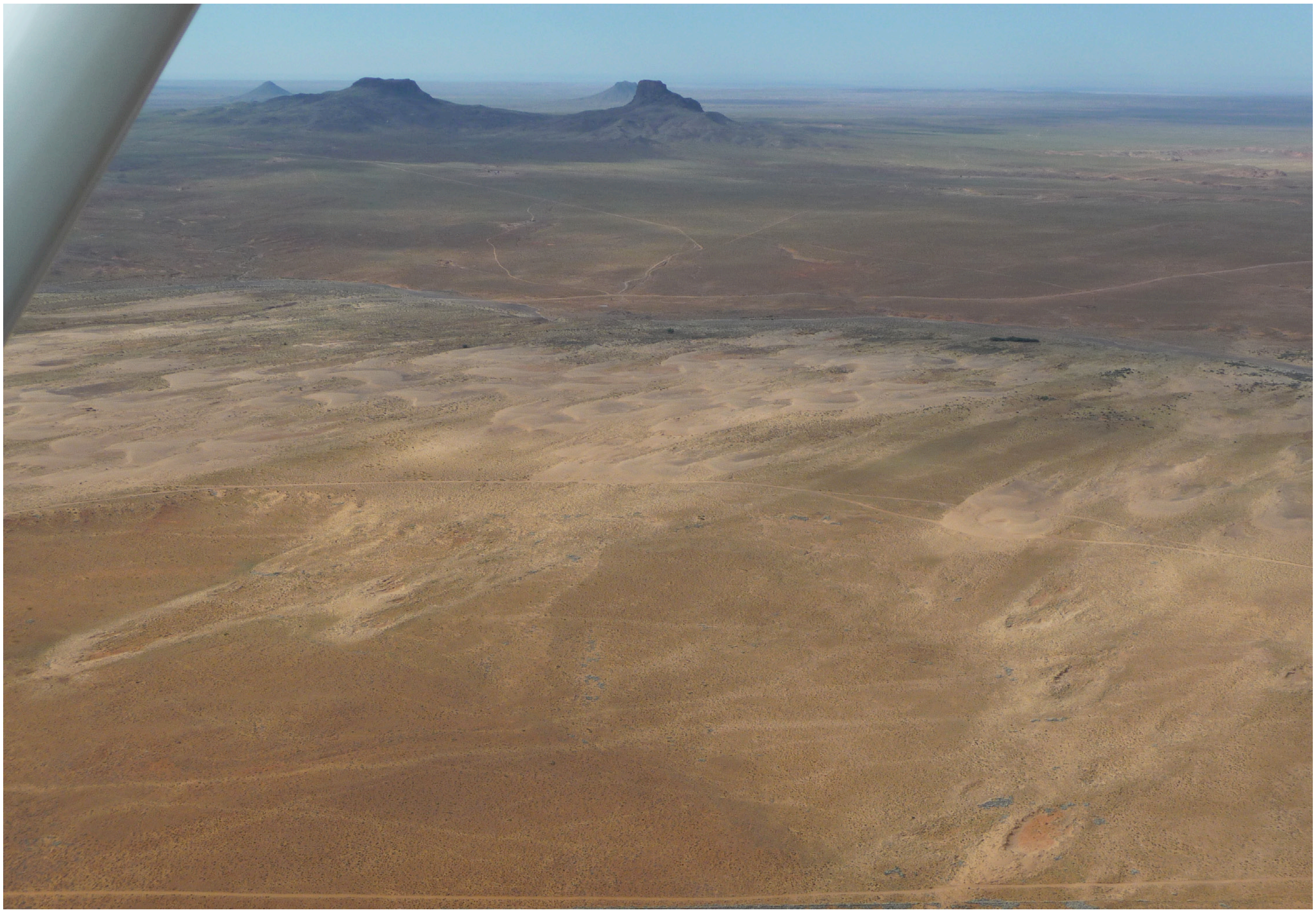
Vegetation, Substrate, and Eolian Sediment Transport at Teesto Wash, Navajo Nation, 2009–2012



Scientific Investigations Report 2012–5095

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FRONT COVER:

Aerial photograph taken in April 2012 of Teesto Wash, Navajo Nation, approximately 45 miles north of Winslow, Arizona. View is to the southeast. Photo by Jon Mason, USGS.

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By Amy E. Draut,[1] Margaret Hiza Redsteer,[2] and Lee Amoroso[2]

Abstract

On the Navajo Nation, southwestern United States, warming temperatures and recent drought have increased eolian (windblown) sediment mobility such that large, migrating sand dunes affect grazing lands, housing, and road access. We present an assessment of seasonal variations in sand transport, mobility, and ground cover (vegetation and substrate) within a 0.2-km^2 study area near Teesto Wash, southern Navajo Nation, as part of a multiyear study measuring the effects of drought on landscape stability. Sand mobility in the study area decreased substantially as one year (2010) with near-normal monsoon rainfall somewhat abated a decade-long drought, temporarily doubling vegetation cover. The invasive annual plant Russian thistle (*Salsola* sp.), in particular, thrived after the monsoon rains of 2010. Vegetation that grew during that year with adequate rain died off rapidly during drier conditions in 2011 and 2012, and the proportion of bare, open sand area increased steadily after summer 2010. We infer that isolated seasonal increases in rainfall will not improve landscape stability in the long term because sustained increase in perennial plants, which are more effective than annual plants at stabilizing sand against wind erosion, requires multiple consecutive seasons of adequate rain. On the basis of climate projections, a warmer, drier climate and potentially enhanced sediment supply from ephemeral washes may further increase eolian sediment transport and dune activity, worsening the present challenges to people living in this region. Connections between climate, vegetation cover, and eolian sediment erodibility in this region also are highly relevant for studies in other regions worldwide with similar environmental characteristics.

Introduction

The Navajo Nation, comprising the largest tribal reservation within the United States (fig. 1), is presently restricted to arid and semiarid lands within the Navajo ancestral homeland. These lands have been stressed by drought, land-use practices, and rapid population growth during the 20th century. As in many other Native American communities, the Navajo people face economic disadvantages and, owing to livestock-management regulations and cultural ties, cannot readily relocate either their grazing lands or settlements (Redsteer and others, 2010a). Among the environmental challenges to the Navajo Nation are shifting vegetation patterns, including the spread of invasive species, and eolian (windblown) sediment mobility. Warming temperatures and recent drought (fig. 2) have contributed to reduced streamflow and vegetation loss. These factors have increased eolian sediment mobility such that regional duststorms are common and large, migrating sand dunes now affect grazing lands, housing, and transportation (Redsteer and others, 2011). This report presents recent sediment-transport and vegetation measurements in order to elucidate and quantify some of the factors affecting landscape stability and sand mobility on the Navajo Nation, as part of a study of the effects of drought in this region. In addition to affecting the quality of life for regional residents, eolian sediment mobility in this part of the Colorado Plateau also has important implications for the longevity of the Rocky Mountains snowpack and thus for regional water supply in the western United States.

With an area of 67,000 km^2 spanning parts of Arizona, New Mexico, and Utah (fig. 1), Navajo reservation lands range in elevation from 1,200 to 3,000 m, with a regional average annual rainfall ranging from 100 to 300 mm. As of 2010, more than 169,000 of the 332,000 Navajo tribal members were living on the reservation (Norris and others, 2010). The population grew substantially in the late 20th century; in 2000, the median age of the Navajo reservation population was 24 years, in comparison with 35.3 years for the general U.S. population (U.S. Census Bureau, 2000). The Navajo lifestyle and economy historically have been tied closely to livestock production and husbandry, but for more than a century it has been recognized that livestock populations can overgraze Navajo lands to a degree that reduces native vegetation substantially (Bailey and Bailey, 1986). Around the turn of the 20th century, regional vegetation communities began to be affected not only

[1]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA 95060.

[2] U.S. Geological Survey, Flagstaff Science Center, Flagstaff, AZ 86001.

by overgrazing but also by the Eurasian annual plant Russian thistle (*Salsola* spp.), which spreads quickly on loose, sandy soils such as those that occur over much of the Navajo Nation. In its dry form known as tumbleweed, Russian thistle disperses great distances aided by wind and is one of the most widespread invasive plants on Navajo lands today.

