create a detailed summary spreadsheet.

**Implications:** The researchers produced a summary spreadsheet that provides information on the effectiveness of mitigation treatments after wildfire. Results from their review can inform future mitigation efforts and treatments associated with postwildfire rehabilitation.

**Topics:** habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: cultural control; soils or geology

## Ransom, C.V., and Whitesides, R.E., 2012, Proactive EBIPM—Establishing weed prevention areas: Rangelands, v. 34, no. 6, p. 35–38.

**DOI:** https://www.doi.org/10.2111/RANGELANDS-D-12-00055.1

**Background:** Weed prevention is a cost-effective approach to limit the spread of invasive and exotic plants, and using weed prevention areas (WPAs) allows managers to invest in prevention efforts. Introduced weeds can negatively affect native plants and economic systems, such as grazing forage. Ecologically based invasive plant management is one framework that focuses on changes due to invasive species and control strategies that should be implemented.

**Objectives:** The authors sought to (1) describe the WPA concept and (2) present preliminary findings on a case study using this framework.

**Methods:** The authors defined WPAs, reviewed their guide to establishing these areas, and summarized a case study in how this framework has been implemented.

**Location:** Utah

**Findings:** WPAs are implemented to protect large areas of land by limiting spread and dispersal of invasive plants before they cause economic loss. This framework indicates that managers and landowners spend time and effort treating smaller infestations that can be more successfully controlled before targeting widespread invasions. In the case study, multiple partners collaborated to manage medusahead on rangelands, where leadership met two to four times per year. Coordinators established monitoring sites, mapped and sprayed infestations, led educational sessions, and implemented revegetation projects in the area. In addition, they monitored and inventoried the area using remote sensing to determine the extent of spread. After 3 years, public awareness increased, which led to the detection of other areas with invasive species, resulting in additional funding for invasive plant control. From this case study, other groups were able to implement these methods in areas invaded by medusahead.

**Implications:** The authors suggest that applying an ecologically based approach to invasive plant management is more economically feasible than restoring degraded areas. Specifically, they suggest that managers should focus on limiting the spread of known infestations and preventing dispersal to susceptible areas.

**Topics:** dispersal, spread, vectors, and pathways; nonnative invasive plants; weed management; human dimensions or economics

## Rector, B.G., Ashley, M.C., Gaskin, J.F., and Longland, W.S., 2013, Use of wheat SSRs to assess genetic diversity in medusahead (*Taeniatherum caput-medusae*): Invasive Plant Science and Management, v. 6, no. 3, p. 352–361.

**DOI:** https://doi.org/10.1614/IPSM-D-12-00087.1

**Background:** Medusahead invasions have threatened livestock forage and native plant diversity, and increased wildfire risk in western North America. However, few genetic markers are available to study medusahead. Common wheat is a relative of medusahead whose genetics have been studied, and research indicates that genetic markers from this species may also be useful for the study of medusahead, which would provide a cost-effective way to facilitate studies that could track the spread of invasion.

**Objectives:** The authors aimed to explore if known genetic markers from common wheat could be adapted for use in medusahead.

**Methods:** The authors collected medusahead seeds from six populations and obtained wheat seeds from one cultivar population. In a controlled setting, they planted medusahead and wheat seeds into soil. After 12 to 17 days, they harvested leaves and performed genetic analyses on each species population. They used advanced techniques to search for genetic markers from common wheat that were also identified in medusahead and used these markers to analyze the population genetics of medusahead.

**Location:** California, Nevada

**Findings:** The authors identified that medusahead and common wheat had some closely related genetic markers. They determined that medusahead populations most likely originated from two different sources and posed that local climate conditions may have affected the success of medusahead establishment.

**Implications:** The authors suggest that other researchers can use common wheat genetic markers to understand the origins of medusahead populations when used in a similar genetic analysis. They state that understanding the original and modern populations of medusahead and the associated traits may help to improve management control strategies. They conclude that the discovery of shared genetic markers between medusahead and common wheat provides a cost-effective tool for future study of medusahead.

**Topics:** population estimates or targets; genetics; nonnative invasive plants

## Reiner, R., and Craig, A., 2011, Conservation easements in California blue oak woodlands—Testing the assumption of livestock grazing as a compatible use: Natural Areas Journal, v. 31, no. 4, p. 408–413.

**DOI:** https://www.doi.org/10.3375/043.031.0411

**Background:** Blue oak woodlands have low seedling regeneration and are being threatened by land-use conversion and invasive grasses, such as medusahead. Land trusts with conservation easements may have terms that allow commercial grazing, which has been shown to increase native plant diversity, reduce invasive grass cover, and potentially reduce oak recovery at certain locations. However, it is less clear how grazing may affect blue oak woodlands.

**Objectives:** The authors sought to determine if allowing grazing during the growing season affects (1) blue oak seedlings, (2) medusahead, and (3) native plant cover and species richness.

**Methods:** Between 2004 and 2008, the researchers established three pairs of plots on five ranches, where one of each pair was grazed and the other fenced, excluding grazing. They measured blue oak seedling counts, vegetation cover, and species richness before treatment and the following 4 years after treatment. They performed statistical analyses to examine the effects of grazing treatments through time.

**Location:** California

**Findings:** In the last year, oak seedling density was lower in grazed plots at three of the ranches, and the other two had no establishment. Medusahead cover increased in both grazed and nongrazed treatments after the second year, but by the last year, cover and thatch was significantly greater in nongrazed plots. Native species richness and cover did not change through time or with treatments.

**Implications:** The authors suggest that although grazing may have reduced blue oak seedling densities, it remains unclear what other contributing factors affect seedling survival and recruitment to the sapling stage. They suggest that grazing is effective in reducing medusahead but recommend long-term monitoring on easement properties.

**Topics:** population estimates or targets; survival; site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Rigge, M.B., Bunde, B., Shi, H., and Postma, K., 2021, Rangeland Condition Monitoring Assessment and Projection (RCMAP) fractional component time-series across the western U.S. 1985–2020 (ver. 2.0, October 2021): U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P95IQ4BT

**Background:** For the previous version of this dataset, see Homer and others (2020; https://doi.org/10.5066/P9C9O66W). Climate change, altered fire regimes, and management practices are affecting western ecosystems in the United States. There is a need to provide land managers with fine-scale datasets of ecosystem components to monitor rangeland habitat changes for informed management decisions.

**Objectives:** The authors sought to provide a remote sensing dataset to show vegetation and ecosystem component changes through time and across the landscape.

**Methods:** The researchers used Landsat imagery from summer and fall at a 30-m resolution spanning from 1985 to 2020, except 2012, to determine the percent cover of rangeland components. They identified nonrangeland areas and included several other variables in their models, consisting of topographic features, water, climate, fire, and indices related to land cover types. They trained their models and applied an automated method to evaluate vegetation changes through time. To validate their methods, they evaluated Landsat predictions against field data from 126 plots, collected from 2008 to 2018, and against a second set of 1,865 independent plots collected from 2013 to 2020. The authors surveyed seven regions and included eight fractional components in the dataset: annual herbaceous, bare ground, herbaceous, litter, nonsagebrush shrubs, perennial herbaceous, sagebrush, and shrub.

**Location:** Arizona, California, Colorado, Idaho, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The researchers provide the Rangeland Condition Monitoring Assessment and Projection dataset that quantifies the change of percent cover for eight components across the western United States. They determined that the component changes occurred gradually and were captured in field-collected data and remotely sensed imagery.

**Implications:** The authors suggest that this dataset can be used by land managers to inventory and monitor vegetation changes across western rangelands.

**Topics:** broad-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; water; soils or geology; includes new geospatial data

## Rigge, M., Homer, C., Cleeves, L., Meyer, D.K., Bunde, B., Shi, H., Xian, G., Schell, S., and Bobo, M., 2020, Quantifying western U.S. rangelands as fractional components with multi-resolution remote sensing and in situ data: Remote Sensing, v. 12, no. 3, article 412, 26 p.

**DOI:** https://doi.org/10.3390/rs12030412

**Background:** Rangelands in the western United States comprise several ecosystems and are quickly changing due to several factors, such as annual grass invasion. Concern about the future of sagebrush systems is increasing, and new models may assist in managing these ecosystems.

**Objectives:** The authors' aim was to (1) map western U.S. rangelands based on vegetation and ground cover, (2) compare ecoregion ground cover and climate, and (3) assess the accuracy of their models.

**Methods:** The authors used fractional component analysis to characterize western U.S. rangelands at a 30-m resolution using publicly available remote sensing and field-collected data from 2013 to 2017. They created models to predict nine components, which included cover of shrub, big sagebrush, other sagebrush species, herbaceous, annual herbaceous, litter, and bare ground, and height of shrubs and sagebrush. They calculated total cover of each component for 27 ecoregions and correlated these maps with topographic and climate variables. Finally, they used two validation methods to assess model accuracy.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Oklahoma, Oregon, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** Most ecoregions were dominated by bare ground, a few were dominated by herbaceous plants, and one was dominated by shrubs. Correlations of cover types and precipitation matched expected ecological relations. Shrubs tended to be in more arid areas, and big sagebrush was the dominant shrub type. Sagebrush covered a small proportion of the total study area but was present at least at low levels in nearly half of the study locations. Annual herbaceous cover was present in one-third of the study area and was greatest along the western edge of the study area. Their models best predicted herbaceous and bare ground cover and had the lowest accuracy in predicting the height of shrubs and sagebrush.

**Implications:** The authors state that their maps provide a new method for monitoring rangelands and that their predictions are more accurate than other similar models, while covering a larger geographic area and predicting vegetation at local scales. They suggest that users should use caution in using their height measurements because they were the values with the greatest error.

**Topics:** population estimates or targets; broad-scale habitat characteristics; site-scale habitat characteristics; effect distances or spatial scale; nonnative invasive plants; weather and climate patterns; soils or geology; includes new geospatial data

## Rigge, M., Homer, C., Shi, H., Meyer, D., Bunde, B., Granneman, B., Postma, K., Danielson, P., Case, A., and Xian, G., 2021, Rangeland fractional components across the western United States from 1985 to 2018: Remote Sensing, v. 13, no. 4, article 813, 24 p.

**DOI:** https://doi.org/10.3390/rs13040813

**Background:** Remote sensing can be a tool for managers to monitor vegetation change, evaluate past management practices, and guide future improvements. Previous spatial products present observed and predicted vegetation component changes, but there have been several new improvements to a dataset that may further contribute to detecting vegetation changes through time at a landscape scale.

**Objectives:** The authors sought to describe the methodology used to create a remote sensing dataset and determine (1) changes in vegetation through time, (2) climate factors that drive changes, and (3) differences across ecoregions.

**Methods:** The authors used remotely sensed imagery spanning from 1985 to 2018 to calculate percent cover (fractional) of components, consisting of bare ground, herbaceous, annual herbaceous, litter, shrub, and sagebrush using 30-m-resolution Landsat imagery. They used automated methods to identify changing conditions between years and trained models to predict yearly component cover. The authors also incorporated other model variables, consisting of topography, soil factors, and climate data. They calculated component trends through time, evaluated cover change and climate, and demonstrated model utility using three case studies.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nevada, New Mexico, Nebraska, North Dakota, Oregon, Oklahoma, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** Across the study area on average, shrub, sagebrush, and litter cover decreased, annual herbaceous cover increased, and bare ground and herbaceous cover did not change. Across the study period, in unburned areas, sagebrush cover increased, whereas shrub and annual herbaceous cover did not change. Across ecoregions, component cover and climate trends varied; some regions were affected by fire history, and most regions saw an increase in annual herbaceous cover. Climate factors, consisting of temperature maximums and growing season precipitation, were associated with all component cover trends, but bare ground was the most climate sensitive. Case studies demonstrated on-the-ground applicability of the dataset in relation to various causes of cover change.

**Implications:** The authors suggest that component cover trends change gradually across the landscape and are associated with management practices, interannual climate variation, vegetation composition, and annual grass invasions. They also suggest that these remote sensing datasets can provide managers with a widescale ecosystem perspective to assess patterns, which may inform decisions on a local scale.

**Topics:** broad-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; drought; water; soils or geology; includes new geospatial data

## Rinella, M.J., Bellows, S.E., Davy, J.S., Forero, L.C., Hatler, W.L., and James, J.J., 2021, Pasture-scale evaluation of postemergence applications of aminopyralid for controlling medusahead (*Taeniatherum caput-medusae*): Rangeland Ecology and Management, v. 79, p. 201–207.

**DOI:** https://doi.org/10.1016/j.rama.2021.09.001

**Background:** Herbicides for controlling medusahead are not reliably effective and can damage desirable species. Aminopyralid poses fewer risks to desirable forage grasses, but existing research on this herbicide is restricted to small plots and research in larger pastures is needed.

**Objectives:** The researchers sought to assess responses of medusahead, forage grasses, and forbs to (1) aminopyralid and grazing in a pasture experiment and (2) aminopyralid application timing and spray volume in a small plot experiment.

**Methods:** Yearly in the spring months of 2018 to 2020, the researchers performed two experiments in an annual grassland. In the pasture experiment, researchers applied all combinations of 2 grazing treatments and 2 herbicide treatments (grazed, herbicide; ungrazed, herbicide; grazed, no herbicide; ungrazed, no herbicide) with 3 replicates each, totaling 12 treatment pastures. Throughout the experiment, they collected seeds along transects and measured plant cover in each pasture. In 2019, the researchers established treatments and replicates for a plot experiment, which included 4 different aminopyralid spray volumes, 3 different application timings, and either 1 or 2 replicates within a block, totaling 24 plots in the experiment. Within each plot, they recorded grass growth stages at the time of herbicide application, collected seeds, and measured cover. They performed statistical analyses to assess differences between treatments in both experiments.

**Location:** California

**Findings:** In the pasture experiment, grazing did not modify the effects of herbicide. Aminopyralid significantly reduced medusahead germination and slightly reduced germination of the desirable grasses: Italian rye (2018) and soft brome (2019). Aminopyralid reduced medusahead cover and increased desirable grass cover 1 year after reducing germination. In the plot experiment, aminopyralid spray volume did not affect plant responses, but later application timings controlled medusahead cover more effectively. Aminopyralid negatively affected desirable forbs, but past research indicates these effects will be short lived. Overall, aminopyralid reduced medusahead seed production and cover and increased forage grasses in pastures and small plots.

**Implications:** The authors suggest that environmental variation across large treatment areas does not influence aminopyralid effectiveness, but herbicide application timing is critical. They also suggest that low rates of aminopyralid can be used when the herbicide is applied postemergence, making this option more cost effective compared to when this herbicide is used preemergence. Finally, they suggest that aminopyralid can be used to target yellow star thistle and medusahead simultaneously.

**Topics:** behavior or demographics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: herbicides; weed management subtopic: cultural control

## Rinella, M.J., Bellows, S.E., and Roth, A.D., 2014, Aminopyralid constrains seed production of the invasive annual grasses medusahead and ventenata: Rangeland Ecology and Management, v. 67, no. 4, p. 406–411.

**DOI:** https://doi.org/10.2111/REM-D-13-00138.1

The summary for this article was previously published in Poor and others (2021, p. 23–24; https://doi.org/10.3133/ofr20211031).

## Rinella, M.J., Davy, J.S., Kyser, G.B., Mashiri, F.E., Bellows, S.E., James, J.J., and Peterson, V.F., 2018, Timing aminopyralid to prevent seed production controls medusahead (*Taeniatherum caput-medusae*) and increases forage grasses: Invasive Plant Science and Management, v. 11, no. 1, p. 61–68.

**DOI:** https://www.doi.org/10.1017/inp.2017.41

**Background:** Invasive annual grasses, such as medusahead and cheatgrass, are threatening western grasslands. Growth-regulating herbicides are sometimes used to control exotic grasses. However, it is unclear how the timing of herbicide application affects current populations (this year) and future seed production (following year) of medusahead and other exotic grasses.