Precipitation occurs bimodally in the southwestern United States, during winter storms (December–March) and the North American monsoon season (July–September), with 45 percent of annual precipitation on Navajo lands falling during the summer monsoon (Redsteer and others, 2010a). These two wet seasons are separated by a dry, windy spring (for example, Hack, 1941; Draut and Rubin, 2006; Jewell and Nicoll, 2011; Munson and others, 2011). For most of the past century precipitation has been declining in Navajo lands (fig. 2) and climate has been warming more rapidly in the southwestern United States than in many other regions of North America, resulting in associated ecologic changes (Westerling and others, 2006; Seager, 2007a; Weiss and others, 2009). Declining precipitation, a shift from snowfall to rainfall, and increased potential evapotranspiration have contributed to a reduction in surface water on Navajo lands. At least 30 streams and lakes that were perennial in the 1920s are now dry or ephemeral (Redsteer and others, 2010a). Climate models project increasingly drier and warmer conditions throughout the southwestern United States for the coming decades (Seager and others, 2007b; Solomon and others, 2007; Dominguez and others, 2010).

Eolian sand covers much of the Navajo lands (Hack, 1941). Nearly a third of the Navajo reservation has loose, sandy soil that the wind winnows and shapes into dunes; the Four Corners region of the Colorado Plateau contains the largest area of eolian sand dunes within the southwestern United States (Muhs and others, 2003; Muhs and Been, 2004; Redsteer and others, 2010a). New sand dunes have formed and enlarged substantially on Navajo lands since the mid-20th century in areas with sandy soils and sparse vegetation (Redsteer and others, 2011). Particularly after a 1950s drought, loss of perennial streamflow left riverbeds dry, providing a source from which the wind mobilizes sediment (Redsteer and others, 2010b). Aerial photographs show evidence for eolian sand transport downwind of many streambeds in the Navajo Nation, commonly forming well developed dune fields (fig. 1*B*) similar to the so-called “source-bordering dunes” that occur

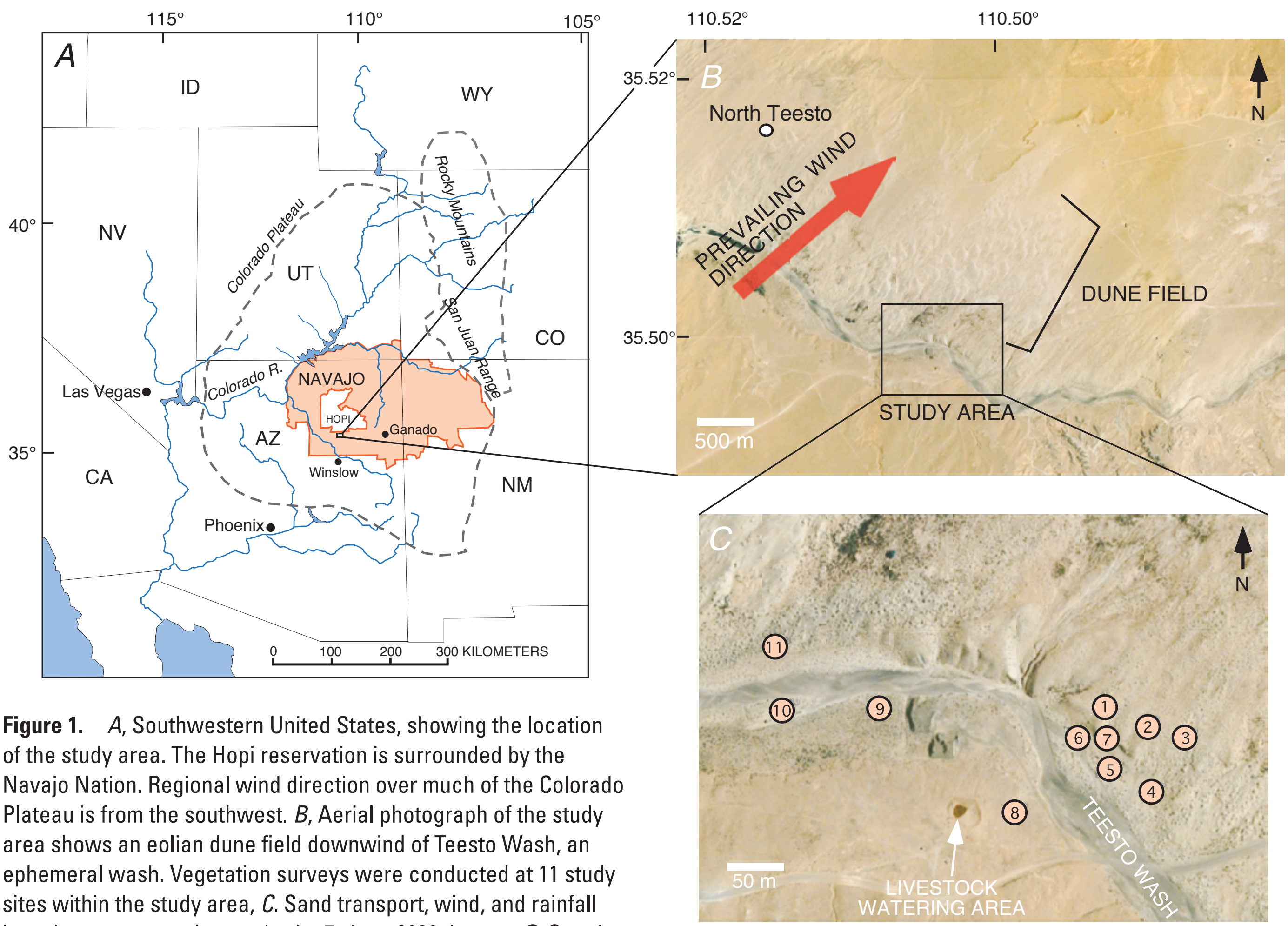

Figure 1. *A*, Southwestern United States, showing the location of the study area. The Hopi reservation is surrounded by the Navajo Nation. Regional wind direction over much of the Colorado Plateau is from the southwest. *B*, Aerial photograph of the study area shows an eolian dune field downwind of Teesto Wash, an ephemeral wash. Vegetation surveys were conducted at 11 study sites within the study area, *C*. Sand transport, wind, and rainfall have been measured at study site 7 since 2009. Images © Google Earth, 2007.