**Objectives:** The authors compared the effectiveness of applying a preemergent herbicide on medusahead and forage grasses when applied prior to medusahead (1) emergence and (2) heading.

**Methods:** Between 2013 and 2017, researchers performed two experiments, each at four sites, replicated four times each, to determine the effects of herbicide (aminopyralid) applied at different growth stages of medusahead and forage grasses. In the falls of 2013 and 2015, they applied herbicides at medium and high herbicide application rates. In the following springs (2014 and 2016), they applied herbicides at low, medium, and high application rates. They compared timing of herbicide application and herbicide application rates using a no-herbicide control. They measured species cover during two growing seasons after herbicide application and tested seed viability of medusahead and other forage grasses. Statistical analysis compared the cover of each species and seed viability per treatment.

**Location:** California

**Findings:** In the first growing season after fall treatments, herbicides reduced medusahead cover in half of the experiments. During the second growing season, medusahead seed production decreased only in the high herbicide application rate. In the second fall experiment, treatments reduced cover more than during the first fall. Spring herbicide application at all rates reduced cover and seed production across locations. Fall herbicide treatments negatively affected preferred forbs in three experiments but moderately increased forage grasses. Spring herbicide application increased some forage grass production but also reduced some seed production.

**Implications:** The authors suggest that applying herbicides prior to heading can reduce the seed bank and allows for easier application to medusahead patches. They recommend applying herbicides in a 2-week spring window that reduces medusahead to mitigate the risk of decreasing annual forage grass seed production.

**Topics:** survival or demographics; nonnative invasive plants; weed management; weed management subtopics: hericides

## Rodhouse, T.J., Irvine, K.M., and Bowersock, L., 2020, Post-fire vegetation response in a repeatedly burned low-elevation sagebrush steppe protected area provides insights about resilience and invasion resistance: Frontiers in Ecology and Evolution, v. 8, 14 p.

**DOI:** https://www.doi.org/10.3389/fevo.2020.584726

**Background:** Sagebrush-dominant ecosystems have increasingly been degraded from species invasions and altered fire regimes. Developing techniques to identify site characteristics that provide resilience to fire and resistance to invasive annual grasses is important for conservation decision making.

**Objectives:** The authors sought to evaluate the responses of (1) native perennial and (2) nonnative annual grasses to repeated burning in a national monument.

**Methods:** Between 2011 and 2017, the authors observationally assessed postfire response patterns of two native bunchgrass species (bluebunch wheatgrass and Thurber's needlegrass) and two invasive annual grass species (cheatgrass and medusahead) in an area that had burned in 2011. They estimated species cover in 85 to 211 plots annually across the study area. They used statistical modeling and remotely sensed data to evaluate the effect of year since fire, ecological site, topography, fire severity, and water deficit on species occurrence and abundance.

**Location:** Oregon

**Findings:** Woody species and forbs were rare throughout the study period. Native bunchgrass abundance did not change with time since fire. Cheatgrass was the most abundant species across plots throughout the study, and medusahead frequency increased postfire. Species abundance did not vary by ecological site during the study. Burn severity negatively affected native bunchgrasses and positively affected annual grasses, strongly influencing medusahead. High water deficit years were positively associated with Thurber's needlegrass and medusahead and negatively associated with cheatgrass. In general, topography was most influential on grass cover. North-facing slopes were associated with the greatest invasion resistance and highest presence of bluebunch wheatgrass, compared to shallow slopes associated with medusahead. South-facing slopes were associated with needlegrass and, to a lesser degree, cheatgrass.

**Implications:** The authors suggest that once an area has become more homogeneous in species composition, invasion resistance decreases, causing a shift toward annual grass communities, despite the apparent fire resilience of some perennial species. They suggest that postfire medusahead dynamics are unique from cheatgrass because medusahead can withstand water deficits and recover rapidly postfire. They suggest fire protection in the largest continuous stands of perennial grass communities because annual grassland states are difficult to reverse.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; fire; nonnative invasive plants; weather and climate patterns; climate change; drought; weed management; water; soils or geology; protected lands or areas

## Rodhouse, T.J., Irvine, K.M., Sheley, R.L., Smith, B.S., Hoh, S., Esposito, D.M., and Mata-Gonzalez, R., 2014, Predicting foundation bunchgrass species abundances—Model-assisted decision-making in protected-area sagebrush steppe: Ecosphere, v. 5, no. 9, 16 p.

**DOI:** https://www.doi.org/10.1890/ES14-00169.1

**Background:** Protecting foundation species—dominant species that support ecological stability—may allow land managers to promote ecosystem resilience for conservation of sagebrush systems invaded by annual grasses. Spatially modeling the abundance of foundation species can help managers identify conservation priorities.

**Objectives:** The authors sought to identify distribution and abundance of (1) foundation species and (2) invasive annual grasses, based on ecosystem characteristics, to model priority areas for conservation in a protected landscape.

**Methods:** The researchers estimated percent cover in June 2009 and 2011 in randomly distributed plots. Based on cover estimates, they predicted abundance across the study area. They developed a dataset with many predictor variables related to topography, elevation, flow accumulation (drainage and soil moisture), precipitation, fire disturbance history, distance to roads and the park boundary, and abundance of annual invasive grasses. They developed models to identify areas with high abundance of foundation species and evaluated these models by comparing results with field observations. They then created conservation prioritization maps, focusing on the primary foundation species (bluebunch wheatgrass), but also considering Thurber’s needlegrass and Sandberg bluegrass.

**Location:** Oregon

**Findings:** The authors identified cheatgrass, medusahead, and bluebunch wheatgrass as the most abundant species. Topography was the most important predictor of abundance patterns. Bluebunch wheatgrass was associated with north-facing slopes and steep south-facing slopes, cheatgrass was associated with south-facing slopes, and medusahead was associated with flat landscapes. Native bunchgrasses were more commonly associated with higher elevations than annual grasses. Flow accumulation, precipitation, and distance to the park boundary and roads had weak or no effect on abundance patterns. Fire history positively affected invasive grass abundance. Invasive grass abundance strongly affected native bunchgrass abundance negatively. Based on these trends, the prioritization map yielded potential priority locations of concentrated bluebunch wheatgrass abundance.

**Implications:** The authors suggest that their model demonstrates resilience of the native ecosystem in more productive sites across the study area. They also suggest that spatial modeling of the distribution of foundation species could guide conservation actions that use existing resilient landscape features. Lastly, they suggest that their approach could be useful in protected areas where resilient foundation species exist.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive plants; grazing/herbivory; infrastructure; weather and climate patterns; drought; weed management; water; cultural, historical, Native American, or archaeological sites or values; protected lands or areas

## Rood, S.B., Braatne, J.H., and Goater, L.A., 2010, Favorable fragmentation—River reservoirs can impede downstream expansion of riparian weeds: Ecological Applications, v. 20, no. 6, p. 1664–1677.

**DOI:** https://doi.org/10.1890/09-0063.1

**Background:** Riparian areas support diverse plant and wildlife communities and are disturbed through frequent floods and ice events, leading to increased weed invasions. Dams and reservoirs interrupt river continuity and could affect weed occurrence and abundance in several, such as preventing weed expansion.

**Objectives:** The authors sought to determine patterns of riparian weed abundance and occurrence related to river flows and reservoir levels.

**Methods:** Between 1998 and 2001, the researchers established transects along a 315-km section of river that included reservoirs where three dams were constructed. They established plots within each transect to identify herbaceous plants, shrubs, and trees and categorize weeds based on traits and elevational distributions. They also measured river and reservoir elevations in relation to plant occurrence. They subdivided groups based on their dependence on riparian areas. They estimated plant stem and leaf cover for each species and determined weed patterns along the stream reaches and reservoirs. Additionally, the authors analyzed historical river flows and reservoir levels.

**Location:** Idaho, Oregon, Washington

**Findings:** Of the problem plants, the majority were exotic or introduced, and one was an invasive native. The upland plants varied based on stream reaches, where Canada thistle and morning glory were common along upstream areas, St. John's wort was common downstream, and Scotch thistle was common along the entire corridor. Medusahead was abundant along the reservoirs but rarely present in upstream and downstream river reaches. All riparian weed species were abundant above the dams, and occurrence and abundance declined along the course of the longest river segment. The river flows were dominated by seasonal snowmelt and typically decreased throughout the year except when water was dam released. Reservoirs with greater annual water fluctuations were associated with lower weed abundance.

**Implications:** The authors suggest that although dams may cause drought or flood stress in this area, dams have prevented the downward expansion of riparian weeds. They suggest that this could be due to the varied water levels and interruption of river seed transport.

**Topics:** broad-scale habitat characteristics; dispersal, spread, vectors, and pathways; nonnative invasive plants; water; wetlands/riparian

## Root, H.T., Miller, J.E.D., and Rosentreter, R., 2020, Grazing disturbance promotes exotic annual grasses by degrading soil biocrust communities: Ecological Applications, v. 30, no. 1, article e02016, 10 p.

**DOI:** https://www.doi.org/10.1002/eap.2016

**Background:** Prior research has indicated that soil biocrust (communities of organisms on the soil surface) cover is negatively correlated with invasion by exotic grass species and that soil biocrusts are sensitive to disturbances such as livestock grazing. Identifying specific causal relations between soil biocrusts and exotic grasses at the landscape scale can improve management of ecosystems at risk of invasion.

**Objectives:** The authors sought to (1) determine the direct and indirect (through changes to soil biocrusts) effects of livestock grazing on the establishment of exotic grass species and (2) study variation among soil biocrust functional groups in response to grazing.

**Methods:** The authors sampled 26 plots between 2014 and 2017 that they randomly selected across grazing and vegetation gradients. They collected data on soil biocrust abundance and percent cover and assigned biocrusts to lichen and bryophyte functional groups. They also measured vegetation percent cover, identified plant species, and classified plants as either exotic annual grasses or perennial grasses. They analyzed relations between variables using models of hypothesized causal networks.

**Location:** Idaho

**Findings:** The authors determined that soil biocrust cover and species richness were both negatively associated with grazing intensity. Biocrust cover was moderate to high in moderate and light grazing but was low in heavily grazed areas. Abundance of exotic annual grasses was highest in high grazing intensity plots. Increased abundance of exotic annual grasses in high grazing intensity plots resulted from reductions in soil biocrust cover and species richness because of grazing. They identified that the short mosses functional group had the strongest negative correlation with exotic annual grasses. Several biocrust indicator species occurred only in low intensity grazing plots, and no species were associated most strongly with medium- or high-intensity grazing.

**Implications:** The authors suggest that soil biocrusts, especially short mosses, may help grasslands resist invasion by large-seeded exotic annual grasses and that this research supports previous studies showing that soil biocrusts may decrease seedling success. The authors note that fire and other landscape disturbances likely also have a role in the relationship between exotic annual grasses and soil biocrusts. The authors suggest that establishing methods to cultivate biocrust species may aid future restoration efforts.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat selection; habitat restoration or reclamation; fire; nonnative invasive plants; grazing/herbivory; climate change; weed management; soils or geology

## Rottler, C.M., Noseworthy, C.E., Fowers, B., and Beck, J.L., 2015, Effects of conversion from sagebrush to non-native grasslands on sagebrush-associated species: Rangelands, v. 37, no. 1, p. 1–6.

**DOI:** https://www.doi.org/10.1016/j.rala.2014.12.004

**Background:** Disturbances, like grazing and fire, have converted large parts of sagebrush habitat to nonnative grasslands, affecting sagebrush-dependent species. Although studies have primarily focused on ungulates and sage-grouse, less-studied species, such as passerine birds, rodents, and rabbits, are also affected by sagebrush habitat loss.

**Objectives:** The authors sought to summarize the (1) conversion of the sagebrush steppe to nonnative grasslands and (2) effects on native wildlife species.

**Methods:** The authors summarized the effects of grazing and fire on the sagebrush community. They focused on effects on sagebrush-obligate passerines, non-sagebrush-obligate birds, pygmy rabbits, and rodents.

**Location:** Canada, United States

**Findings:** Historically, sagebrush systems were treated to increase forage for livestock grazing, ultimately converting these areas to nonnative grasslands. Crested wheatgrass was widely seeded after disturbances to increase forage production, resulting in competition with native flora. Increased fire frequencies also contributed to the conversion of sagebrush habitats to nonnative grasslands, dominated by species like cheatgrass, medusahead, and ventenata. Nonnative grasses generally provide unsuitable habitat for sagebrush-obligate birds, but Brewer's sparrows have successfully nested in areas with dense smooth brome. Non-sagebrush-obligate birds varied in their responses to grassland conversion, but they often preferred native to invasive grass habitats. Areas where sagebrush and grasses were codominant supported a greater diversity of bird species than areas dominated by one vegetation group. Sagebrush habitat loss decreased pygmy rabbit food availability and burrowing locations. Cheatgrass invasions reduced small rodent abundance due to decreased food availability and increased predation rates.

**Implications:** The authors suggest that conversion from sagebrush to nonnative annual and perennial grasslands can increase fire frequency and lead to increased competition with native species. They suggest conserving intact sagebrush communities to reduce threats to wildlife, especially sagebrush-obligate species.

**Topics:** broad-scale habitat characteristics; fire; nonnative invasive plants; grazing/herbivory; sensitive/rare wildlife

## Ryals, R., Eviner, V.T., Stein, C., Suding, K.N., and Silver, W.L., 2016, Grassland compost amendments increase plant production without changing plant communities: Ecosphere, v. 7, no. 3, article e01270, 15 p.

**DOI:** https://www.doi.org/10.1002/ecs2.1270

**Background:** Grasslands can provide many ecosystem services, such as carbon sequestration, which may be important for mitigating the effects of climate change. Applying composted material to grasslands has been shown to sequester carbon and increase mineral nitrogen availability and plant productivity. However, the effects of compost amendments on grassland dynamics are not well known because inorganic nitrogen inputs have been attributed to native plant loss and species invasions.

**Objectives:** The authors sought to determine plant dynamics in grasslands managed for capturing carbon to evaluate the effects of compost amendments on (1) plant productivity and (2) nitrogen content.

**Methods:** From October 2008 to September 2012, the researchers established three plots at two grasslands with two treatments: an untreated control and one with an added composted organic matter. Both sites were rotationally grazed by cattle at a medium intensity. Prior to grazing, the researchers measured nitrogen content and concentrations. Before and after grazing, they measured aboveground biomass. They measured annual plant diversity and species cover at the end of each growing season and determined species richness. Finally, they tested if adding compost affected the relative abundance of medusahead and woolly distaff thistle. They used statistical analyses to determine the effects of adding compost on each measured variable.

**Location:** California

**Findings:** In both locations, biomass increased with compost addition across the study period and was higher pregrazing compared to untreated plots. Postgrazed biomass did not differ between treatments. Nitrogen content of pregrazed biomass was greater in composted treatments at both sites throughout the study. Pregrazed nitrogen concentrations in aboveground vegetation were greater in the composted plots in both locations but varied by year. In both grasslands, major shifts of species richness or composition with compost amendments were not seen. In the first location, medusahead was the second most abundant species and only increased in the third year in the untreated plot, whereas woolly distaff thistle did not change with treatments.

**Implications:** The authors suggest that the nitrogen input from a single application of compost combined with rotational grazing can increase carbon capture and aboveground forage biomass without increasing invasive species.

**Topics:** population estimates or targets; site-scale habitat characteristics; nonnative invasive plants; grazing/herbivory; soils or geology

## Saher, D.J., Shyvers, J.E., Tarbox, B.C., Van Schmidt, N.D., Heinrichs, J.A., and Aldridge, C.L., 2022, Compendium to invasive annual grass spatial products for the western United States, January 2010–February 2021: U.S. Geological Survey Data Report 2022–1152, 63 p.

**DOI:** https://doi.org/10.3133/dr1152

**Background:** Invasive annual grasses in western North America have displaced native plant communities, altered disturbance regimes, and degraded sagebrush habitats, resulting in socioeconomic costs for land managers, fire managers, and livestock producers. Landscape-scale maps of invasive annual grass distribution and abundance can provide valuable information for managing invasions and wildfires.

**Objectives:** The authors sought to summarize the attributes of recent datasets that provided spatial data about invasive annual grasses.

**Methods:** The authors searched for regional and national spatial datasets published from 2010 to 2021 that included invasive annual grass data in the western United States. The authors focused on spatial data developed for cheatgrass, medusahead, and ventenata. They identified 23 datasets that met their search criteria. They summarized and compared these datasets by species, vegetation characteristics, resolution, date, study area, model type, modeling approach, and methods for training and validating models. They also described any limitations that the models' original authors identified. They provided citations for and links to all datasets.

**Location:** Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming

**Findings:** The authors wrote comparison tables and 2-page summaries for each dataset that met their search criteria. They also included appendices listing web-based resources and additional spatial products that did not meet their original search criteria.

**Implications:** The authors compiled the dataset summaries to serve as a compendium for a public database. The compendium and public database are components of an information series to guide land managers in awareness, comparison, and selection of spatial datasets of invasive annual grasses. The authors suggested the compendium can help land managers find and select appropriate spatial data to inform management of invasive annual grasses.

**Topics:** population estimates or targets; nonnative invasive plants; includes new geospatial data

## Schantz, M., Sheley, R., and Hardegree, S., 2019, Restoring perennial grasses in medusahead habitat—Role of tilling, fire, herbicides, and seeding rate: Rangeland Ecology and Management, v. 72, no. 2, p. 249–259.

**DOI:** https://doi.org/10.1016/j.rama.2018.10.012

**Background:** To restore native grasses in areas dominated by invasive grasses, managers must actively use methods like tilling, seeding, fire, and herbicides. However, each of these methods have pros and cons, and combining methods may be most effective.

**Objectives:** The authors sought to determine how individual and combined tilling, burning, and herbicide treatments affect (1) established invasive grasses and (2) desired species seeded at different rates across years and changing weather conditions.

**Methods:** The authors established 8 blocks with 250 experimental plots per block and applied treatments from 2009 to 2012. They randomly assigned plots a treatment year and application and replicated applications six times per block. Their treatment applications were fire (yes or no), herbicide (imazapic, none or one of three concentrations), site preparation (tilling or no tilling), seeding rate (no seeds or one of five rates), and all possible combinations of each. The authors collected data on weather variables and measured percent cover of cheatgrass, medusahead, and ground litter in May the year after seeding. They also measured the density of annual and perennial forbs and seeded species and used models to determine treatment effects.

**Location:** Idaho

**Findings:** The authors identified that medusahead cover in unseeded sites was lower when the sites were tilled, burned, or selected for combined treatments. Cheatgrass cover was higher on unseeded sites that were burned without tilling or herbicide treatments. On seeded sites, medusahead and cheatgrass cover was lower where herbicides and (or) burning was applied. Control plots with no seeding and plots with the highest seeding rate had the lowest medusahead and cheatgrass cover. In all years, seeded species were densest when herbicides were combined with burn treatments. Seeded species were denser at higher seeding rates and benefited in years with favorable weather, specifically when winters had lower temperature variability and the following spring had above-average precipitation.

**Implications:** The authors state that in this study a combined effort using tilling, herbicides, and burns was most effective at reducing cover of invasive annual grasses. They determined that increasing seeding to five times the recommended rate increased seeded species density but note that weather variability affected the success of seedling recruitment. They suggest that weather conditions play the biggest role in determining seeding success.

**Topics:** habitat restoration or reclamation; fire; fuels and fuels management; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Schantz, M.C., Sheley, R.L., and James, J.J., 2015, Role of propagule pressure and priority effects on seedlings during invasion and restoration of shrub-steppe: Biological Invasions, v. 17, p. 73–85.

**DOI:** www.doi.org/10.1007/s10530-014-0705-2

**Background:** In restoration projects to control annual invasive grasses and promote perennial native grasses, the ability to predict potential spread of annual grasses is important. Information about the effects of propagule pressure and time of seed dispersal for all annual invasive grasses is needed to make accurate predictions.

**Objectives:** The authors' aim was to determine the effects of (1) seeding rate, (2) time of seeding, and (3) water availability on emergence, establishment, and biomass of annual and perennial grasses.

**Methods:** In 2011, the researchers applied herbicide (glyphosate) and tilled the study area to remove existing vegetation prior to treatments. In November 2011, they hand seeded four densities of an annual grass seed mix (50:50 ratio of cheatgrass and medusahead) with every possible combination of the same four densities of a perennial grass seed mix (bluebunch wheatgrass, bottlebrush squirreltail, Sandberg bluegrass, and Thurber's needlegrass in equal proportions) by hand, resulting in 16 combinations of annual to perennial seeding rates. They also tested each seeding ratio with every possible combination of watering/no watering and fall seeding/delayed winter seeding (February 2012) for the exotic annual grasses. They replicated treatments three times for a total of 196 plots. They measured precipitation, air temperature, soil moisture, and soil temperature; plant density from March to June 2012; time of grass emergence; and final density and harvest biomass in June 2013.

**Location:** Oregon

**Findings:** Annual grasses emerged earlier and at higher rates than perennial grasses across all seeding rates. In the first year, watering and delayed seeding resulted in higher annual grass densities. Delaying annual grass seeding also initially resulted in higher perennial grass densities. Perennial grass density in the second year increased with higher seeding rates of perennial grasses and at the lowest annual grass seeding rate. Annual grass seedling density in the second year was highest when grasses were seeded in the fall, when water was added, and at higher annual grass seeding rates. Annual grass biomass was highest at the lowest annual grass seeding rate.

**Implications:** The authors suggest that earlier emergence of annual grasses may preempt the use of available resources by perennial grasses. Additionally, they state that initial annual grass seed density may be the greatest determinant of success of seeded perennial grasses. To promote establishment of perennial grasses in annual invaded grass systems, the authors suggest limiting the seed bank of annual invasive grasses and seeding perennial grasses at high rates.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control

## Schantz, M.C., Sheley, R.L., and James, J.J., 2018, Effects of propagule pressure and priority effects on seedling recruitment during restoration of invaded grassland: Journal of Arid Environments, v. 150, p. 62–70.

**DOI:** https://www.doi.org/10.1016/j.jaridenv.2017.12.001

**Background:** Invasive annual grasses are dominating arid lands and producing more seeds annually than perennial grasses. Seeding native grasses at optimal times and rates may increase seedling success. However, less is understood about how competition with annual invasive grasses affects survival of perennial grasses during transitions between life history stages.

**Objectives:** The authors sought to understand the effects of (1) number of seeds, (2) timing of seeding, and (3) water availability on annual and perennial grass survival across life history stages.

**Methods:** In 2011, the researchers sprayed herbicide (glyphosate) and tilled to remove vegetation prior to seeding treatments. They established 192 plots by seeding an annual grass seed mix (50:50 ratio of cheatgrass and medusahead) with every possible combination of the same four densities of a perennial grass seed mix (bluebunch wheatgrass, bottlebrush squirreltail, Sandberg bluegrass, and Thurber's needlegrass in equal proportions) by hand, resulting in 16 combinations of annual to perennial seeding rates, replicated three times per treatment. They seeded perennial grasses in fall 2011 and seeded annual grasses with perennial grasses in the fall or in the following spring. In spring, they watered half of the plots with two times greater than the historical average precipitation. They also planted grass seeds into germination bags and assessed how the number of seeds and timing of seeding affected germination rates. They monitored annual and perennial grass emergence and density and assessed life history growth stages for 1 year postseeding.

**Location:** Oregon

**Findings:** Perennial grass germination was higher when seeded with annuals in the fall. Annual grass germination was not affected by planting time or annual and perennial grass seed rate. Higher perennial grass seeding rates and lower annual grass seeding rates resulted in greater perennial grass densities, and number of surviving adults did not change between the first and second growing seasons. Adding water increased annual and perennial grass density when both were planted at the two lowest seeding rates. Across species, survival rates were lowest between germination and emergence life history stages.

**Implications:** The authors recommend increasing perennial grass seeding rates, planting perennial grasses prior to annual grass emergence, and seeding perennial grasses when forecasts are calling for higher annual precipitation to increase success when annual grasses are present. They also suggest that perennial and annual grass survival was most limited between the germination and plant emergence stage.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; weed management; weed management subtopic: cultural control

## Schantz, M.C., Sheley, R.L., and James, J.J., 2019, Propagule pressure and priority seeding effects on the demography of invasive annual and native perennial grass species: Plant Ecology and Diversity, v. 12, no. 2, p. 139–150.

**DOI:** https://doi.org/10.1080/17550874.2019.1613696

**Background:** Invasive annual grasses have physiological advantages over many native perennial grasses, such as faster germination times and higher growth rates. These traits likely help invasive grasses invade grasslands, but this effect has not been quantified in previous studies.

**Objectives:** The authors sought to quantify the effects of seeding time, seeding rate, and water availability on annual and perennial grasses.

**Methods:** The authors implemented two seeding treatments in November 2011 (autumn) and February 2012 (spring). In treatment 1, they seeded annual grasses (medusahead and cheatgrass) in autumn and native perennial grasses in spring. In treatment 2, they seeded annual grasses (50:50 ratio of medusahead and cheatgrass) in autumn and split perennial seeding (bluebunch wheatgrass, bottlebrush squirreltail, Sandberg bluegrass, and Thurber's needlegrass in equal proportions) evenly between fall and spring. They used 16 annual-to-perennial seed ratios and watered half the treatments with double the historical average precipitation. They replicated treatments three times, totaling 288 plots. They also performed germination assessments by burying germination bags with 16 annual-to-perennial seed ratios in either November 2012 or February 2013, harvesting bags in March 2013. They collected data on plant density, mortality, and growth stage for 1 year and used statistics to compare results.

**Location:** Oregon

**Findings:** Seeding time of perennial grasses did not affect their germination rates. Seeding perennial grass in spring produced the highest first-season density, but seeding them in fall resulted in higher second-year density. Adding water in the first season doubled perennial growth in the second season compared to natural precipitation. Highest perennial grass density resulted from the combination of high perennial grass seeding rates, doubled water, and spring perennial grass seeding. Highest annual grass densities resulted from high seeding rates of annual as well as perennial grasses, from increased water, and from autumnal perennial grass seeding.

**Implications:** The authors suggest that water availability is the most important factor for perennial grass growth because additional water benefited perennial grasses more than annual grasses. The authors indicate that annual grasses may not be as limited by environmental factors. To promote growth of perennial grass and limit growth of annual grass, the authors indicate that perennial grass seeding ought to be delayed to spring or the seeding rate should be increased in autumn and spring. They conclude that managers should also focus on facilitating plant establishment that occurs between germination and emergence by using these adaptive management strategies and manipulating the timing of seeding.

**Topics:** survival, behavior, or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; weather and climate patterns; weed management; water; soils or geology

## Schantz, M.C., Sheley, R.L., James, J.J., and Hamerlynck, E.P., 2016, Role of dispersal timing and frequency in annual grass-invaded Great Basin ecosystems—How modifying seeding strategies increases restoration success: Western North American Naturalist, v. 76, no. 1, p. 36–52.

**DOI:** https://doi.org/10.3398/064.076.0106

**Background:** Seeding native plants can increase population recovery in invaded grasslands but often with meager success. Previous studies have indicated perennial grass recruitment in invaded areas may be higher when seeded in the fall. However, it is unclear how increasing seeding frequency to both fall and spring affects annual and perennial composition through time.

**Objectives:** The authors sought to determine how seeding regimes of perennial grasses affects the (1) emergence, (2) density, and (3) biomass of annual and perennial grasses through multiple years.

**Methods:** In September 2011, the researchers applied herbicide (glyphosate) and tilled the study area to remove existing vegetation prior to treatments. They seeded an annual grass seed mix (50:50 ratio of cheatgrass and medusahead) with every possible combination of the same four densities of a perennial grass seed mix (bluebunch wheatgrass, bottlebrush squirreltail, Sandberg bluegrass, and Thurber's needlegrass in equal proportions) by hand, resulting in 16 combinations of annual to perennial seeding rates. The researchers seeded annuals in November 2011. They seeded perennials in November 2011 (fall only), February 2012 (spring only), or split seeding evenly between fall and spring. During spring 2012, they administered watering treatments to half of the plots. They replicated treatments three times for 288 total plots. From March to June 2012, they measured plant density, and in June 2013, they measured final density and biomass.

**Location:** Oregon

**Findings:** Annual grasses began growth earlier and emerged at a higher rate than perennial grasses. Final perennial grass density was greater at the highest seeding rate and when seeding was split between fall and spring. Emerging perennial grass densities were highest at the two highest seeding rates, with watering treatments, and when annual grass seeding was at the lowest rate. Across seeding rates, final perennial grass biomass was highest when seeded in both the fall and spring. Annual grass density increased with higher seeding rates and was higher with fall seeded perennial grasses. Final annual grass biomass was highest when perennial grass seeding was seasonally split and when watered.

**Implications:** The authors suggest that increasing the frequency and rate of perennial grass seeding may lead to increased recruitment of perennial grasses in annual-grass-dominated areas. However, they state that if the annual grass seed rate is too high when seeding perennial grasses, restoration efforts may be unsuccessful.

**Topics:** dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control; water

## Schohr, T.K., Gornish, E.S., Woodmansee, G., Shaw, J., Tate, K.W., and Roche, L.M., 2020, Practitioner insights into weed management on California's rangelands and natural areas: Environmental Management, v. 65, p. 212–219.

**DOI:** https://www.doi.org/10.1007/s00267-019-01238-8

**Background:** Weedy and invasive plants are threatening working rangelands resulting in negative economic and environmental effects. Integrated weed management approaches, which involve adaptive and landscape-scale treatments, are commonly used among land managers and practitioners, but there are few studies on the effectiveness of integrative weed control approaches. Identifying management priorities, practices, and challenges across rangelands could support management decisions.

**Objectives:** The authors sought to (1) document weed management experiences and priorities from California's land managers and (2) understand implementation practices and perceived effectiveness of weed control techniques.

**Methods:** The researchers distributed social surveys across seven extension education workshops that they offered for a broad range of land managers (public and private) interested in invasive plants and weed management. They used statistics to characterize land management experiences, priorities and strategies, and management information resources.

**Location:** California

**Findings:** Most respondents were natural resources management agency personnel or were involved with primary decision making in weed management. The most recognized management priorities were livestock forage production and conservation and habitat management. Weed management was rated a high priority for respondents. Across bioregions, medusahead and yellow star thistle were rated as highly problematic species coinciding with top management goals. The most common management practices used and reported in order of effectiveness were herbicides, mechanical and livestock grazing, and seeding or burning. Respondents were concerned about obstacles in implementation and public perception of these control practices.

**Implications:** The authors suggest that land managers and practitioners have similar weed management goals, control efforts, and implementation barriers. They recommend management-science collaborations to implement proactive strategies prior to invasions and additional training to reduce information gaps in invasive plant management.

**Topics:** fire; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; human dimensions or economics

## Seabloom, E.W., Borer, E.T., Lacroix, C., Mitchel, C.E., and Power, A.G., 2013, Richness and composition of niche-assembled viral pathogen communities: PLOS ONE, v. 8, no. 2, article e55675, 9 p.

**DOI:** https://doi.org/10.1371/journal.pone.0055675

**Background:** All organisms are exposed to infection from pathogens, which can substantially alter their biology. However, little is known about how pathogen communities are formed in natural systems and how biotic and abiotic factors affect their formation with hosts.