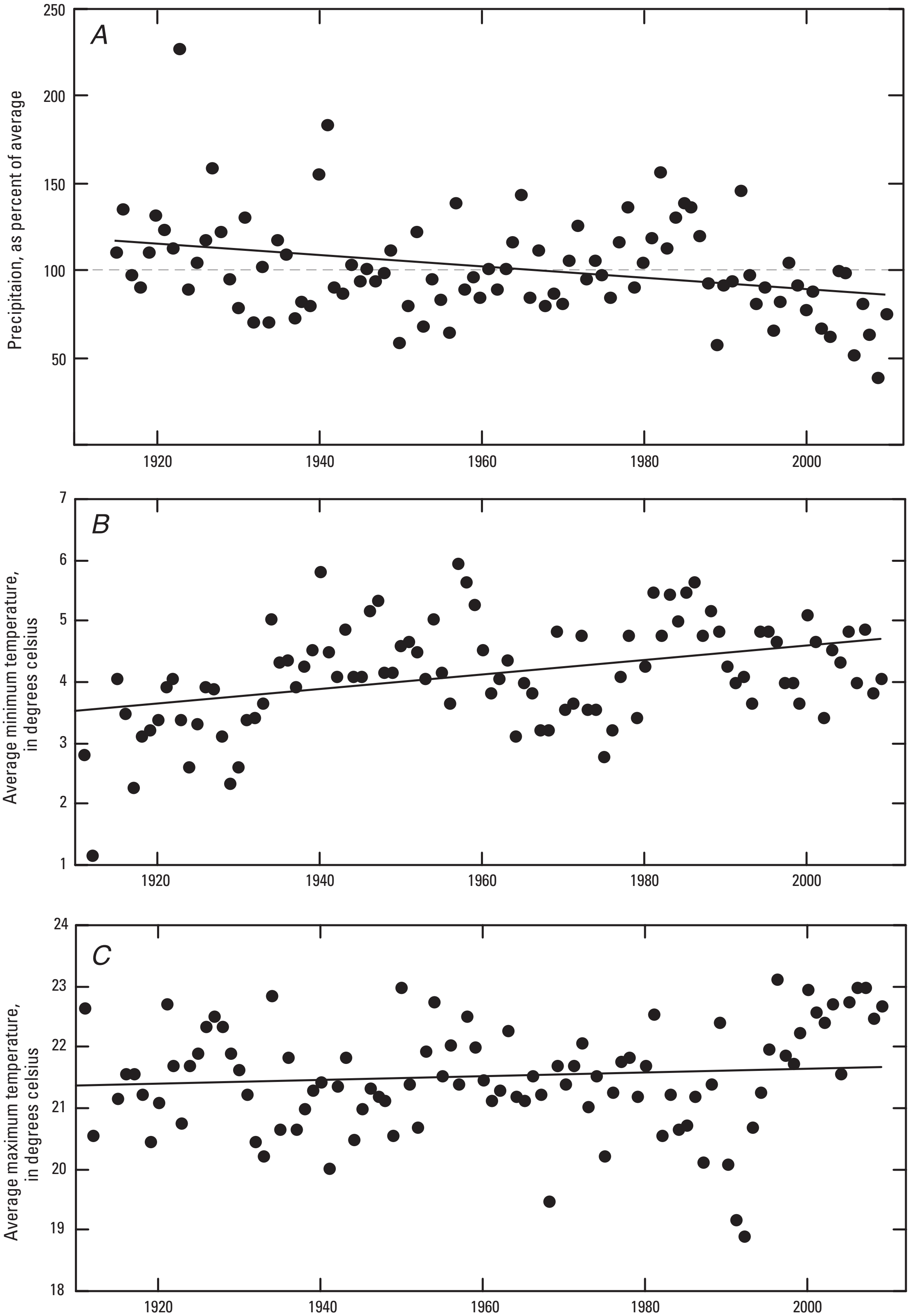

Figure 2. Trends in precipitation and temperature on the Navajo Nation. *A*, Rainfall on the southern Navajo reservation, as a percentage of the 1915–2010 average, using combined data from Winslow and Ganado, Arizona, the two weather stations nearest the study area with long-term records (see fig. 1*A* for locations). *B*, Average monthly minimum temperature measured at Winslow, Arizona, from 1915 to 2010. *C*, Average monthly maximum temperature measured at Winslow, Arizona, from 1915 to 2010. Best-fit linear regressions are shown.

immediately downwind of desert streambeds in other dryland regions globally (Bullard and McTainsh, 2003). Eolian sediment mobilization and dune activation commonly occur in response to climatic change, not only on Navajo lands but also in other field settings (Muhs and Holliday, 1995; Lancaster, 1997; see reviews by Bullard and Livingstone, 2002, Bullard and McTainsh, 2003; and Cornelis, 2006). The environmental effects of increased eolian sediment mobility and transport during dry intervals are substantial and affect many residents of the Navajo Nation—airborne dust reduces air quality, causing health risks, and sand dunes that can migrate as fast as tens of meters per year frequently impede road access and have even destroyed houses (fig. 3; Redsteer and others, 2010a, b).

Because the Navajo lands are fairly remote, quantitative measurements of environmental parameters are scarce. The U.S. Geological Survey (USGS) began a pilot drought-monitoring program there in 2005 that deployed new weather stations. Several years later, this study was expanded to measure eolian sediment transport and vegetation. We present some results of this monitoring study, with the goal of understanding the influence of seasonal weather patterns on eolian sediment mobility, and vegetation type and abundance. Eolian sediment mobility is a useful indicator of dryland environmental conditions—the air-quality and landscape-stability issues it represents are vital to evaluating the habitability of the Navajo reservation and the longevity of the Rocky Mountains snowpack as the 21st-century climate becomes warmer and drier.

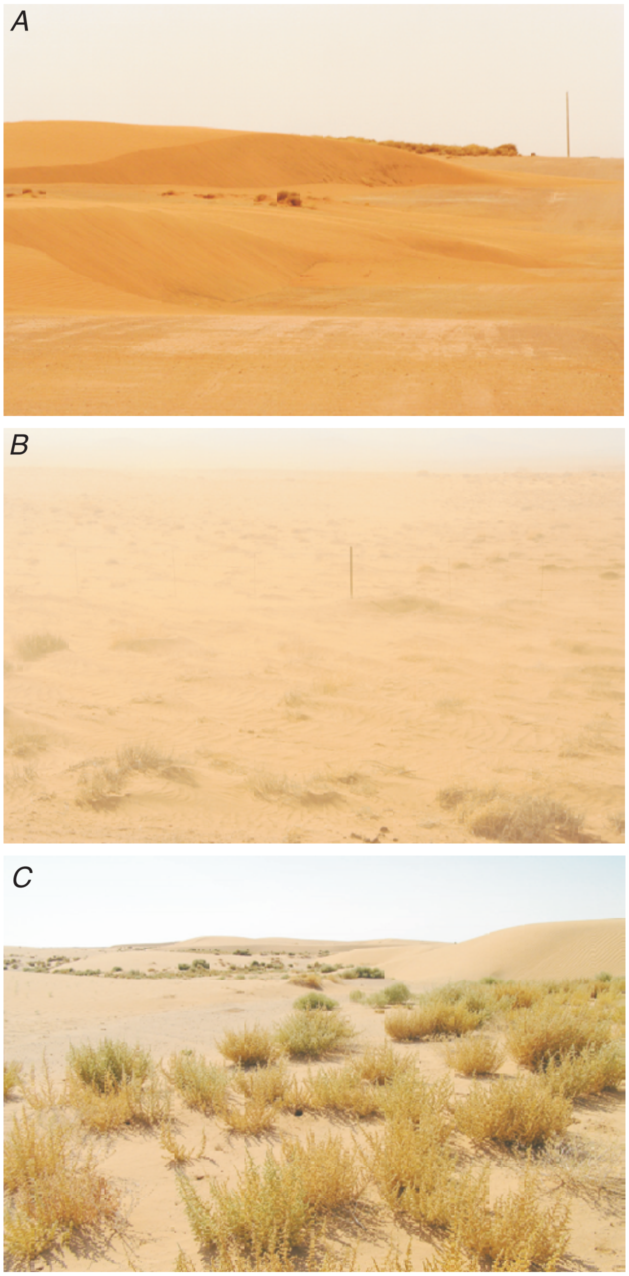

Figure 3. Wind-dominated landscapes on the southern Navajo reservation near the study area (fig. 1) in October 2008. *A*, Dunes migrating from left to right across a road. *B*, Haze from airborne dust in an area where sandy soils are readily mobilized by wind. Fencepost in center of photograph is 1 m high. *C*, Nonnative Russian thistle plants dominating vegetation in an eolian dune field.

Methods

Wind, rainfall, eolian sediment transport, and ground cover (vegetation and substrate) were measured between 2009 and 2012 in a study area that, though small in comparison with the vast size of the Navajo Nation, is representative of where many settlements are situated. Some 15,000 to 20,000 Navajo people reside on landscapes with ground cover similar to that of the 0.2-km^2 study area—sandy soils on and near dune fields and an ephemeral wash, in an area with livestock use and occasional offroad-vehicle traffic (fig. 1*C*).

Wind, Precipitation, and Sediment-Transport Measurements

Wind velocity, precipitation, and eolian sediment transport were measured beginning in March 2009 at the site marked "7" in figure 1*C*. A weather station and sand traps were deployed approximately 10 m apart, each surrounded by fenced enclosures to prevent damage by livestock; the instrument deployments are shown in figure 4. The weather station included an Onset wind speed and direction sensor (spinning-cup anemometer with wind vane) mounted on a tripod at a height of 2 m above the bed. This anemometer measured wind speed with 0.2-m/s resolution, and wind direction as vector components with a resolution of 1.4° and an accuracy range of ±5°. An Onset tipping-bucket rain gage measured precipitation with a resolution of 0.2 mm and an accuracy of ±1 percent. Wind and precipitation measurements were recorded on an Onset™ digital datalogger. Precipitation was recorded as 4-minute total rainfall amounts, and wind speed and wind direction every 4 minutes as 4-minute averages using a 3-s sampling interval.