**Objectives:** The authors sought to examine the response of five different aphid-transmitted viruses to (1) site location, (2) host species, (3) gradients in natural local plant composition, and (4) nutrients.

**Methods:** The authors treated 40 plots across 5 sites with varying levels of phosphorous and nitrogen starting in December 2006. They selected three pairs (six species) of closely related native perennial and invasive annual grasses. They collected seeds from all species, pregerminated them in greenhouses, and transplanted them at sites in January 2008. They collected all aboveground mass of seeded species in May and June 2008, then weighed the dried mass and examined each sample for the five viruses. They also collected data on total plant biomass, community composition, and area cover and performed greenhouse experiments on aphid vector host preference. They used statistical analyses to examine changes in the viral communities.

**Location:** California, Oregon

**Findings:** About a quarter of host grasses analyzed carried one virus, and around half carried more than one. Host survival was high and did not vary by species. Medusahead had the highest infection prevalence whereas wild oat had the lowest. Increased perennial grass cover led to an increase in all but one virus and an increase in the number of viruses per host. Increased annual grass cover decreased the prevalence of two viruses. Virus communities varied widely across all spatial scales above the plot level. Increased phosphorous led to an increase in two viruses but no change in the others. In the greenhouse experiments, the strong preference of aphids (*Rhopalosiphum padi*) for the six host species (all grass species such as medusahead) was the variable most correlated with virus infection rates.

**Implications:** The authors state their results provide insights into the biotic and abiotic factors influencing virus diversity in grasses. They suggest that different species' vulnerability to viral infection could explain the patterns they observed. They state that differences in host nutrition and physiology could affect species being co-infected by viruses. Finally, they state that exploiting vector preference could provide a good strategy for managing disease risk.

**Topics:** other: species and population characteristics; effect distances or spatial scale; nonnative invasive plants

## Sebastian, D.J., Nissen, S.J., and De Souza Rodrigues, J., 2016, Pre-emergence control of six invasive winter annual grasses with imazapic and indaziflam: Invasive Plant Science and Management, v. 9, no. 4, p. 308–316.

**URL:** https://bioone.org/journals/invasive-plant-science-and-management/volume-9/issue-4/IPSM-D-16-00045.1/Pre-emergence-Contro-=[,m l-of-Six-Invasive-Winter-Annual-Grasses-with/10.1614/IPSM-D-16-00045.1.full

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## Shapero, M.W.K., Huntsinger, L., Becchetti, T.A., Mashiri, F.E., and James, J.J., 2018, Land manager perceptions of opportunities and constraints of using livestock to manage invasive plants: Rangeland Ecology and Management, v. 71, no. 5, p. 603–611.

**DOI:** https://doi.org/10.1016/j.rama.2018.04.006

**Background:** Invasive plants have had significant effects on rangelands. Livestock grazing is considered a practical and efficient method of controlling invasive plants at large spatial scales, but less is known about limitations managers face when implementing this method. Addressing and understanding constraints managers face, such as balancing running a successful business with ecological restoration, is important for developing management strategies for invasive plants.

**Objectives:** The authors sought to characterize different managers' perceptions about (1) invasive plants, (2) their understanding of invasive plant management, and (3) the use of grazing as an invasive plant control method.

**Methods:** From June to August 2015, the authors organized interviews with 42 managers from three categories: ranchers, public agency staff, and nongovernmental organizations (NGOs) or land trust staff. Interviewees worked in annual grass and hardwood rangelands in 22 counties in California. The interviews consisted of questions about land management history, management goals, and responsibilities.

**Location:** California

**Findings:** Medusahead was frequently mentioned as problematic, though there was regional variation in its perceived importance. Managers from NGOs and land trusts considered managing invasive plants a high priority and emphasized protecting natural resources. Ranchers focused on livestock operations, and many considered controlling invasive plants a low priority. Public agencies generally spent more time and resources managing invasive plants than private landowners. All interviewees agreed that grazing could be used to control invasive plants, but primary motivations differed between groups. Ranchers generally understood strategies for using grazing as a control method but stated they often made grazing decisions based on other factors.

**Implications:** The authors state their results show that different land managers have different priorities that affect their management of invasive plants, with agency and NGO managers mainly focused on conservation and ranchers primarily focused on running a successful business. They suggest that ranchers could be motivated to increase efforts to control invasive plants by either providing incentives or showing how controlling invasives could be economically valuable. Finally, they state that a full understanding of different land managers' requirements, constraints, and motivations as well as actively engaging with different land managers is critical to successful management of invasive plants.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; human dimensions or economics

## Sheley, R.L., Bingham, B.S., and Davies, K.W., 2012, Rehabilitating medusahead (*Taeniatherum caput-medusae*) infested rangeland using a single-entry approach: Weed Science, v. 60, no. 4, p. 612–617.

**DOI:** https://doi.org/10.1614/WS-D-12-00017.1

**Background:** Management strategies used to reduce medusahead invasion, such as prescribed burns and herbicides, show varied results. Seeding affected areas with desired vegetation may increase success; however, getting desired species to establish can be challenging. A single-entry approach, where seeding and herbicide are applied simultaneously, may be cheaper and more reliable, but this has not yet been tested in medusahead-invaded areas.

**Objectives:** The authors sought to test if (1) revegetation using a single-entry approach could be successful in medusahead-invaded areas and (2) if the addition of prescribed burns could increase revegetation success.

**Methods:** In October 2006, the authors applied treatments to plots at two sites, consisting of (1) seeding with three rates (none, medium, high) of desired species, (2) applying or not applying herbicide (imazapic), and (3) burning or not burning. They tested all possible treatment combinations and replicated each four times. Their seed mix included fall-dormant species. They also recorded other nonseeded species present at the sites. The authors measured plant density and biomass in each plot in July 2007 to 2010 and grouped measurements into three types: medusahead, seeded species, or nonseeded species. They used statistics to make comparisons between treatments.

**Location:** Oregon

**Findings:** The effects of seeding on desired species density differed by site; however, desired species biomass increased at both sites with either seeding or herbicides. Higher seeding rates increased desired species biomass more than lower rates. Nonseeded desired species density increased when burning was combined with herbicide treatment, whereas biomass increased with only herbicides. When herbicides were applied, medusahead density in unburned and burned plots and biomass in burned plots was lower than in plots without herbicides in early years. However, in later years, medusahead in herbicide plots was either greater or the same as plots without herbicides, with burned areas suppressing medusahead slightly longer.

**Implications:** The authors suggest that applying herbicides simultaneously with seeding fall-dormant species in a single-entry system can control medusahead and promote revegetation of desired species, while also cutting costs. However, the authors note that predicting outcomes under varied conditions is challenging and that seeding may not be needed for recovery.

**Topics:** population estimates or targets; habitat restoration or reclamation; fire; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Sheley, R.L., and James, J., 2010, Resistance of native plant functional groups to invasion by medusahead (*Taeniatherum caput-medusae*): Invasive Plant Science and Management, v. 3, no. 3, p. 294–300.

**DOI:** https://www.doi.org/10.1614/IPSM-D-09-00056.1

**Background:** Medusahead invasions perpetuate fire cycles and outcompete perennial grasses within sagebrush ecosystems. Maintaining a resistant and healthy plant community may depend on traits across vegetation groups, and understanding these characteristics is important for reducing medusahead invasions.

**Objectives:** The researchers sought to determine vegetation group differences that are important for minimizing medusahead invasion in an intact Wyoming big sagebrush-bluebunch wheatgrass community by (1) removing different vegetation groups and (2) assessing resulting medusahead density and biomass.

**Methods:** Between 2004 and 2009, the researchers implemented seven removal treatments across vegetation groups, with four replicates per site. They compared treatments across two sites, using a site with shrubs where Wyoming big sagebrush was dominant and another site without shrubs, dominated by perennial bunchgrasses. The removal groups included all vegetation, shrubs, perennial grasses, taprooted forbs, rhizomatous forbs, annual forbs, and mosses. They also included a no-removal treatment. In spring 2004, they removed vegetation using a foliar herbicide (glyphosate), clipped remaining aboveground biomass, and maintained monthly removal throughout the growing season until 2009. After two growing seasons, they seeded medusahead and then measured medusahead density and biomass. Statistical analyses compared medusahead biomass differences across removal plots.

**Location:** Oregon

**Findings:** On the site without shrubs, the highest biomass removed was associated with perennial grasses because this vegetation group dominated the site. On the shrub site, the highest biomass removed was shrubs. Regardless of year or site, removal of perennial grasses resulted in the greatest increase in medusahead density and biomass, followed by rhizomatous forbs. Removal of all vegetation groups resulted in the lowest medusahead density.

**Implications:** The authors suggest that increasing invasion resistance depends on species' traits and their relative abundance. They recommend focusing on efforts that increase certain vegetation groups, such as perennial grasses, to minimize medusahead invasion.

**Topics:** site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; sagebrush removal; weed management

## Sheley, R.L., and James, J.J., 2014, Simultaneous intraspecific facilitation and interspecific competition between native and annual grasses: Journal of Arid Environments, v. 104, p. 80–87.

**DOI:** https://doi.org/10.1016/j.jaridenv.2014.01.019

**Background:** Plant-plant interactions can be positive or negative and may change based on resource availability and plant age, size, and density. Managers may be able to use plant-plant interactions to understand competitive effects between native and invasive plants for restoration purposes. However, there is little knowledge about how initial ecological conditions and differences in growth strategies affect plant interactions.

**Objectives:** The authors sought to determine how variations in (1) native plant life stage and (2) soil water content affect interactions between a native perennial bunchgrass and an invasive annual grass when planted in low nutrient soils.

**Methods:** During spring 2010, the authors planted medusahead seeds with bottlebrush squirreltail seedlings together at four densities (0, 2, 4, 6 seeds per pot for medusahead and 0, 3, 20, 40 seedlings per pot for squirreltail) using all possible density ratio combinations. They also planted medusahead seeds with squirreltail seedlings at three increasingly larger plant sizes at the same density ratios. The authors also organized a watering experiment where each density combination was watered with either high or low water content. After 85 days, the authors collected, dried, and weighed each plant and used models to determine treatment effects.

**Location:** Oregon

**Findings:** Total squirreltail weight decreased with increasing medusahead density but increased with increasing squirreltail density and when seedlings were planted at larger sizes. Higher water content increased squirreltail weight and the positive facilitative effects of higher squirreltail density on other squirreltail individuals but simultaneously increased negative effects from medusahead. Total medusahead weight increased with increasing medusahead density but decreased with increasing squirreltail density and when squirreltail was planted at larger sizes. Higher water content increased medusahead weight but also increased the negative effects from higher densities of squirreltail.

**Implications:** The authors state that this study demonstrates the ability for plants to facilitate better environments for their own species while having simultaneous negative effects on different species. They identified that facilitation between squirreltail plants increased with plant size, and they suggest that developmental stage may play a larger role in plant-plant competition. They suggest that stressors, such as drought, likely cause competitive shifts that may favor native species over invasives.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; drought; weed management; weed management subtopic: cultural control; water

## Sheley, R., Sheley, J., and Smith, B., 2014, Cost/benefit analysis of managing invasive annual grasses in partially invaded sagebrush steppe ecosystems: Weed Science, v. 62, no. 1, p. 38–44.

**DOI:** https://doi.org/10.1614/WS-D-13-00056.1

**Background:** Annual invasive grasses, such as medusahead and cheatgrass, have had widespread effects on agriculture, wildlife, and ecosystem functions. Understanding the costs and benefits associated with different strategies for managing invasive grasses is important for planning restoration efforts.

**Objectives:** The authors sought to assess the costs and benefits of both single-application herbicide and targeted grazing treatments for restoring sagebrush steppe rangeland partially invaded by annual grasses.

**Methods:** The authors used a previously created model to examine the costs and benefits of two different management strategies: single-application herbicide and targeted grazing. They set the starting state of the model as having 85 percent of production coming from invasive plants. To mimic decreased grazing based on palatability of invasive grasses, the authors modeled livestock consumption of 60 percent, 40 percent, or 20 percent of the invasive grass available. They then calculated the costs and forage benefits of each treatment during a 20-year timespan on a 404-ha site.

**Location:** Not specified

**Findings:** The authors determined that the single herbicide treatment was less cost effective than the targeted grazing treatment regardless of if 60 percent, 40 percent, or 20 percent of the invasive grasses were grazed. They determined the forage benefits of the herbicide treatment never exceeded the costs, whereas the benefits of the grazing treatment broke even with the costs within the first 2 years, after 5 years, and after 7 years for the 60 percent, 40 percent, and 20 percent utilization rates, respectively.

**Implications:** The authors state their results show that targeted grazing can be a cost-effective strategy for managing invasive grasses in sagebrush steppe ecosystems. They do caution that the results of their model represent a best-case scenario of reclaiming rangeland with native perennial grasses within 10 years. They conclude by stating that a complete understanding of the costs and benefits of rangeland management requires further analysis of other benefits, such as carbon sequestration and water quality.

**Topics:** population estimates or targets; habitat restoration or reclamation**;** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Sheley, R.L., Vasquez, E.A., Chamberlain, A.M., and Smith, B.S., 2012, Landscape-scale rehabilitation of medusahead (*Taeniatherum caput-medusae*) dominated sagebrush steppe: Invasive Plant Science and Management, v. 5, no. 4, p. 436–442.

**DOI:** https://doi.org/10.1614/IPSM-D-12-00030.1

**Background:** Winter annual grasses, like medusahead, negatively affect ecosystems in the western United States. Revegetation of perennial grasses is key to restoring medusahead-infested areas, but reestablishing desired species is difficult and costly. Simultaneously applying seeds and herbicides in a single-entry approach can be cost efficient and more effective at revegetating medusahead-invaded rangelands; however, this method has not been tested across large diverse landscapes.

**Objectives:** The authors examined the effectiveness of using a single-entry approach to revegetate medusahead-invaded areas across diverse environments at the landscape scale.

**Methods:** In November 2009, the authors applied four treatments, consisting of (1) both herbicide (imazapic) and seeding (single-entry approach), (2) only herbicide, (3) only seeding, and (4) a control with no seeding or herbicides, to plots at five separate sites. The seed mix they applied was a mixture of a crested wheatgrass hybrid and Sandberg bluegrass. In July 2010 and 2011, the authors sampled plant density and biomass and used these measurements to model responses to treatments.

**Location:** Oregon

**Findings:** Crested wheatgrass density was higher in plots that used the single-entry approach when compared to control plots, whereas biomass was higher in plots that used the single-entry approach when compared to all other treatments. Sandberg bluegrass density was higher in plots using the single-entry approach when compared to seeding-only and control plots, but not herbicide-only plots. Biomass of Sandberg bluegrass was not affected by treatments in 2010; however, in 2011, bluegrass biomass more than doubled in herbicides-only and single-entry-approach plots. In 2010, herbicides and the single-entry approach greatly reduced medusahead density and biomass, whereas in 2011, only the single-entry approach remained effective in reducing medusahead density. Seeding alone and the single-entry approach increased biomass and density of forbs when compared to other treatments; however, this effect was only seen in 2010.

**Implications:** The authors suggest that their study supports the idea that the single-entry approach can be effective for reducing invasive annual grasses and restoring desired perennial grasses across highly varied landscapes. They also state that this approach should reduce management costs and may allow for earlier management of newly invaded areas.

**Topics:** population estimates or targets; broad-scale habitat characteristics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: herbicides

## Shinneman, D.J., Pilliod, D.S., Arkle, R.S., and Glenn, N.F., 2015, Quantifying and predicting fuels and the effects of reduction treatments along successional and invasion gradients in sagebrush habitats: Joint Fire Science Program Project 11-1-2-30 Report, 44 p.