Windblown sediment was collected in four passive-sampling Big Spring Number Eight (BSNE) traps (Fryrear, 1986) mounted on a vertical pole 10 m upwind of the weather station (fig. 4). Each trap was equipped with a vane that turned the sampler into the wind. The bases of the 5-cm-tall trap orifices were set at heights of 0.1, 0.4, 0.7, and 1.0 m above the ground, so placed because most eolian sediment transport occurs within 1 m of the bed (Anderson and Hallet, 1986; Sterk and Raats, 1996; Zobeck and others, 2003). Wind-tunnel studies (Goossens and others, 2000) indicate a BSNE sand-trap efficiency range of 70–130 percent for the wind velocities and sediment grain sizes measured at this study site. An efficiency less than 100 percent indicates that airflow is directed away from the orifice, such that the trap undersamples windblown sediment, whereas an efficiency greater than 100 percent indicates that air flow is directed into the trap, over sampling windblown sediment. A conservative efficiency range of 70–130 percent was used to estimate error in the sand-transport data reported here because it is the best available for this type of bulk sand-transport data.

Approximately every 4 weeks, sediment was emptied from the traps, oven-dried overnight at 65°C in the USGS laboratory in Santa Cruz, California, and then weighed. Organic matter was not removed from sediment samples before weighing, because the organic-matter proportion of the sample was negligible. Sediment-transport rates were calculated by dividing the total mass of sediment in the traps by the number of days over which it accumulated. To avoid introducing uncertainty, measured sediment fluxes were not extrapolated down to the bed; thus, although measurements do not account for the absolute total mass flux, trends in relative amounts of transport over time still are apparent. Sediment-transport rates were normalized to show sediment mobility without the effects of varying wind speed over different time intervals; to normalize the data, each sediment-flux measurement was divided by the cumulative flux predicted for that interval by the Dong and others (2003) transport equation. This formulation, a modification of that proposed by O'Brien and Rindlaub (1936), was chosen because it treats wind strength as a function of velocity rather than shear velocity; to extrapolate shear velocity from wind velocity measured at only one height would introduce additional, unwanted uncertainty.

Particle-size analysis was performed on 24 sediment samples that were selected because they represented eolian sediment transport during the spring windy seasons of 2009, 2010, and 2011. Samples were analyzed at the U.S. Geological

Figure 4. Weather station, sand traps, and vicinity of study site 7 (see fig. 1*C* for location). *A*, Weather station, with anemometer and wind-direction sensor mounted on instrument tripod 2 m above ground. The rain gage is on the left; fenced enclosure surrounds the station. View is southeastward across Teesto Wash. *B*, Cistern and cattle near study site 8, viewed from study site 7 across Teesto Wash. *C*, Weather station at study site 7. View northeastward. *D*, Sand-trap deployment at study site 7. Four Big Spring Number Eight (BSNE) sand traps were mounted on a vertical pole and surrounded by a fenced enclosure. White measuring tape along ground was used to measure gap length during ground-cover surveys. View southwestward.

Survey's Geology and Environmental Change Science Center laboratory in Denver, Colorado. Bulk samples were split with a chute splitter and treated with 30 percent aqueous hydrogen peroxide to remove organic matter. Sodium hexametaphosphate was added to all samples as a deflocculant, and the samples were shaken on a shaker table for 4 hours to ensure deflocculation of clay material. Grain size was determined by using a Malvern Mastersizer 2000 laser analyzer. Each sample was introduced into an aqueous medium and pumped through the laser analyzer for particle-size measurements.

Vegetation and Substrate Measurements

Vegetation and substrate cover were measured once at each of the 11 study sites (fig. 1*C*) during each of five surveys, in spring and fall 2010, spring and fall 2011, and spring 2012, in a layout of circles and linear transects referred to here as a "pod" (Draut and Gillette, 2010; Draut, 2011). As shown in figure 5, each pod consisted of two orthogonal transects marked out with measuring-tape reels (one oriented parallel and another oriented perpendicular to the prevailing wind direction) and five 3-m-radius circles outlined in the sand (one in the center of the pod and another at the end of each of the four transects).

Along each of the transects within a pod, gap lengths were measured where the measuring tape crossed bare, open sand without rocks, biologic soil crust, leaf litter, or overhanging plant canopy. Biologic soil crust, a common component of desert ecosystems, consists of cyanobacteria living symbiotically with lichen, mosses, fungi, and algae (Belnap and others, 2001; Belnap and Lange, 2003). This method of measuring gap length was modified from that used by Herrick and others (2005), with their criteria to define plant-canopy gaps, as a means to measure the spacing and abundance of roughness elements, vegetation, and patches of biologic crust that could reduce eolian sediment mobility (Ash and Wasson, 1983; Leys and Eldridge, 1998; Belnap and Lange, 2003; Goossens, 2004). The proportion of bare, open sand in the dune field then was estimated for each of the 11 study sites by adding all the measured gap lengths from each transect to compile a cumulative gap-length measurement representing total gap length as a percentage of total transect length. Gap lengths between plant bases (basal gap length; Herrick and others, 2005) also were measured.

Within each of the five circles in a pod, the percentage of vegetation cover was measured, as were the types of substrate in which the plants were growing. Vegetation was identified to species level wherever possible, using the names and

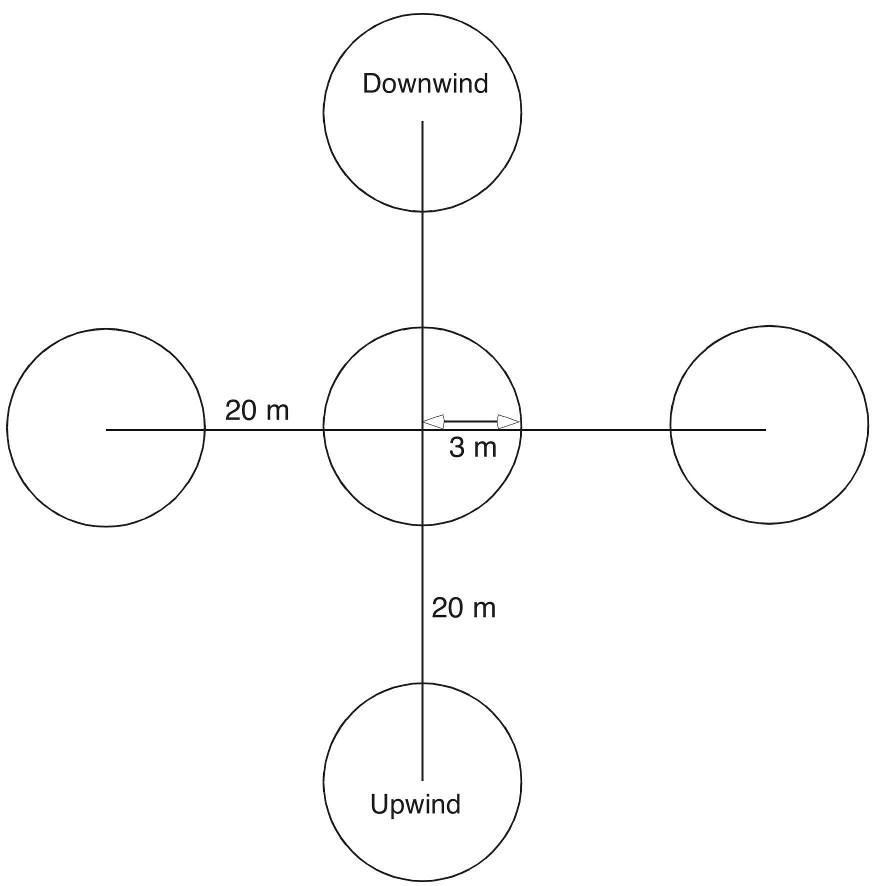

Figure 5. Scale diagram of "pod" configuration used to measure vegetation and substrate.

descriptions provided by Taylor (1992), Williams (2000), and Huisinga and others (2006), supplemented with identifications made by experts on plant communities of the Navajo Nation area (L. Begay and A. Clifford, oral commun., 2009) and maintaining consistency with the U.S. Department of Agriculture plant database (http://plants.usda.gov, accessed June 20, 2012). Where species identification was uncertain, plants were identified by their family or genus, or by designation as annual or perennial grass, forb, or shrub. Substrates were divided into four categories: open sand, biologic soil crust, leaf litter, and rock. To estimate the percentage of cover of both plants and substrate, a disc of known size was compared with the area covered by a plant, rock, patch of soil crust, or other object of interest. The disc (20-cm radius) has an area (0.13 m^2) approximately 0.5 percent of the circle size studied (28.3 m^2). By holding a disc of known radius above plants or patches of biologic crust to estimate their size and percentage of cover, researchers avoided disturbing the ground surface unnecessarily, as would happen from handling plants or placing measuring devices directly on sensitive, soil-encrusted ground. The uncertainty in this method of ground-cover measurement is estimated conservatively to be no more than 5 percent, on the basis of the consistency of measurements made during repeated visits, within the same season, to several test circles. Annual variations in plant cover were minimized by repeating the surveys of each season within a week of the dates on which the survey had been conducted in the previous year; thus, the three March surveys (2010, 2011, and 2012) were conducted between March 12 and 19, and the two August surveys on August 8 and 9 (2010 and 2011).

Vegetation that appeared to be dead but that was still rooted in the ground was included in the category of vegetation cover, whereas dead vegetation no longer rooted in the ground was classified as litter substrate. Vegetation cover was considered to be dead if one specimen of a particular plant remained brown and did not bloom during the time when other plants of its species were green and blooming, or if some part of a shrub was seen to be brown while another part of the same shrub was green. With those two exceptions of circumstance, vegetation cover was assumed to be living; especially during winter, perennial grasses and shrubs are dormant and so do not appear green.

Results

Seasonal patterns in wind, precipitation, and sediment transport varied substantially throughout the study interval (figs. 6, 7). Because the anemometer and datalogger deployed in the study area malfunctioned several times during 2009 and 2010, two intervals during those years are represented in figure 6 by using data collected 1.5 km northwest of the study site at another weather station with a configuration similar to that at the study site (North Teesto, fig. 1*B*). Wind and rain data from North Teesto are plotted for year days 202–314 (July 21 to Nov. 10) in 2009, and North Teesto wind data for year days 91–219 (Apr. 1 to Aug. 7) in 2010, in figure 6.

As is common in this region, wind velocity (accompanied by dry conditions) and corresponding eolian sediment transport were greatest during spring. Sediment-transport rates in spring 2009 and 2010 were approximately 10 times higher than in other seasons, and springtime sand mobility in those years was approximately 10 to 100 times greater than in other seasons (fig. 6). Sediment transport and mobility in 2011 were markedly lower than in the preceding 2 years, particularly during spring (fig. 7), observations consistent with a large increase in vegetation cover during 2010, as discussed below.

During the study interval, hydrologic conditions in the southwestern United States spanned several years in the La Niña phase of the El Niño–Southern Oscillation (ENSO) cycle (2009, 2011, 2012) and one weak El Niño year (2010). In 2009, Arizona recorded its fourth-driest year in 117 years, and the preceding 3 years also had been abnormally dry (National Climatic Data Center, 2012). Several wetter seasons followed in 2010, which was Arizona's 85th-driest year on record with above-normal rainfall state wide, although northeastern Arizona received below-average rainfall (fig. 2). Dry conditions returned again in 2011, a year that received below-average rainfall and was the 23d driest on record in Arizona. Rainfall in the study area occurred predominately during the summer monsoon and winter storm seasons, although, unusual for that time of year, 15 mm of rain also fell on May 21, 2009. The largest rain event measured during the study interval was an intense monsoon storm on the evening of July 31, 2010, that delivered 38 mm of rain, 29 mm of which fell within 20 minutes. That rain event produced the only known discharge in Teesto Wash during the study interval. Using the slope-area method retroactively to gage discharge in Teesto Wash within the study area, we estimated the flow from that event to have been approximately 10 m^3/s. Runoff caused by the July 31, 2010, storm incised more than 1 m into nearby graded gravel roads and formed gullies within eolian sand (fig. 8) that remained visible for several months.

Vegetation abundance and species assemblage varied substantially between 2010 and 2012, both seasonally and longer term (figs. 9–11; tables 1–7). Vegetation assemblages at the study sites typically contained from 5 to 15 different plant species (tables 1, 3–7). Native plants that commonly occur in the study area included perennial bunchgrasses, such as Indian ricegrass (*Oryzopsis hymenoides*, also known as genus *Achnatherum*), sandhill muhly (*Muhlenbergia pungens*), galleta grass (*Pleuraphis jamesii*), and several species of dropseed (*Sporobolus* spp.). Common native shrubs and forbs included rabbitbrush (*Ericameria nauseosus*), snakeweed (*Gutierrezia sarothrae*), Mojave indigobush (*Psorothamnus arborescens*), globemallow (*Sphaeralcea* sp.), and stickleaf (*Mentzelia pumila*). Less common native shrubs included saltbush (*Atriplex* sp.), ephedra (*Ephedra* sp.), and narrowleaf yucca (*Yucca angustissima*). In the August 2010 vegetation survey (table 4), which followed abundant monsoon rainfall, the vegetation assemblage in the study area also commonly contained the