**DOI:** https://www.doi.org/10.3133/70159656

**Background:** Monitoring fuel amounts and types is important to fire management; however, temporal variation in fuel loads because of invasive species can reduce predictability of fire behavior. Developing fine-scale, rapid measurement tools and effective fuel treatments is critical for restoring degraded sagebrush lands.

**Objectives:** The authors sought to evaluate (1) site-level variation in fuels, (2) how fuel reduction treatments affect invaded areas, and (3) how to characterize vegetation changes with remotely sensed imagery.

**Methods:** To measure variation in fuel loading, between 2012 and 2014, the researchers established 148 plots across a combination of historically burned, unburned, treated, and untreated areas. They sampled vegetation cover, density, and fuel types in 57 plots. To test treatment effectiveness, they treated 48 plots in 3 replicated blocks with mowing, herbicide (glyphosate), and a combination of both, seeding native species in half of each treatment. They sampled species composition, fuel loading, plant density, and cover pretreatment and posttreatment. Finally, they used satellite, aerial, and terrestrial remote sensing techniques to determine vegetation types and fuel characteristics. They trained imagery with field-collected data to determine succession and invasion characteristics.

**Location:** Idaho

**Findings:** Herbaceous biomass was lower in plots with higher shrub cover, and invasive plants contributed most of the herbaceous biomass. Herbaceous fuels, particularly in plots dominated by invasive species, varied across the landscape and depended on the year. Mowing, herbicides, and combined treatments did not affect herbaceous biomass through time; however, nonnative annual grass cover varied more than perennial grass cover across treatments. Native plant seeds did not establish, but the

survival probability of sagebrush increased after mowing treatments. Remote sensing techniques provided varying advantages in assessing fuel characteristics. Satellite imagery efficiently mapped shrub biomass and cover at larger scales, and terrestrial sampling better quantified herbaceous cover and biomass.

**Implications:** Because of the short duration of treatment effectiveness, the authors suggest repeating fuel reduction treatments through time. They suggest that using remote sensing technology can provide long-term monitoring of fuel estimates, and when combined with field assessments, can be an effective management strategy to forecast fire risk on a highly varied landscape.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; fire; fuels and fuels management; nonnative invasive plants; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; protected lands or areas

## Shyvers, J.E., Tarbox, B.C., Van Schmidt, N.D., Saher, D.J., Heinrichs, J.A., and Aldridge, C.L., 2022, Database of invasive annual grass spatial products for the western United States January 2010 to February 2021: U.S. Geological Survey data release.

**DOI:** https://doi.org/10.5066/P9VW97AO

**Background:** The spread of invasive annual grasses in the sagebrush biome has resulted in ecosystem degradation, increased wildfire risk, and negative effects on ecosystem services and sagebrush-obligate wildlife species. Managers can use spatial data products that map invasive annual grasses to inform management decisions, but there is often a gap between product development and on-the-ground management applications.

**Objectives:** The authors sought to summarize spatial data products on three species of invasive annual grasses to improve accessibility and interpretation of these data and models to land managers.

**Methods:** The authors performed a literature review of publicly available invasive annual grass spatial data products published between January 2010 and February 2021, which included 23 products. For each product, the authors provided basic product information, links to access the data, intended use(s) and caveats, and information on model development and evaluation.

**Location:** United States

**Findings:** The authors developed a database that summarizes spatial data products, including maps that describe aspects of cheatgrass, medusahead, and ventenata. The database is part of a series of resources developed to assist land managers in understanding and selecting spatial products for management needs.

**Implications:** The authors suggest that using a searchable, filterable, and sortable database may help bridge the research-management implementation gap by making geospatial information on invasive annual grasses more accessible to managers.

**Topics:** population estimates or targets; broad-scale habitat characteristics; nonnative invasive plants; weed management; includes new geospatial data

## Smith, J.T., Allred, B.W., Boyd, C.S., Davies, K.W., Jones, M.O., Kleinhesselink, A.R., Maestas, J.D., Morford, S.L., and Naugle, D.E., 2022, The elevational ascent and spread of exotic annual grass dominance in the Great Basin, USA: Diversity and Distributions, v. 28, no. 1, p. 83–96.

**DOI:** https://doi.org/10.1111/ddi.13440

**Background:** Annual grasses are highly successful invaders in sagebrush and salt desert shrublands. It is hypothesized that grasses are gaining dominance at higher elevations in response to warming temperatures from climate change. Remote sensing has been used to map spread but has yet to provide actionable information of spread through time.

**Objectives:** The authors' aim was to (1) quantify the extent of annual grasses in the Great Basin and (2) assess potential relations between grass distribution and topographic gradients within the past three decades.

**Methods:** The authors used remote sensing to first classify areas at a 30-m resolution within three ecoregions of the Great Basin that were dominated by annual invasive grasses, consisting of cheatgrass, medusahead, ventenata, and red brome from 1990 to 2020. They used existing remotely sensed data of aerial cover of vegetative functional groups, bare ground, and litter, and they validated the resulting classifications using field-collected data from 1,486 plots monitored between 2004 and 2019 by the Bureau of Land Management (BLM) or the National Resources Conservation Service. Next, they used this aerial cover data to determine when an area transitioned to annual grasslands and related this year to the area's elevation and aspect. Additionally, they calculated climate data for the period and related climate variables with annual grass invasion.

**Location:** California, Idaho, Nevada, Oregon, Utah

**Findings:** Annual invasive grass dominance quickly expanded across the Great Basin during the study period and the authors state that it now dominates one-fifth of the region. Expansion was the fastest from 2010 to 2020. During the entire study period, grasses moved upward in elevation more quickly on south-facing slopes, and recent transitions have occurred more on north-facing slopes.

**Implications:** The authors suggest that in the long term, annual grasses will continue to invade upslope and that invasion may be driven by broad-scale changes in climate. They also state that modern conceptions about invasion risk may not be true in the future. The authors recommend that managers focus on preventing invasion over restoration efforts, advocating a shift in management paradigms to actively prevent shrublands of the Great Basin from transitioning to annual-grass-dominated communities within the next few decades.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; site-scale habitat characteristics; habitat selection; effect distances or spatial scale; nonnative invasive plants; weather and climate patterns; climate change; drought; includes new geospatial data

## Smith DiCarlo, L.A., and DeBano, S.J., 2019, Spider community responses to grassland restoration—Balancing trade-offs between abundance and diversity: Restoration Ecology, v. 27, no. 1, p. 210–219.

**DOI:** https://doi.org/10.1111/rec.12832

**Background:** Grassland invertebrates, particularly spiders, provide ecosystem services and should be considered in grassland restoration efforts. However, most restoration studies focus on vegetation or vertebrates. Restoration effects on grassland spiders remain unknown.

**Objectives:** The authors sought to explore native, restored, and degraded habitats to (1) compare spider abundance, richness, and community composition, (2) examine how these variables change across time since restoration, and (3) determine which habitat variables may drive observed patterns.

**Methods:** From June to September 2014 to 2016, the authors collected spiders three times per summer at six restored, six native, and six degraded grassland sites. They caught spiders using eight traps per site and opened traps 1 week before collection. After collection, they sorted juvenile and mature spiders and identified them to genus or species, respectively. The authors also collected habitat data at each site, consisting of cover of invasive annual grasses (cheatgrass and medusahead), biological soil crusts, litter, forbs, and vegetation height. They used statistics and modeling to compare spider and habitat data between sites.

**Location:** Oregon

**Findings:** The authors collected 2,752 spiders. Spider abundance and invasive grass cover were higher on degraded and restored sites than native sites. Spider species diversity was lowest on degraded sites. Spider community composition on native sites differed in comparison to restored and degraded sites. On restored sites, spider abundance decreased with time since restoration. Soil crust cover was highest in native sites, whereas litter cover was lowest.

**Implications:** The authors suggest that presence of invasive annual grasses, and their resulting high ground litter, were primary factors driving differences in spider communities between the three sites. They note that degraded areas favored one spider group, which likely led to heightened spider abundance, but lower richness, on degraded sites. They suggest that restoration can change spider communities to resemble those at native sites but note that changes may take years to occur and there may be tradeoffs between abundance and biodiversity. They state that it is important to consider spiders when measuring grassland restoration success.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat selection; habitat restoration or reclamation; nonnative invasive plants; soils or geology

## Smith DiCarlo, L.A., and DeBano, S.J., 2021, Spider community variability and response to restoration in arid grasslands of the Pacific Northwest, USA: Insects, v. 12, no 3, 15 p.

**DOI:** https://doi.org/10.3390/insects12030249

**Background:** Spiders can be a useful indicator for monitoring the effectiveness of restoration efforts. However, existing studies on spider responses to grassland restoration show inconsistent results depending on a variety of environmental variables. A greater understanding of the effects of restoration efforts on invertebrates is needed, particularly in arid and semi-arid grasslands of the Pacific Northwest.

**Objectives:** The authors sought to 1) describe spider communities in Pacific Northwest grasslands, 2) determine environmental variables that affect spider communities, and 3) compare the effects of passive and active restoration on environmental variables and spider communities.

**Methods:** The authors established 11 actively restored, 11 passively restored, and 8 native control sites across three grassland locations. They treated actively restored sites with herbicides and controlled burns before seeding with native species, and passively restored sites simply had the cessation of livestock grazing. They placed eight traps at each site, collected spiders three times between June and September of 2015, and identified all spiders to family or species. The authors determined abundance, richness, diversity, and species composition for each spider collection period. They also collected environmental information from each site, including the percent cover of invasive grasses (including medusahead). The authors used statistical tests to compare spider communities and specific environmental variables to actively and passively restored grasslands.

**Location:** Oregon

**Findings:** The authors found that spider community richness and diversity varied by location. They determined that high litter cover and invasive grass cover were associated with increased spider abundance. They found that increased species richness was associated with increases in elevation. Diversity increased in sites with more forb cover and higher elevation. Diversity decreased with increased biological soil crust cover. The authors found no significant differences between actively and passively restored sites in respect to spider richness, abundance, or diversity.

**Implications:** The authors state that some spider species benefit from the effects of litter cover and high elevation because of their associations with improved hunting habitat and moisture, respectively. They suggest that managers consider litter cover if they are concerned about spider communities in restoration sites. The authors conclude that the variation in spider responses to restoration is more heavily influenced by site-specific conditions and less influenced by restoration treatment type.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: herbicides; weed management subtopic: cultural control; soils or geology

## Smith DiCarlo, L.A., DeBano, S.J., and Burrows, S., 2019, Short-term response of two beneficial invertebrate groups to wildfire in an arid grassland system, United States: Rangeland Ecology and Management, v. 72, no. 3, p. 551–560.

**DOI:** https://doi.org/10.1016/j.rama.2018.11.011

**Background:** Invertebrates, like bees and spiders, support rangeland ecosystems through pollination and pest management. The invasion of nonnative annual grasses in rangelands has changed fire regimes and may affect beneficial invertebrate communities. Studies that include prefire data are needed to contextualize findings about the effects of fire on grassland invertebrates.

**Objectives:** The authors sought to (1) study the effects of wildfire on the abundance, composition, species richness, and diversity of native bees and spiders and (2) identify which habitat factors are associated with the observed patterns in invertebrates.

**Methods:** In 2014, the authors established 18 plots in their study area containing native grasses and nonnative annual grasses, such as cheatgrass and medusahead. In June 2015, five plots unexpectedly burned, so they considered unburned sites a control to compare to burned sites. From 2014 to 2016, they trapped and identified spiders in each plot three times from June to September and bees twice between July and September to measure abundance, diversity, and species richness. Additionally, they collected habitat and vegetation data—consisting of percent cover, flowering plant identification, and maximum vegetation height—once in 2014 and three times in 2016. They analyzed their data in four groups: control prefire, control postfire, burned prefire, and burned postfire.

**Location:** Oregon

**Findings:** The authors collected 811 and 895 spiders in 2014 and 2016, respectively, representing 30 total species across years. They collected 4,109 bees representing 37 species in 2014 and 3,392 bees representing 31 species in 2016. The authors determined that fire significantly increased the diversity and species richness of bees but had no significant effect on spiders. They observed preburn and postburn community changes in spiders and bees and identified indicator species in the four groups. The authors determined that burned plots had decreased percent cover of invasive annual grasses and biological soil crusts. They also observed that fire increased forb abundance.

**Implications:** The authors suggest that grassland invertebrates like bees and spiders have strong short-term responses to wildfire and can be used to monitor rangelands after wildfire. The authors note that similar studies identified that bee diversity and richness increased after fire possibly due to increased nesting and floral resources.

**Topics:** survival; population estimates or targets; other: species and population characteristics; site-scale habitat characteristics; habitat selection; fire; nonnative invasive plants; climate change

## Smith DiCarlo, L.A., DeBano, S.J., and Burrows, S., 2020, Arid grassland bee communities—Associated environmental variables and responses to restoration: Restoration Ecology, v. 28, no. S1, p. A54–A64.

**DOI:** https://www.doi.org/10.1111/rec.13074

**Background:** Bees and other invertebrates provide essential ecosystem services in grasslands, yet few studies have examined the invertebrate community's response to grassland restoration efforts.

**Objectives:** The authors sought to (1) describe the bee community in Pacific Northwest arid grasslands, (2) determine which environmental variables affect this bee community, and (3) study the response of bees to restoration.

**Methods:** The authors established 18 sites representing actively restored grasslands (livestock grazing removal, herbicide [glyphosate], and drill seeding), passively restored grasslands (livestock grazing removal only), and intact native grasslands. They placed nine traps at each site and collected bees twice during the summer of 2014 and three times during the summers of 2015 and 2016 to count and identify bee species. The authors collected vegetation data once in the summer of 2014 and three times in 2015 and 2016. They estimated available floral resources and percent cover of invasive annual grasses (including medusahead), biological soil crusts, and litter. The authors analyzed the data to determine the temporal changes in bee abundance, species richness, and diversity across different treatment sites.

**Location:** Oregon

**Findings:** The authors collected 12,996 bees representing 62 species during the study. The bee community varied between years and seasons with higher abundance mid-season than late season and higher species richness in the early and mid-seasons. Bee abundance was greater at sites with more litter. They also identified that species richness was associated with taller vegetation and that bee diversity was lower in sites with more stems. They determined that native sites had more floral resources and lower cover of invasive grasses and litter. They determined that bee community composition was affected by the type of restoration treatment. Neither the active nor the passive restoration treatments restored bee richness and diversity to levels present in the intact native grasslands.

**Implications:** The authors suggest that bee communities do not strongly respond to grassland restoration in the Pacific Northwest, but they do vary seasonally and annually. The authors argue that the results of their study show that neither restoration treatment created similar environmental conditions to native sites. They suggest that invasive annual grasses contribute to increased litter cover that some bees prefer for nesting and that future restoration efforts should focus on increasing floral and nesting resources for bees.

**Topics:** population estimates or targets; site-scale habitat characteristics; habitat selection; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory

## Smith, B.S., and Sheley, R.L., 2015, Implementing strategic weed prevention programs to protect rangeland ecosystems. Invasive Plant Science and Management, v. 8, no. 2, p. 233–242.

**DOI:** https://www.doi.org/10.1614/IPSM-D-13-00075.1

**Background:** Prevention is the most effective and affordable strategy for controlling invasive plants; however, implementing prevention programs poses challenges for land managers. Standardizing planning and implementation approaches may support widespread use of prevention programs.

**Objectives:** The authors sought to (1) provide standard terminology for weed prevention strategies, (2) develop a flow model framework for implementing weed prevention programs, and (3) test their flow model in a case study.