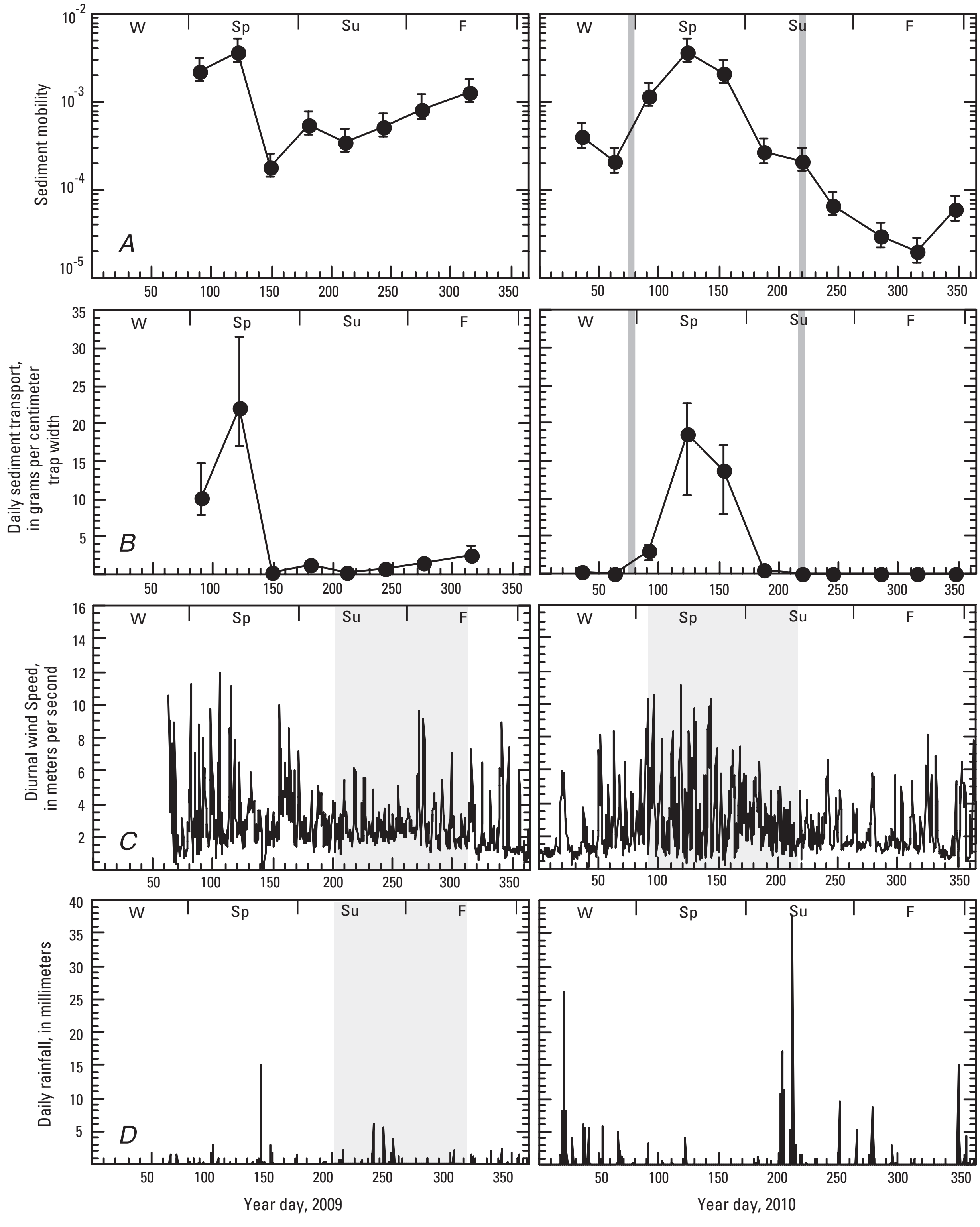

Figure 6. Eolian sediment mobility and transport, wind speed, and rainfall measured at study site 7 in 2009 and 2010 (see fig. 1*C* for location). *A*, Sediment mobility, in dimensionless units obtained by normalizing the sediment-transport measurements plotted in figure 6*B* against cumulative sand flux predicted for each time interval, as a function of wind speed, by the transport equation of Dong and others (2003). Gray vertical bars indicate times of vegetation surveys. *B*, Direct measurements of eolian sediment transport obtained from sampled mass collected in Big Spring Number Eight (BSNE) traps divided by the number of days over which it accumulated. Error bars factor in a 70–130-percent efficiency range for BSNE traps (Goossens and others, 2000). *C*, Wind speed, expressed as daytime (06:00–18:00) and nighttime (18:00–06:00) averages of 4-minute data. *D*, Daily rainfall summed from 4-minute measurements. Gray-shaded regions in figures 6*C* and 6*D* indicate data from a weather station at North Teesto (fig. 1) during instrument malfunction at study site 7.

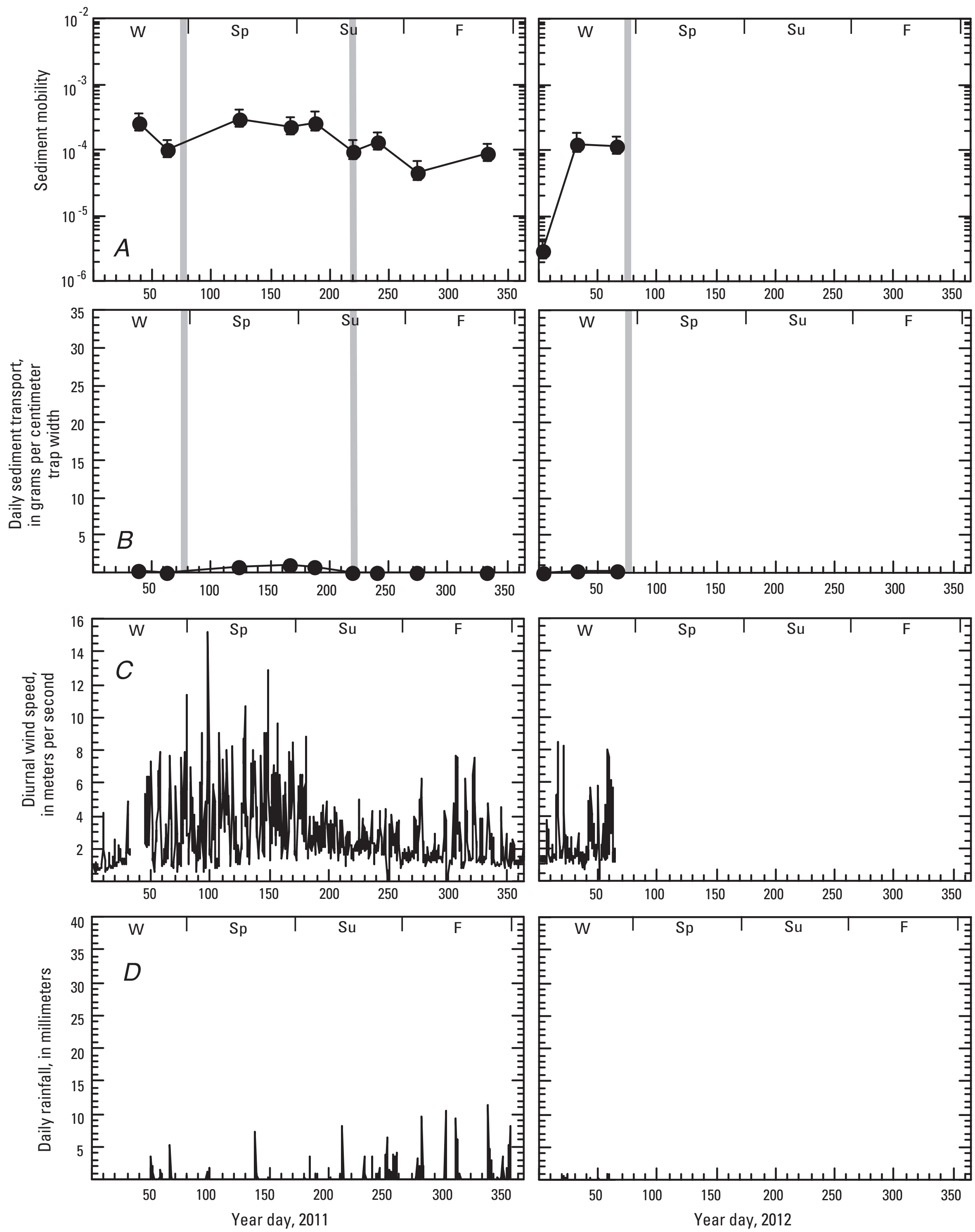

Figure 7. Eolian sediment mobility and transport, wind speed, and rainfall measured at study site 7 in 2011 and 2012. *A*, Sediment mobility, in dimensionless units obtained by normalizing the sand-transport measurements plotted in figure 7*B* against cumulative sand flux predicted for each time interval, as a function of wind speed, by the transport equation of Dong and others (2003). Gray vertical bars indicate times of vegetation surveys. Note that vertical scale of figure 7*A* encompasses one order of magnitude more than does the scale in figure 6*A*. *B*, Direct measurements of eolian sediment transport obtained from sampled mass collected in Big Spring Number Eight (BSNE) traps divided by the number of days over which it accumulated. Error bars factor in a 70–130-percent efficiency range for BSNE traps (Goossens and others, 2000). Beginning in winter 2011, sand-transport measurements probably were artificially low owing to tumbleweed accumulating at the upwind side of sand-trap enclosure. *C*, Wind speed, expressed as daytime (06:00–18:00) and nighttime (18:00–06:00) averages of 4-minute data. *D*, Daily rainfall summed from 4-minute measurements.