**Methods:** The authors established definitions for protection zones, action zones, containment zones, and high-risk areas. They designed a decision support flow model to support managers in implementing weed prevention programs. The first three steps in the flow model are (1) creating landscape goals, (2) developing a list of priority species, and (3) creating a map incorporating data from invasive weed surveys. After completing the first three steps of the flow model, the authors propose moving on to create strategies for education, early detection, and eradication, and also interrupting the movement or spread of invasive weeds through vectors and corridors. The authors tested their flow model on a ranch where owners were primarily concerned with the spread of medusahead. The ranch owners identified a goal, selected medusahead as their priority species, and mapped their property for invasive plants. The ranch owners then filled out a logic model with strategies to promote education and early detection and interrupt the spread of medusahead.

**Location:** Oregon

**Findings:** The authors determined that their flow model was effective at leading ranch owners through the process of implementing a prevention program. They also determined that the most critical factor for success was that the ranch owners dedicated the appropriate resources, like funding and staff, to the prevention program.

**Implications:** The authors suggest that using standardized terminology and flow model frameworks can assist managers with finding appropriate prevention plans to reduce the spread of invasive species and encourage a more proactive approach to invasive plant management.

**Topics:** dispersal, spread, vectors, and pathways; nonnative invasive plants; weed management; human dimensions or economics

## Smith, L.J., Smith DiCarlo, L.A., and DeBano, S.J., 2019, Ground crab spiders (Thomisidae: *Xysticus*) more abundant in grasslands invaded by cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*): Biological Invasions, v. 21, p. 1473–1479.

**DOI:** https://doi.org/10.1007/s10530-019-01926-w

**Background:** Cheatgrass and medusahead invasion can significantly alter grassland and shrub steppe ecosystems in the western United States. These altered ecosystems can affect plants and wildlife through direct and indirect effects that can be positive or negative depending on the species. Spiders may be especially sensitive to habitat changes from invasive grasses; however, this response has been insufficiently studied.

**Objectives:** The authors sought to (1) determine how ground crab spiders respond to environmental changes caused by cheatgrass and medusahead and (2) examine other environmental variables that may drive spider responses.

**Methods:** From 2014 to 2016, the authors used pitfall traps to sample spiders at 18 sites during 3 sampling periods from June through September. After sampling, they sorted spiders by age, identified mature spiders to species and immature spiders to genus, and quantified spider abundance per trap. They also performed vegetation surveys at each of the sampling sites and estimated cover of medusahead, cheatgrass, and litter. They used statistics and modeling to evaluate the relationship between spiders and invasive annual grasses.

**Location:** Oregon

**Findings:** Out of all spider groups that were collected, ground crab spiders were the most abundant genus. The authors collected 453 ground crab spiders from 4 species during their 3 years of sampling. Medusahead and cheatgrass cover varied at each site. On average, cheatgrass cover was about three times higher than medusahead cover. During the course of the study, cheatgrass and medusahead cover doubled. Litter at each site was positively associated with invasive grass cover. Ground crab spider abundance was positively associated with litter and invasive grass cover.

**Implications:** The authors suggest that their research indicates a potential positive association between ground crab spiders and invasive annual grasses. They state that effects from invasive grasses on spiders may cause cascading effects that could affect other species and environmental processes. They suggest the need for a better understanding of significant species within medusahead- and cheatgrass-invaded ecosystems when creating management goals.

**Topics:** population estimates or targets; site-scale habitat characteristics; nonnative invasive plants

## Spackman, C.N., Monaco, T.A., Stonecipher, C.A., and Villalba, J.J., 2020. Plant silicon as a factor in medusahead (*Taeniatherum caput-medusae*) invasion: Invasive Plant Science and Management, v. 13, no. 3, p. 143–154.

**DOI:** https://www.doi.org/10.1017/inp.2020.20

**Background:** Medusahead takes up silicon that is stored as mineral silica within stems, leaves, and reproductive tissues. The high tissue silica concentration present in medusahead increases the plant's fitness and may make the plant more invasive and abundant. Information about the causes of medusahead invasion and the role of tissue silicon in those processes can be used to improve management strategies.

**Objectives:** The authors sought to (1) summarize knowledge of tissue silica in plants, (2) provide information on the role of tissue silica in specific medusahead characteristics and invasion mechanisms through a conceptual model, (3) explore the effectiveness of existing medusahead control strategies, and (4) recommend new control strategies incorporating the relationship of medusahead and tissue silica.

**Methods:** The authors synthesized literature relevant to understanding the role of tissue silica in facilitating the invasiveness of medusahead.

**Location:** Not specified

**Findings:** The authors stated that medusahead is a hyperaccumulator of tissue silica, unlike other semiarid grasses that are considered intermediate accumulators. Most semiarid grasses passively absorb minerals from the soil, but medusahead is thought to actively take up silicon. The authors stated that high tissue silica concentration in medusahead results in increased fitness through affecting litter, root development, soils, and other mechanisms. They determined that high concentrations of tissue silica affect plant structural factors consisting of resistance to metal toxicity, protection from ultraviolet radiation, improved rigidity, strengthened immune abilities, and altered plant texture. The authors compiled information indicating that high concentrations of tissue silica affect the nutrient content and digestibility of medusahead, making it less palatable to livestock. For all the reasons stated herein, the authors concluded that medusahead invasion is a self-reinforcing positive feedback cycle. Modern methods to control medusahead include mowing, tilling, using prescribed fire, and using herbicides, but none of these strategies account for the silica content in medusahead.

**Implications:** The authors recommend future research to develop methods to interrupt the self-reinforcing positive feedback cycle of medusahead and its uptake of tissue silica to strengthen management outcomes. The authors suggest implementing strategies to control for silica content by integrating previous management methods with new or developing approaches.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; fire; fuels and fuels management; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides; weed management subtopic: mechanical vegetation removal; soils or geology

## Spackman, C., Stonecipher, C., Panter, K., and Villalba, J., 2018, 420 Exploring the fermentation kinetics of medusahead treated with glyphosate at different particle lengths: Journal of Animal Science, v. 96, no. S3, p. 207.

**DOI:** https://www.doi.org/10.1093/jas/sky404.449

**Background:** Treatment with the herbicide glyphosate may increase livestock preference for medusahead, but little is known about how the digestibility of medusahead is affected by varying rates of herbicides.

**Objectives:** The authors sought to determine the digestibility of medusahead for livestock across (1) herbicide concentrations and (2) medusahead particle lengths.

**Methods:** The authors applied glyphosate to medusahead in three concentrations (none, low, and high) during the late vegetative to early reproductive stages at two locations. They measured digestion in the laboratory across herbicide concentration, particle lengths (1, 20, 30, and 40 mm), and sampling locations.

**Location:** Utah, Washington

**Findings:** Apparent digestibility was greatest across all herbicide-particle combinations at low herbicide concentration and the smallest particle size, 1 mm. Independent of particle size, however, increasing herbicide concentrations increased digestibility. Independent of herbicide concentration, decreasing particle size increased digestibility. Potential gas production through fermentation was greatest for the highest herbicide rate and 20-mm particle length. Time to fermentation was lowest with the smallest particle size.

**Implications:** The authors suggest that medusahead palatability and digestibility increased with herbicide concentrations. However, as particle size increased, medusahead digestibility decreased and this differed across sites, which could explain varied grazing preferences at different locations.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management subtopic; weed management: cultural control; weed management subtopic: herbicides

## Spackman, C., Stonecipher, C.A., Panter, K.E., and Villalba, J.J., 2021, Grazing rotation on restored rangeland as a new tool for medusahead control: Western North American Naturalist, v. 81, no. 3, p. 438–442.

**DOI:** https://doi.org/10.3398/064.081.0312

**Background:** Livestock grazing is a common management strategy used to control invasive grasses, such as medusahead, due to its low cost and high feasibility. Although this control method is typically limited to spring grazing, providing nutrient-rich forage to cattle in the autumn may provide appropriate nutrition and allow increased medusahead consumption.

**Objectives:** The authors sought to determine if fall rotational grazing between revegetated pastures with higher nutritional forage and medusahead-invaded pastures would affect livestock consumption of medusahead.

**Methods:** In fall 2010, the researchers established a revegetated pasture seeded with Siberian wheatgrass followed by forage kochia in winter 2011 to improve forage quality. They arranged three medusahead-invaded pastures adjacent to the revegetated pasture using electric fencing, and they randomly assigned pastures to three treatments: grazing with nutrient supplementation, grazing with no nutrient supplementation, and ungrazed. The researchers randomly assigned cows to each grazing treatment and allowed them to graze for 8 days in October 2016. Supplemented animals grazed for 45 minutes in the revegetated pasture prior to grazing in the medusahead-invaded pastures, and nonsupplemented cows only grazed in the medusahead pastures. The researchers clipped aboveground vegetation pregrazing and postgrazing and separated samples into vegetation types (medusahead, other annual grasses, perennial grasses, green forbs, dry forbs, and thatch) to analyze nutrient content. Observers also recorded daily bite counts for each forage type.

**Location:** Washington

**Findings:** Supplemented cattle consumed more medusahead than nonsupplemented cattle. Cattle initially ate more annual grasses, perennial grasses, and forbs. Medushead intake increased initially as consumption of other forage declined. Thatch intake increased throughout the study. There were no differences in nutritional content between vegetation types across plots, except for green forbs, which varied in nutrient quality.

**Implications:** The authors suggest that although cattle initially avoided medusahead and preferred perennial grasses and forbs, medusahead consumption increased when cattle grazed in the supplemented pasture, and supplemented fall grazing of medusahead may be considered as a management strategy. They recommend that managers exercise awareness so that they avoid overgrazing of preferred forage vegetation.

**Topics:** other: species and population characteristics; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Stein, C., Hallett, L.M., Harpole, W.S., and Suding, K.N., 2014, Evaluating ecosystem services provided by non-native species—An experimental test in California grasslands: PLOS ONE, v. 9, no. 9, article e75396.

**DOI:** https://www.doi.org/10.1371/journal.pone.0075396

**Background:** Ecosystem functions that affect human well-being are referred to as "ecosystem services." It is thought that invasion by nonnative plant species negatively affects ecosystem services. Developing a method to evaluate ecosystem services may be useful for land managers tasked with prioritizing needs in changing landscapes.

**Objectives:** The authors sought to study how different grassland species assemblages support different ecosystem services at three levels of grazing intensity.

**Methods:** In 2007, the authors established 72 plots representing native perennial bunchgrass, nonnative annual forage grass, and nonnative invasive weed species (medusahead) assemblages across a gradient of grazing intensity simulated by mowing and cattle trampling. The authors measured residual dry matter and species abundance annually between 2008 and 2010. In 2010, they also measured ecosystem functions of the plots related to the following ecosystem services: forage production, native cover and diversity, invasibility, belowground net primary productivity, carbon mineralization, nitrogen cycling, and decomposition rate. The authors analyzed ecosystem functions by grazing intensity and vegetation assemblages.

**Location:** California

**Findings:** The authors determined that different vegetation assemblages had differing responses in ecosystem functions when grazed. Residual dry matter was reduced with increased grazing intensity in all three vegetation assemblages. Forage production increased with grazing for the two nonnative vegetation assemblages and was consistently high across all grazing treatments in the native perennial assemblage. Native cover was highest in the native vegetation plots and decreased under higher grazing intensity. Nitrogen decreased in all vegetation assemblages with increased grazing intensity. Belowground net primary productivity decreased in the native vegetation assemblage with increased grazing but increased in the nonnative weed assemblages. Decomposition was decreased in all species assemblages with higher grazing intensity.

**Implications:** The authors suggest that there is value in managing for ecosystem services in conjunction with targeting specific species or assemblages but warn that managers need to be aware of potential tradeoffs. They also suggest that their strategy can help with decisions about vegetation management in changing and emerging ecosystems.

**Topics:** dispersal, spread, vectors, and pathways; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; soils or geology; human dimensions or economics

## Stein, C., Harpole, W.S., and Suding, K.N., 2016, Transitions and invasion along a grazing gradient in experimental California grasslands: Ecology, v. 97, no. 9, p. 2319–2330.

**DOI:** https://doi.org/10.1002/ecy.1478

**Background:** Efforts to understand ecological resilience often focus on the concept that critical (and often irreversible) ecological transition events can permanently alter ecosystems. Confirming the critical transition concept is challenging, so an experimental test of habitat transitions in grazing systems is needed to better understand invasion of weedy plants.

**Objectives:** The authors studied if critical transitions occur across vegetation types along a grazing gradient.

**Methods:** The authors began excluding large herbivores from their study area in 2006, then established 12 sites representing three vegetation types (native perennial bunchgrass, nonnative annual forage grasses, and nonnative invasive weed species—primarily medusahead) by seeding in May 2007. They split each plot into six levels of grazing intensity, ranging from no grazing to overgrazed, and replicated this method for a total of 144 plots. In the falls of 2008 and 2009, they replicated invasion by spreading seeds from all three vegetation types in each plot. The authors collected data on species composition, grazing intensity, and precipitation annually from 2008 to 2013. They performed statistical analyses to identify directional transitions, bidirectional transitions, and nontransitions across treatments, and defined a transition occurring when 55 percent of the relative abundance of species within a plot fit within their definition of a vegetation type.

**Location:** California

**Findings:** The authors observed invasion of exotic forbs despite their absence in the seed mixes, so they added exotic forbs as a fourth vegetation type in the analysis. They determined that 35 percent of all observed transitions were directional and unlikely to be easily reversed. They identified that transitions of native grasses to medusahead and transitions of all vegetation types to exotic forbs under heavy grazing pressure were likely the least reversible. They identified that most transitions were bidirectional and that grazing intensity did not affect transitions within the three grass vegetation types but had a large effect on exotic forbs. The year 2011 had the most precipitation, and the authors determined that transitions into nonnative annual forage significantly increased this year. Medusahead invasions increased in later years.

**Implications:** The authors suggest that many vegetation transitions are reversible and that the permanence of transitions is heavily dependent on precipitation and the life cycles of vegetation. They recommend longer-term studies on vegetation transition thresholds with more detailed grazing analysis.

**Topics:** behavior or demographics; population estimates or targets; dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weather and climate patterns; weed management

## Stonecipher, C.A., Panter, K.E., Jensen, K.B., Rigby, C.W., and Villalba, J.J., 2017, Revegetation of medusahead-invaded rangelands in the Channeled Scablands of eastern Washington: Rangeland Ecology and Management, v. 70, no. 3, p. 388–395.

**DOI:** https://www.doi.org/10.1016/j.rama.2016.11.002

**Background:** Medusahead monocultures reduce available livestock forage, resulting in increased dependence on poisonous forbs like velvet lupine, which can cause crooked calf syndrome. Developing effective methods to promote revegetation of perennial grasses is needed to reduce the negative effects of medusahead invasion to livestock.

**Objectives:** The authors sought to (1) test efficacy of revegetation treatments to suppress medusahead and (2) determine if revegetation treatments increased production of preferred forage.

**Methods:** The authors established 96 plots across 3 ranches and divided each plot into a disturbed and undisturbed treatment. After treating plots with herbicides (glyphosate and 2,4-D), the authors randomly applied seven seed treatments of multiple grass species (November 2010) and forage kochia (January 2011), and one unseeded treatment across plots. They visually estimated the frequency of seeded grasses and weeds in June 2011 and 2013 and used a frequency grid to measure the frequency of seeded grasses in July 2012. They measured and analyzed biomass production for all treatments by harvesting vegetation during the summers of 2012 and 2013 and compared the nutritional value of vegetation by month and year.

**Location:** Washington

**Findings:** Crested wheatgrass, Russian wildrye, Siberian wheatgrass, and Sherman big bluegrass established 1 year after seeding. During the 3-year study, the authors identified that grass persistence of Sherman big bluegrass increased, Siberian wheatgrass remained stable, crested wheatgrass decreased slightly, and Russian wildrye decreased. They determined that biomass of plants other than perennial grasses was the highest in the undisturbed and Russian wildrye plots and lower in the crested wheatgrass, Siberian wheatgrass, and Sherman big bluegrass plots, supporting their assumption that poisonous forbs are displaced within a site by perennial grass biomass. Disturbed plots had a greater biomass of seeded grasses than undisturbed plots. The authors identified that the nutritional value of seeded species depended on the month harvested but that the revegetation treatments increased forage quality.

**Implications:** The authors suggest that seeding crested wheatgrass, Siberian wheatgrass, and Sherman big bluegrass in areas that are similar to this study can effectively suppress medusahead and other weeds while promoting desirable livestock forage. The authors suggest long-term monitoring of revegetated areas to ensure the persistence of the seeded grasses as alternative forage for livestock and to reduce the effects of crooked calf syndrome in these areas.

**Topics:** population estimates or targets; dispersal, spread, vectors, and pathways; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: herbicides

## Stonecipher, C.A., Panter, K.E., and Villalba, J.J., 2016, Effect of protein supplementation on forage utilization by cattle in annual grass-dominated rangelands in the Channeled Scablands of eastern Washington: Journal of Animal Science, v. 94, no. 6, p. 2572–2582.

**DOI:** https://doi.org/10.2527/jas.2016-0369

**Background:** Livestock often avoid exotic grasses such as medusahead at later growth stages, but high-protein feed supplements can be used to alter cattle food preferences. However, it is unclear if providing a protein-rich supplement to increase medusahead consumption is an effective weed control method.

**Objectives:** The authors sought to assess the (1) effects of providing a protein-rich supplement to grazing cattle on medusahead consumption, (2) effects of grazing on forage production and medusahead abundance, and (3) role of forage quality.

**Methods:** From June to August 2012 and 2013, the researchers established 8 pastures for three 10-day grazing periods for 24 total pastures. A total of 16 animals grazed in three different pastures each year, with half the animals receiving a protein supplement, canola meal. The researchers clipped aboveground forage production pregrazing and postgrazing and measured quality by analyzing crude protein content, fiber content, and digestibility. They also measured the proportion of medusahead and other annual grasses. During each grazing day, the researchers observed cattle to determine number of bites per forage category. Statistical analyses compared the effects of treatments across time on forage production and quality, medusahead proportions, and bite counts for each vegetation group.

**Location:** Washington

**Findings:** During the first grazing period, cattle preferred forbs and perennial grasses, which were more abundant earlier compared to greater abundance and intake of mature medusahead later in the season. Cattle supplemented with protein had greater medusahead intake in the later grazing period compared to nonsupplemented cattle, which had a higher intake of forbs. Crude protein was higher in forbs than grasses, and crude protein in medusahead was greatest in June prior to maturity. Digestibility and fiber content of annual grasses did not differ from June to August. Annual grass intake increased in all grazing periods in the second year. Medusahead decreased in the second and third year in grazed pastures and remained similar in ungrazed pastures across time.

**Implications:** The authors claim that both the timing of grazing and providing supplements increase the ability for managers to control medusahead with livestock grazing. To put their results into a broader management context, the authors suggest that grazing can be alternatively used in late summer and fall months before herbicide application is typically applied in grazing operations. Supplementing protein to grazing cattle can also increase annual grass consumption, and using protein blocks at larger scales may be cost effective.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Stonecipher, C.A., Spackman, C., Panter, K.E., and Villalba, J.J., 2021, The use of herbicide as a tool to increase livestock consumption of medusahead (*Taeniatherum caput-medusae*): Invasive Plant Science and Management, v. 14, no. 2, p. 106–114.

**DOI:** https://doi.org/10.1017/inp.2021.12

**Background:** Grazing can be used to manage medusahead in invaded sagebrush steppe ecosystems, but medusahead becomes unpalatable to livestock early in its growth cycle. Prior studies have demonstrated that some herbicides can increase the duration of palatability of medusahead.

**Objectives:** The authors explored if treating medusahead with the herbicide glyphosate would increase (1) the duration of palatability and nutrient retention in medusahead and (2) cattle utilization of medusahead.

**Methods:** The authors established 44 treatment and 12 control plots across 2 sites. In April 2016, prior to medusahead flowering, the authors applied two types of glyphosate at three application rates in a total of four replicates at their first site. In June 2019, at the second site, they applied one type of glyphosate at only the highest rate. Cattle began grazing all plots approximately 20 days after herbicide application. The authors measured biomass and forage quality for six vegetation groups before herbicide treatment, 15 days after treatment, and after grazing. For medusahead, they also measured available energy and silica content. They used statistical methods to isolate treatment effects.

**Location:** Utah, Washington

**Findings:** Across most vegetation groups, biomass was lower in treated than untreated plots after herbicide application. After grazing, biomass of only medusahead was lower in high-application-rate plots at the first site, and biomass of all vegetation groups was lower with treatment at the second site. Medusahead carbohydrate content increased in high-application-rate plots. Medusahead silica content decreased in high-application-rate and untreated plots at the first site. Crude protein content of medusahead, other annual grasses, and annual forbs was higher in treated than untreated plots at the second site. Treated and untreated plots did not differ in digestibility for most vegetation groups, and digestibility of medusahead remained high after treatment. Cattle consumed the most medusahead biomass in the highest herbicide application treatments, and all herbicide applications extended the time that medusahead biomass was palatable.

**Implications:** The authors suggest that glyphosate halts medusahead development, lengthening the duration of palatability. As a result, the authors indicate that combined herbicide-grazing treatments could substitute for high-intensity grazing. Because glyphosate reduced the biomass of nontarget plants, the authors suggest that treatment can be more specific where medusahead is dominant or before nontarget species emerge.

**Topics:** population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control; weed management subtopic: herbicides

## Stonecipher, C.A., Thacker, E., Welch, K.D., Ralphs, M.H., and Monaco, T.A., 2019, Long-term persistence of cool-season grasses planted to suppress broom snakeweed, downy brome, and weedy forbs: Rangeland Ecology and Management, v. 72, no. 2, p. 266–274.

**DOI:** https://www.doi.org/10.1016/j.rama.2018.10.008

**Background:** Conversion of the sagebrush steppe to annual grass communities in western North America has altered fire return intervals, perpetuating invasive species' populations. Seeding with multiple species can increase productivity and invasion resistance; however, it is important to understand how these species persist long term.

**Objectives:** The authors explored the effectiveness of seeding to limit invasions of snakeweed, downy brome, and annual forbs through the long-term establishment of (1) introduced and (2) native species seed mixtures.

**Methods:** In 2 locations, the researchers established 4 blocks, each with 11 treatments consisting of 9 seeding mixtures and 2 unseeded plots. From 2001 to 2003, they sprayed a few herbicides (picloram, glyphosate, and imazapic) and removed remaining weeds mechanically. In fall 2003, they seeded native and nonnative perennial grasses, and in 2004, they seeded forage kochia across treatments. They estimated seeded and associated species frequency and aboveground biomass in the summers of 2015 to 2017. They used statistical analyses to compare frequency and biomass of seeded and other species across locations, treatments, and years.

**Location:** Utah

**Findings:** In both locations, a crested wheatgrass hybrid and pubescent wheatgrass were the most abundant and frequent of all introduced seeded species, whereas Russian wildrye remained low. Western wheatgrass had the highest frequency of all native seeded grasses, with large declines in big squirreltail and no presence of bluebunch wheatgrass by the end of the study. Snakeweed did not reestablish in either location through time. Once downy brome appeared at the first location, frequency increased through time. Sites seeded with crested, pubescent, or western wheatgrasses at the second location had lower downy brome abundance than other treatments and the controls, although downy brome frequency remained high across the study period. Annual forbs remained low across both sites and varied in biomass across years at both locations. Forage kochia frequency remained low across treatments. Medusahead appeared at the first location in later years, increasing in abundance in the Russian wildrye, big squirreltail, forage kochia, bluebunch wheatgrass, and western wheatgrass plots. Medusahead was never present during the study at the second location.

**Implications:** The authors suggest that managers should consider competitive reseeding after disturbance to control invasive species such as downy brome and annual forbs. They recommend seeding with perennial grasses that persist long term, such as crested, pubescent, and western wheatgrasses.

**Topics:** behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; nonnative invasive plants; weed management; weed management subtopic: cultural control

## Strand, E.K., Launchbaugh, K.L., Limb, R.F., and Torell, L.A., 2014, Livestock grazing effects on fuel loads for wildland fire in sagebrush dominated ecosystems: Journal of Rangeland Applications, v. 1, p. 35–57.

**URL:** https://thejra.nkn.uidaho.edu/index.php/jra/article/view/23

**Background:** Sagebrush steppe ecosystems have shifted toward invasive grass dominance, such as cheatgrass and medusahead, which can increase wildfire return intervals. Livestock grazing affects fire behavior by altering fuel characteristics, reducing fuel loads, and reducing fire ignition potential. Grazing can also be used as a management tool to control annual and perennial grasses.

**Objectives:** The authors sought to synthesize published literature on how livestock grazing can (1) alter plant community composition and fuel characteristics, (2) alter annual wildfire fuel and fire behavior, and (3) be used economically to reduce fuels.

**Methods:** The authors reviewed literature about the effects of livestock grazing on fuels and fire in sagebrush systems.

**Location:** California, Idaho, Nevada, Oregon, Utah, Wyoming

**Findings:** Livestock grazing, introduced to the Great Basin in the mid-19th century, reduced herbaceous fuels and increased sagebrush density. Historical grazing management, which targeted increases in perennial grasses, has led to increasing exotic grass dominance and subsequent increases in wildfire frequency in sagebrush ecosystems. Grazing affects shrub and perennial grass cover and density differently in various site conditions and years. Depending on season and intensity, livestock grazing can reduce short-term woody fuel loads or decrease perennial grass density without affecting sagebrush density. Grazing later in the growing season can reduce perennial grass fuels and suppress annual grass biomass, depending on annual precipitation. Reducing continuous fine fuels by livestock on the landscape creates patches between vegetation and slows fire spread. Grazing treatments are more economical and effective when sagebrush fuels are low and herbaceous fuels are high.

**Implications:** The authors suggest that targeted grazing management can increase shrub density and reduce herbaceous fine fuels, ultimately decreasing fire spread and intensity. They also suggest that the timing of grazing is an important management consideration. However, they recommend that managers consider the site and weather conditions, and if extreme fire weather conditions exist, there are limitations for grazing treatments to alter fire fuels.

**Topics:** dispersal, spread, vectors, and pathways; broad-scale habitat characteristics; fire; fuels and fuels management; nonnative invasive plants; grazing/herbivory; weather and climate patterns; weed management; weed management subtopic: cultural control; human dimensions or economics

## Svejcar, T., Boyd, C., Davies, K., Hamerlynck, E., and Svejcar, L., 2017, Challenges and limitations to native species restoration in the Great Basin, USA: Plant Ecology, v. 218, no. 1, p. 81–94.

**DOI:** https://www.doi.org/10.1007/s11258-016-0648-z

**Background:** The Great Basin spans a wide area of the western United States, largely on public lands, and is dominated by sagebrush across the region. Understanding historical challenges and future opportunities for restoration can facilitate adaptive management strategies.

**Objectives:** The authors sought to (1) characterize the Great Basin, (2) describe past restoration approaches, and (3) describe potential limitations to future restoration in the region.

**Methods:** The authors reviewed previous literature to describe the Great Basin's history and land-use legacies since Euro-American settlement and rangeland restoration practices in the region.

**Location:** California, Idaho, Nevada, Oregon, Utah

**Findings:** The Great Basin has high spatial and climatic variability, which is challenging when implementing site-specific restoration methods. Land-use practices by Euro-American settlers resulted in overgrazing and the introduction of invasive species. Warming temperatures, elevated carbon dioxide, and increased human activity have increased invasive annual grasses and subsequently increased fire frequencies, which are exacerbated by the region's severe drought and harsh winters. Previous restoration methods included seeding crested wheatgrass, which can effectively compete with invasive annual grasses; however, crested wheatgrass can also outcompete native species, impeding subsequent efforts to restore native bunchgrasses. In addition, southern aspects and lower elevations have proven more susceptible to invasions but more difficult to restore. The primary challenge to successful restoration is increasing native perennial species after removing nonnative plants. Establishment of native bunchgrasses may be limited by the timing of seed development. Different seeding technologies have had mixed success, with drill seeding resulting in greater seedling establishment compared to broadcast seeding, which has been unsuccessful at lower elevations.

**Implications:** The authors suggest that to increase successful restoration, managers need to identify limitations in seed establishment, develop strategies to overcome those barriers, and measure success based on biological outcomes rather than implementation. They recommend applying adaptive management strategies to overcome restoration complexities due to landscape variability.

**Topics:** broad-scale habitat characteristics; habitat restoration or reclamation; fire; nonnative invasive species; grazing/herbivory; weather and climate patterns; climate change; drought; weed management; weed management subtopic: cultural control

## Tarbox, B.C., Van Schmidt, N.D., Shyvers, J.E., Saher, D.J., Heinrichs, J.A., and Aldridge, C.L., 2022, Bridging the gap between spatial modeling and management of invasive annual grasses in the imperiled sagebrush biome: Rangeland Ecology and Management, v. 82, p. 104–115.

**DOI:** https://doi.org/10.1016/j.rama.2022.01.006

**Background:** Successful management of invasive annual grasses hinges on proactive approaches informed by spatial products. Despite the availability of relevant spatial data, a research-implementation gap persists.

**Objectives:** The authors sought to (1) review and summarize attributes of spatial products for three invasive annual grasses, (2) identify barriers to the use of spatial products, and (3) suggest avenues for overcoming barriers.

**Methods:** The authors selected a representative stakeholder group of 11 individuals involved in issues related to invasive annual grass management, who provided input about challenges associated with using spatial products. The authors performed a systematic review of invasive annual grass (cheatgrass, medusahead, and ventenata) spatial data to catalogue available products and compile information describing product attributes. They included products that were publicly accessible, published between January 2010 and February 2021, contained a spatial and annual invasive grass search term, and used modeling to map contiguous grass coverage or invasion risk. Their search returned 23 products, and they summarized 41 attributes of the model and map information for each product.

**Location:** United States

**Findings:** The authors identified that most products were from the last 6 years and that temporal and spatial resolution improved through time. Additionally, most spatial products grouped invasive annual grasses rather than mapping individual species, products focused on percent cover rather than habitat suitability or occurrence, and there were very few models of medusahead or ventenata at large spatial extents. Nearly half of the spatial products included plans for regular updates. The authors identified the following barriers related to accessibility, accuracy, and resolution of spatial products: a lack of information about model components, difficulty in assessing model accuracy and applicability, and challenges related to usability and workflow. They developed a flow chart to assist users in selecting the most appropriate product(s) for their goals, as well as a conceptual diagram for enhancing coproduction between modelers and end users.

**Implications:** The authors suggest improving information sharing through proactive communication, plain-language descriptions of products, and standardized documentation of model inputs, limitations, and other key points. They also make suggestions for technical improvements to models and the use of uncertainty maps to clarify regional strengths and weaknesses of any given product. They suggest greater focus on connections between spatial scientists and land managers through coproduction, training programs, and increasing staffing of spatial scientists within agencies.

**Topics:** nonnative invasive plants; weed management; human dimensions or economics

## Tortorelli, C.M., Krawchuk, M.A., and Kerns, B.K., 2020, Expanding the invasion footprint—*Ventenata dubia* and relationships to wildfire, environment, and plant communities in the Blue Mountains of the Inland Northwest, USA: Applied Vegetation Science, v. 23, no. 4, p. 562–574.

**DOI:** https://doi.org/10.1111/avsc.12511

The summary for this article was previously published in Poor and others (2021, p. 25; https://doi.org/10.3133/ofr20211031).

## Tulloss, E.M., and Cadenasso, M.L., 2016, Using realistic nitrogen deposition levels to test the impact of deposition relative to other interacting factors on the germination and establishment of grasses in the California oak savanna: Plant Ecology, v. 217, p. 43–55.