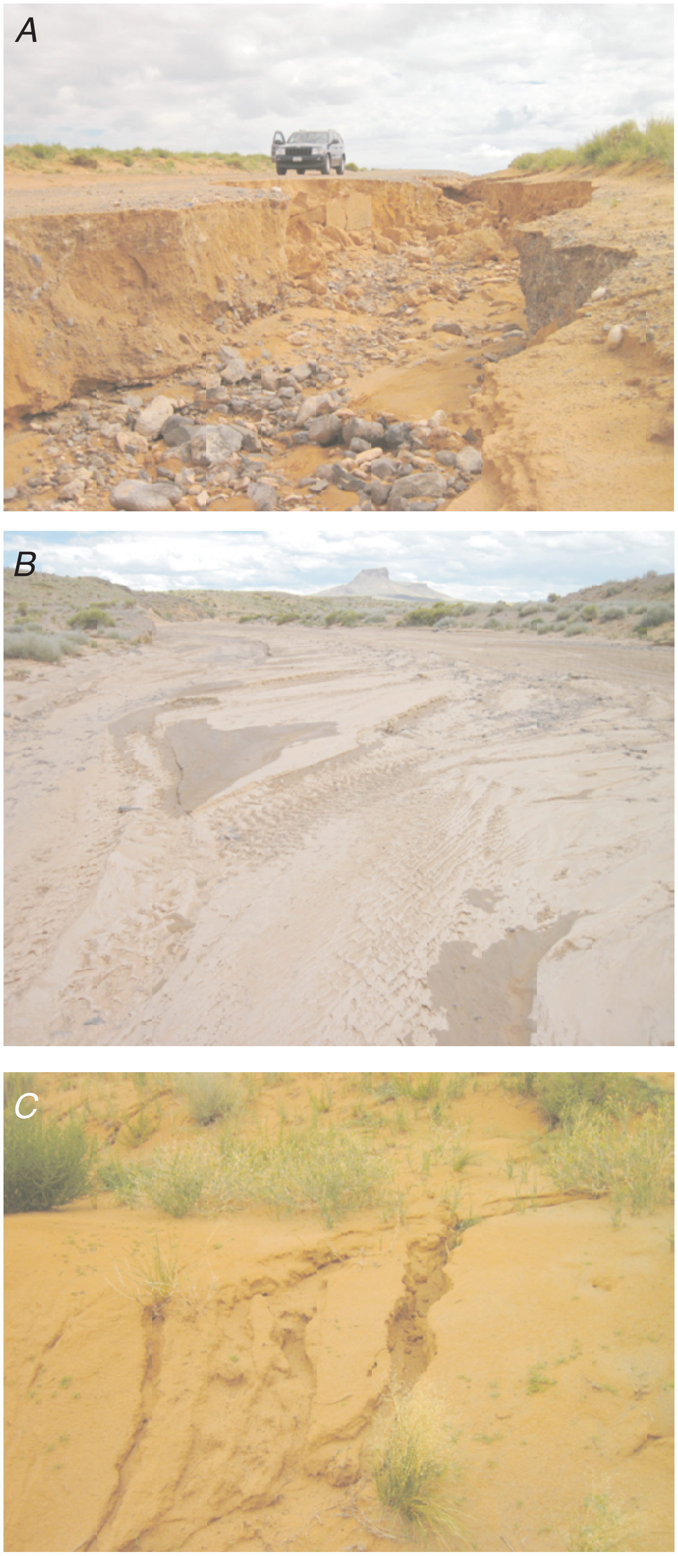

Figure 8. Localities in and near the study area (fig. 1) where an intense monsoon rainstorm occurred on the evening of July 31, 2010. *A*, Gullies more than 1 m deep incised into a graded gravel road, approximately 0.5 km east of the study area. *B*, Streambed of Teesto Wash near study site 9, with ripple structures and still-damp sediment indicating recent flow. *C*, Gullies incised into eolian sand near study site 4.

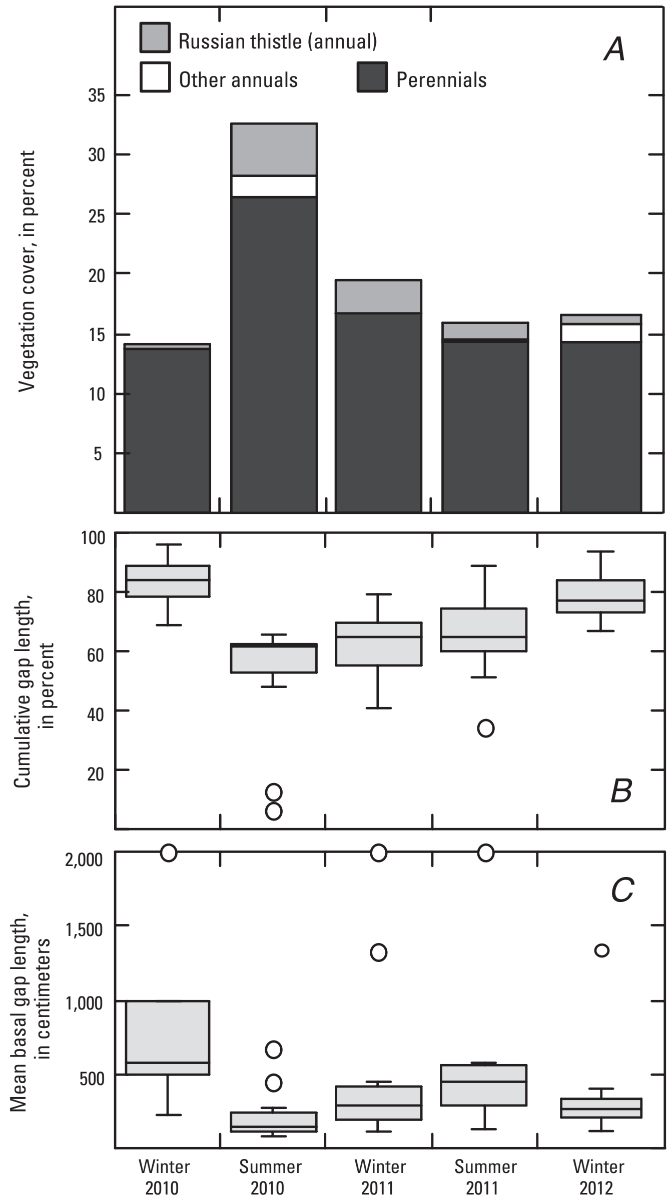

Figure 9. Variations in vegetation abundance and species assemblage. *A*, Vegetation cover, with measurements from circular plots within pods at all 11 study sites (see fig. 1*C* for locations) combined for each of five biannual surveys. *B*, Cumulative gap length where bare, open sand was present on linear transects of each pod (percentage of total transect length). Boxes span interquartile range of data collected at all 11 study sites; horizontal line through each box is median. Circles, outlier points with values more than 1.5 times interquartile range; bars, highest and lowest non-outlier points. *C*, Mean basal gap length (distance between plant bases; Herrick and others, 2005) measured on linear transects of each pod.