**DOI:** https://www.doi.org/10.1007/s11258-015-0558-5

**Background:** Nitrogen deposition may alter plant communities and individual plant performance, potentially favoring invasive species. Timing and quantity of nitrogen deposition vary spatially and may be modulated by environmental factors. Previous studies have focused on the effects of high levels of nitrogen on mature plant stages; however, it is unclear how nitrogen fertilization affects germination and seedling establishment in native and exotic grass species.

**Objectives:** The authors sought to evaluate how nitrogen fertilization affects early growth stages of three oak savanna grass species in relation to (1) soil type, (2) light availability, and (3) competitive interactions.

**Methods:** In summer 2009, the researchers collected soils from three study sites, which they placed in pots in a greenhouse. For each treatment combination, they established 10 replicates for 840 total pots. Their treatment combinations included high and low nitrogen fertilization based on previously measured field deposition rates; low, medium, and high soil fertility; full sun and overstory shading simulated with a shade cloth; and seven combinations of three grass species seed mixes (purple needlegrass, wall barley, and medusahead). In fall 2010, they planted seeds and applied fertilizer weekly. They monitored germination and seedling establishment for 3 months and determined differences across treatments.

**Location:** California

**Findings:** Nitrogen fertilization did not affect germination or establishment, except for medusahead when grown alone. Whether plants grew alone or with other species had the greatest effect on germination and seedling establishment. Increased soil fertility resulted in greater germination and seedling establishment for medusahead, whereas the opposite was true for purple needlegrass. Shade increased germination and establishment, except for wall barley, which had greater germination in full sun. Interactions across treatments were more common than single-factor responses; however, the interactions were too specific to generalize across species.

**Implications:** The authors determined that competitive interactions between species may be the primary factor influencing germination and seedling establishment. They suggest that plants may be more space limited rather than resource limited during earlier life stages. However, they suggest that increased nitrogen deposition may be more critical in mature grass life stages. Managers should consider differences in light availability and soil fertility during germination and seedling establishment.

**Topics:** behavior or demographics; site-scale habitat characteristics; nonnative invasive plants; soils or geology

## Uselman, S.M., Snyder, K.A., Leger, E.A., and Duke, S.E., 2014, First-year establishment, biomass and seed production of early vs. late seral natives in two medusahead (*Taeniatherum caput-medusae*) invaded soils: Invasive Plant Science and Management, v. 7, no. 2, p. 291–302.

**DOI:** https://www.doi.org/10.1614/IPSM-D-13-00068.1

**Background:** One approach to restoring grasslands is to use native seed mixes that can outcompete invasive plants such as medusahead and simultaneously restore the native plant community. Plant characteristics, such as a species' dominance in a successional stage, may inhibit or promote certain species' composition overall. This study compares several factors that may affect success of seeding with different native species to control medusahead.

**Objectives:** The authors sought to (1) determine the effectiveness of two native seed mixes on suppressing medusahead, (2) compare the growth performance of the two seed mixes when grown with medusahead, and (3) examine how soil types affect medusahead growth.

**Methods:** During 2010, the authors collected seeds of medusahead and four native early successional species, purchased a seed mix of four native late successional species, and collected two soil types—clay and sandy loam. Both seed mixes contained two perennial grasses, two forbs, and one shrub. The authors designed, replicated, and began three experiments in October 2010: (1) medusahead seed only: medusahead plus sandy or clay loam, (2) native only: early or late successional seeds plus sandy or clay

loam, and (3) medusahead plus native: medusahead seed plus early or late successional seeds plus sandy or clay loam, totaling 158 experimental units. The authors measured seed production, counted individuals, and collected aboveground biomass from spring to fall 2011. They used statistics to determine differences between and within experiments.

**Location:** Nevada

**Findings:** Medusahead established regularly regardless of seed mix, but its biomass and seed production were diminished when planted with early successional seeds but not with late successional seeds. When grown with medusahead, early successional seeds, particularly grasses and forbs, established better than late successional seeds. Medusahead establishment, biomass, and seed production were higher in clay loam versus sandy loam.

**Implications:** The authors indicate that restoration efforts are more likely to be successful when using early successional species, which are typically not dominant in commercial seed mixes. Bristly fiddleneck was an early successional species that was particularly successful in suppressing the growth of medusahead and was shown in previous studies to suppress cheatgrass. The authors suggest that seeding efforts should include a high density of early successional species such as bristly fiddleneck, while maintaining a diverse seed mix.

**Topics:** survival; behavior or demographics; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control; soils or geology

## Uselman, S.M., Snyder, K.A., Leger, E.A., and Duke, S.E., 2015, Emergence and early survival of early versus late seral species in Great Basin restoration in two different soil types: Applied Vegetation Science, v. 18, no. 4, p. 624–636.

**DOI:** https://doi.org/10.1111/avsc.12175

**Background:** Exotic annual grasses hinder restoration success across the Great Basin. Native species that share traits with exotic species may have a competitive edge in restoration contexts. Research into seedling performance of early versus late successional seed mixes could inform restoration approaches in invaded landscapes.

**Objectives:** The authors sought to (1) assess seedling performance of early versus late successional seed mixes grown alongside cheatgrass or medusahead, (2) compare the effects of different seed mixes on survival of exotic annual grasses, and (3) compare plant performance in two soil types.

**Methods:** The researchers established a common garden and buried pots containing sandy loam and clay loam soils in the ground in October 2010. They implemented three parallel experiments with cheatgrass, medusahead, and no exotic species. Experiments contained combinations of soil types and early and late successional seed mixes. Exotic grass experiments contained 122 pots each, and the experiment without exotics contained 36 pots. The researchers monitored seedling emergence and survival regularly from November 2010 to May 2011. They performed statistical analyses to assess effects of seed mix, soil type, and vegetation group on emergence and seedling performance.

**Location:** Nevada

**Findings:** Early successional species had higher emergence and survival than late successional species, but this varied depending on vegetation group and soil type. Early and late successional species grown without exotics had similar survival. When grown with exotics, native species that emerged in early autumn had higher survival than those that emerged later. Neither seed mix affected emergence or survival of exotic grasses. Cheatgrass survival increased with native seed mixes and on sandy loam soil, but medusahead survival was high regardless of seed mix and soil type. Emergence of native species grown alongside exotics increased in sandy loam soils. Exotic species emerged earlier in sandy loam than clay loam.

**Implications:** The authors suggest that emergence timing and soil characteristics affect seedling performance. They also suggest that early successional native species are more likely to survive and persist with exotic species due to shared traits. Therefore, the authors recommend prioritizing early successional natives for restoration rather than late successional perennials.

**Topics:** survival; behavior or demographics; dispersal, spread, vectors, and pathways; site-scale habitat characteristics; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: cultural control; soils or geology

## Villalba, J.J., and Burritt, E.A., 2015, Intake of medusahead by sheep—Influence of supplements, silica and individual animal variation: Invasive Plant Science and Management, v. 8, no. 2, p. 151–159.

**DOI:** https://www.doi.org/10.1614/IPSM-D-14-00072.1

**Background:** Livestock grazing has been used as a control method for medusahead invasions; however, intake is typically low due to its poor nutritional content. Previous research has shown that individual animals may vary in their preferences for medusahead consumption. To improve targeted grazing, methods that provide dietary supplements may increase medusahead intake and need further exploration.

**Objectives:** The authors sought to determine if (1) high-energy supplements affect sheep preference for medusahead and (2) ingestion of medusahead differs among individual sheep.

**Methods:** In June 2013, the authors performed three experiments with 30 lambs across three treatment groups, which received no supplement, a calcium propionate supplement, or a yeast supplement. In the first two experiments, the authors provided supplements to the treatment groups, then fed all groups early or mature growth stages of medusahead and evaluated preferences between tall fescue hay and medusahead. They determined the amount consumed of each feed and, during the first experiment, evaluated preferences for medusahead plant parts. In the third experiment, in July, the researchers established two new groups of 10 lambs each based on whether lambs consumed high or low levels of medusahead in the first two experiments, regardless of the previous treatment group. The authors fed each group alfalfa pellets with silica additives. They performed statistical analyses to determine differences among groups.

**Location:** Utah

**Findings:** In the first two experiments, supplemented lambs had a cyclic pattern of medusahead consumption, and intake did not differ across groups, except for the nonsupplemented group in the first experiment, where lambs consumed greater amounts of medusahead during the first 2 days. Supplemented lambs gained more weight than nonsupplemented lambs. Across treatment groups, lambs preferred tall fescue hay over medusahead and preferred medusahead seedheads to stems and leaves. Groups that ate more medusahead in the first two experiments also ate more alfalfa with silica and had a similar cyclic intake pattern.

**Implications:** The authors suggest that supplementing animals can improve the efficiency in grazing operations without decreasing medusahead ingestion. They also suggest that because variation among individuals was the greatest determinant of medusahead preference, identifying individual differences may help to increase consumption during targeted grazing.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Villalba, J., Spackman, C., and Lobón, S., 2019, The interplay between exposure and preference for unpalatable foods by lambs: Applied Animal Behaviour Science, v. 212, p. 44–51.

**DOI:** https://www.doi.org/10.1016/j.applanim.2019.01.011

**Background:** Consuming too much unpalatable, nutrient-deficient food can deter lambs from grazing on certain plants. Patterns of avoidance linked to overconsumption could inform efforts to control invasive species through livestock grazing.

**Objectives:** The authors sought to investigate the role of exposure to unpalatable, nutrient-deficient foods in determining forage preference.

**Methods:** In the summer of 2015 and 2016, the researchers performed three experiments, each consisting of 24 lambs separated into three treatment groups. They exposed treatment groups to varying amounts of unpalatable food and subsequently quantified preference of foods varying in nutritional value. The first experiment tested exposure to medusahead, the second tested exposure to varying levels of condensed tannins in alfalfa pellets, and the third tested exposure to wheat straw. They dried and weighed food samples to analyze nutritional content. The researchers performed statistical analyses to understand food preference relative to exposure to unpalatable food sources.

**Location:** Utah

**Findings:** In the first experiment, the group with intermediate exposure showed the greatest average intake of medusahead, followed by the group with the most exposure, and lastly the group with the least exposure. Lambs exposed to the least medusahead consumed more subsequently during preference tests, and medusahead consumption generally decreased as the nutritional value of alternative foods increased. In the second experiment, the level of exposure to tannin-containing alfalfa pellets corresponded to average food intake, and intake did not differ among groups. Groups had different preferences for non-tannin-containing foods; animals with the highest tannin exposure consumed more non-tannin food alternatives. In the third experiment, treatment groups did not affect consumption of wheat straw, but consumption decreased as nutritional value of the alternative foods increased. Generally, the researchers identified that exposure determined food preferences and avoidance trends.

**Implications:** The authors acknowledge that grazing could offer an alternative method for controlling invasive plants, but they suggest that overconsumption can lead to avoidance and increase grazing pressure on native plants. Avoidance could give medusahead a competitive advantage, contributing to future invasion and restricting the benefits of grazing. Thus, the authors suggest that previous exposure to unpalatable invasive species should be considered when weighing the benefits of grazing.

**Topics:** nonnative invasive plants; grazing/herbivory; weed management; weed management subtopic: cultural control

## Weisberg, P.J., Dilts, T.E., Greenberg, J.A., Johnson, K.N., Pai, H., Sladek, C., Kratt, C., Tyler, S.W., and Ready, A., 2021, Phenology-based classification of invasive annual grasses to the species level: Remote Sensing of Environment, v. 263, article 112568, 9 p.

**DOI:** https://doi.org/10.1016/j.rse.2021.112568

**Background:** Remotely sensed imagery can detect changes in light reflectance by plants across phenological events, which correspond to life cycle changes. Collecting images through time at high resolutions using tools such as unoccupied aerial vehicles may facilitate species identification and mapping, which can be important for targeted management of invasive plants.

**Objectives:** The authors sought to identify (1) if phenological imagery from unoccupied aerial vehicles can distinguish plant species, (2) the ideal phenological timing for sampling, and (3) which light bands are most useful for species identification.

**Methods:** The authors used unoccupied aerial vehicles with sensors to collect visible light and near-infrared spectrum imagery at a 2-centimeter (cm) resolution across an approximately 2.78-ha site. The authors collected samples over 8 days during the medusahead and cheatgrass growing seasons from mid-May to mid-July 2017. The authors also collected vegetation or ground cover type field data to validate models. They classified image pixels by cover type and created a series of models using combinations of light bands and sampling dates. The authors evaluated the accuracy of the models using statistical methods.

**Location:** Nevada

**Findings:** The best model for classifying all cover types included all light bands and sampling dates. This large model identified medusahead, cheatgrass, perennial forbs, litter, and bare soil with high sensitivity and specificity. However, this model yielded frequent false positive results for annual forbs, crested wheatgrass, and shrubs. The best models for identifying medusahead or cheatgrass used imagery from three sampling dates; optimal dates varied by species. Among light bands, red was most important for full model accuracy, followed by blue. Red was also most important for identifying medusahead and cheatgrass. The near-infrared bands provided only small improvements to model accuracy.

**Implications:** The authors suggest that collecting visible light images throughout the growing season can effectively substitute for single-sample images that include infrared bands. The authors suggest that unoccupied aerial vehicles could be an efficient tool for small-scale applications such as detection of new invasions and monitoring of priority native plants. However, the authors mention multiple limitations, such as expense and inconsistencies in phenology across years and sites.

**Topics:** population estimates or targets; nonnative invasive plants; weather and climate patterns; includes new geospatial data

## Wilson, R.G., Orloff, S.B., Lancaster, D.L., Kirby, D.W., and Carlson, H.L., 2010, Integrating herbicide use and perennial grass revegetation to suppress weeds in noncrop areas: Invasive Plant Science and Management, v. 3, no. 1, p. 81–92.

**DOI:** https://doi.org/10.1614/IPSM-09-008.1

**Background:** Many noncrop areas, such as roadsides and field edges, are vulnerable to invasion by nonnative plants, such as medusahead, and can serve as vectors for further spread of invasive species. Most weed management in these areas focuses on short-term control, but development of long-term management strategies is needed, possibly through herbicide and planting of perennial grasses.

**Objectives:** The authors sought to investigate the effectiveness of different herbicides paired with perennial grass seeding on reducing weeds in noncrop areas.

**Methods:** The authors established plots at three sites with four different single or multiple herbicide treatments as well as an untreated control. They determined which herbicides to use by which weed species were present at each site and applied herbicides in 2005 and 2006. The authors planted multiple perennial grass species in March 2005 and collected cover data for each species in May, June, or July 2005 to 2007. They also recorded vegetation and bare ground cover as well as perennial seedling presence in 2005. They then used statistical analyses to compare weedy and planted perennial species cover across sites and treatments.

**Location:** California

**Findings:** Herbicide application improved perennial establishment at all sites. The herbicide imazapic best controlled downy brome but also restricted perennial grasses. Imazapic and glyphosate were most effective at controlling downy brome and medusahead, but downy brome increased after the first year on nonimazapic treatments. The most effective herbicide differed

between sites, but herbicides with high residual activity controlled weeds longer than herbicides with low residual activity. Of the perennial species seeded, tall wheatgrass, crested wheatgrass, western wheatgrass, bluebunch wheatgrass, and thickspike wheatgrass were most adaptable. Weed cover decreased at all sites as perennial grass cover increased.

**Implications:** The authors state their results show that weed control is important for perennial establishment in weed-invaded noncrop areas. They state their imazapic findings indicate there is a tradeoff between effectively controlling invasive species and damaging planted or native species. They suggest that applying a short-residual herbicide at planting and a long-residual herbicide after 1 year could be most effective at managing invasive grasses longer term.

**Topics:** survival; population estimates or targets; habitat restoration or reclamation; nonnative invasive plants; weed management; weed management subtopic: herbicides

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