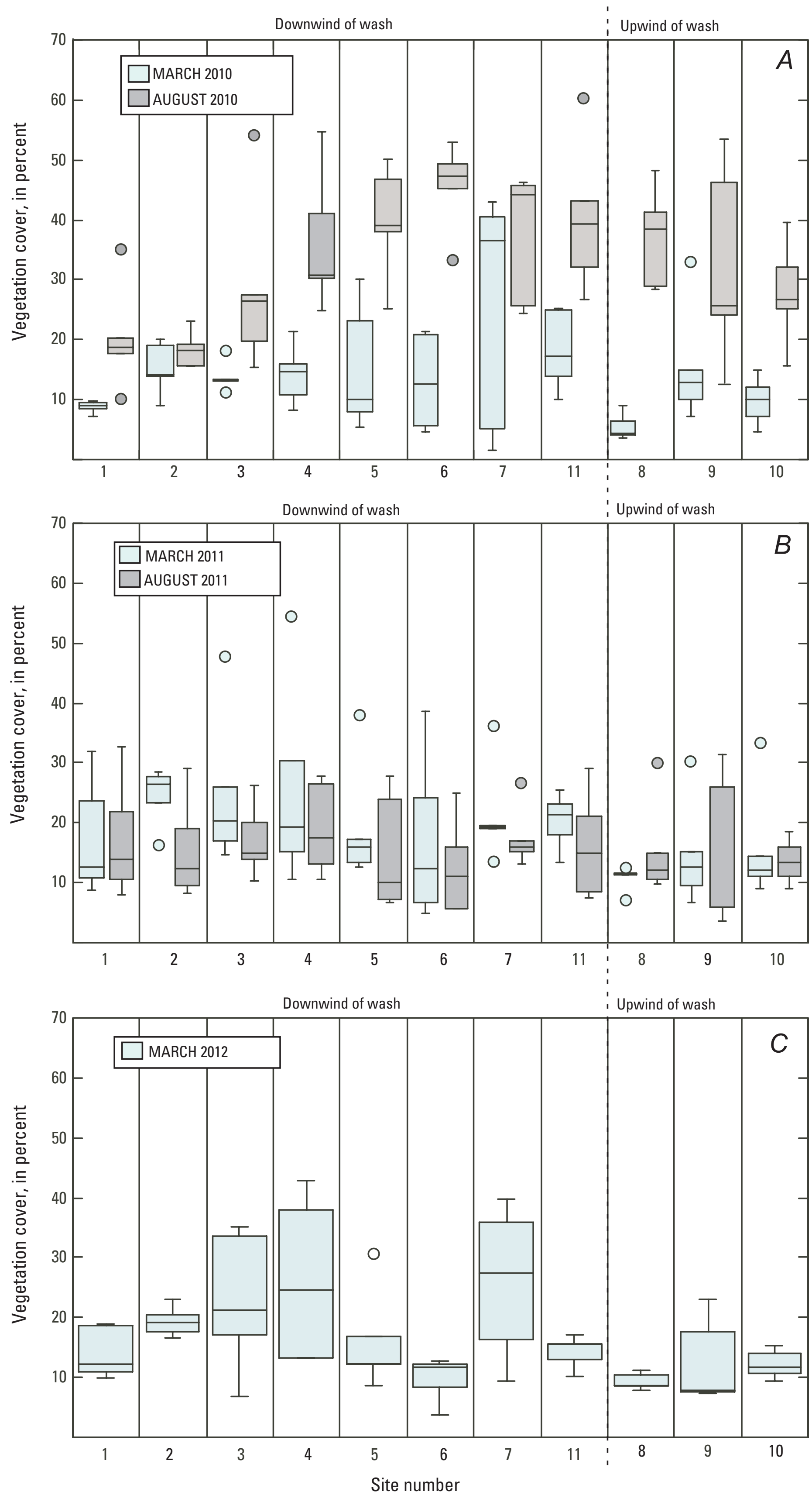

Figure 10. Vegetation cover by study site, showing abundance in March and August surveys in *A*, 2010, *B*, 2011, and *C*, March 2012.

Figure 11. Study area in the Navajo Nation (fig. 1), showing contrast between August vegetation cover during a year with near-normal rainfall (2010) and a year with below-average rainfall (2011). *A*, Study site 1 in August 2010. *B*, Study site 1 in August 2011. *C*, Study site 3 in August 2010. *D*, Study site 3 in August 2011. *E*, Study site 8 in August 2010. *F*, Study site 8 in August 2011.

annual plants desert twinbugs (*Dicoria canescens*), doveweed (*Croton texensis*), Plains spring parsley (*Cymopterus acaulis*), and bindweed heliotrope (*Heliotropium convolvulaceum*). Nonnative plants Russian thistle (*Salsola* sp.), an annual, and silverleaf nightshade (*Solanum elaeagnifolium*), a perennial, were abundant in several of the surveys, particularly in August 2010 (table 4).

Table 1. Plant varieties identified in the study area near Teesto Wash, Navajo Nation, Arizona.

[Some surveys also noted unidentified plants that are omitted from this list but were recorded as unidentified annual or perennial grasses, forbs, or shrubs]

Alkali sacoton (*Sporobolus airoides*)
Basin wildrye (*Leymus cinereus*)
Bindweed heliotrope (*Heliotropium convolvulaceum*)
Dicoria (*Dicoria canescens*)
Doveweed (*Croton texensis*)
Ephedra (*Ephedra* sp.)
Galleta grass (*Pleuraphis jamesii*)
Giant dropseed (*Sporobolus giganteus*)
Globemallow (*Sphaeralcea sp.*)
Grama grass (*Bouteloua sp.*)
Greene's rabbitbrush (*Chrysothamnus greenei*)
Indian ricegrass (*Oryzopsis hymenoides*)
Milkvetch (*Astragalus* sp.)
Milkweed (*Asclepias* sp.)
Mojave indigobush (*Psorothamnus arborescens*)
Narrowleaf yucca (*Yucca angustissima*)
Pigweed (*Amaranthus* sp.)
Plains spring parsley (*Cymopterus acaulis*)
Purple three-awn (*Aristida purpurea*)
Rabbitbrush (*Ericameria nauseosus*)
Russian thistle (*Salsola* sp.)
Saltbush (*Atriplex canescens*)
Sand dropseed (*Sporobolus cryptandrus*)
Sand verbena (*Abronia fragrans*)
Sandhill muhly (*Muhlenbergia pungens*)
Silverleaf nightshade (*Solanum elaeagnifolium*)
Snakeweed (*Gutierrezia sarothrae*)
Spike dropseed (*Sporobolus contractus*)
Stickleaf (*Mentzelia pumila*)
Unidentified aster (*Asteraceae* family)
Wire lettuce (*Stephanomeria pauciflora*)

In 2010, vegetation cover increased substantially between the surveys in March and those during the summer monsoon season (August) of 2010 (figs. 9, 10; table 2). Both annual- and perennial-plant cover increased between March and August 2010, with perennial growth occurring primarily by canopy cover increase on existing plants rather than by recruitment of new plants. No similar increase occurred from winter to summer during the much drier year 2011. Plant cover decreased slightly between March and August 2011, even though warm temperatures and longer daylight hours typically favor plant growth then (fig. 9*A*). During the August 2011 vegetation survey, when monsoon rainfall that year had been only 14 percent of what had fallen by the same date in 2010, vegetation cover was notably less than in August 2010 (fig. 11). Changes in cumulative canopy gap length (fig. 9*B*) largely reflected the increase and subsequent decrease in vegetation abundance during 2010 and 2011. Substrate measurements indicated no substantial change in biologic soil crust or rock area, and little change in accumulated leaf litter that factor into the cumulative-gap-length calculation, and most study sites had >95% sand substrate at each survey (fig. 12). Leaf litter was somewhat more abundant in 2011 than in 2010, as expected, given the abundant vegetation in summer 2010 that had begun to die off by 2011; nevertheless, leaf litter accounted for < 3 percent of substrate area at most sites, even in the surveys when it was most abundant. As of March 2012, vegetation cover apparently had increased slightly relative to that of summer 2011 (table 2), although the amount of increase was within the measurement uncertainty (15.9±0.79 percent in August 2011, in comparison with 16.5±0.83 percent in March 2012). Because perennial-plant cover remained nearly constant between summer 2011 and winter 2012 (fig. 9; table 2), an increase in vegetation in winter 2012 could have been caused by new growth of annual plants, dominantly stickleaf (*Mentzelia pumila*). This increase in annuals reduced the mean basal gap length, although cumulative gap length continued to increase, reflecting a steady increase in bare sand area since summer 2010 (fig. 9). The substantial vegetation growth during the 2010 summer monsoon season was accompanied by a disproportionately greater increase in annual plants relative to perennials (fig. 9*A*). This increase in annual plants also was reflected in the decrease in mean basal gap lengths between winter and summer 2010 (fig. 9*C*)—transects intersect more plant bases after new annual plants have germinated. Basal gap length decreased in 2011 relative to 2010 as annual plants died, because annuals did not germinate extensively during the very dry summer of 2011.

Invasive Russian thistle was by far the most abundant annual plant in the study area. In the first four surveys, Russian thistle composed 100 percent (March 2010), 70 percent (August 2010), 96 percent (March 2011), and 93 percent (August 2011) of the total annual-plant cover. After the 2010 monsoon rains, total vegetation cover increased by a factor of 2.3, whereas Russian thistle increased by a factor of nearly 15. The abundance and rapid increase of Russian thistle during 2010 likely interfered with the capacity of the BSNE traps to collect eolian sediment. By winter 2011, Russian thistle had died and produced abundant wind-mobile tumbleweed that accumulated in thick piles at the upwind side of the fence enclosing the sand traps, apparently inhibiting sand movement locally until the tumbleweed was removed during monthly maintenance visits. These conditions likely affected the relation between our measurements of vegetation cover and sand mobility. Loose Russian-thistle debris (tumbleweed) was abundant enough in 2011 and 2012 to warrant including it as a separate category in measurements of ground cover; at many study sites it covered 1–3 percent or more of the ground (tables 5–7). Canopy gap length corresponded well in 2010 to sand mobility as plant cover grew between March and August and as several dry years transitioned into the wetter year 2010 (fig. 9). However, even though plant cover in summer 2011 was only half that in summer 2010, measured sand transport did not increase correspondingly, possibly as an artifact of antecedent Russian thistle abundance, such that tumbleweed that grew during the 2010 monsoon rains interfered with sand collection in 2011 and even into 2012.

In contrast to the previous four surveys, the fifth survey (March 2012) showed Russian thistle composing only 32

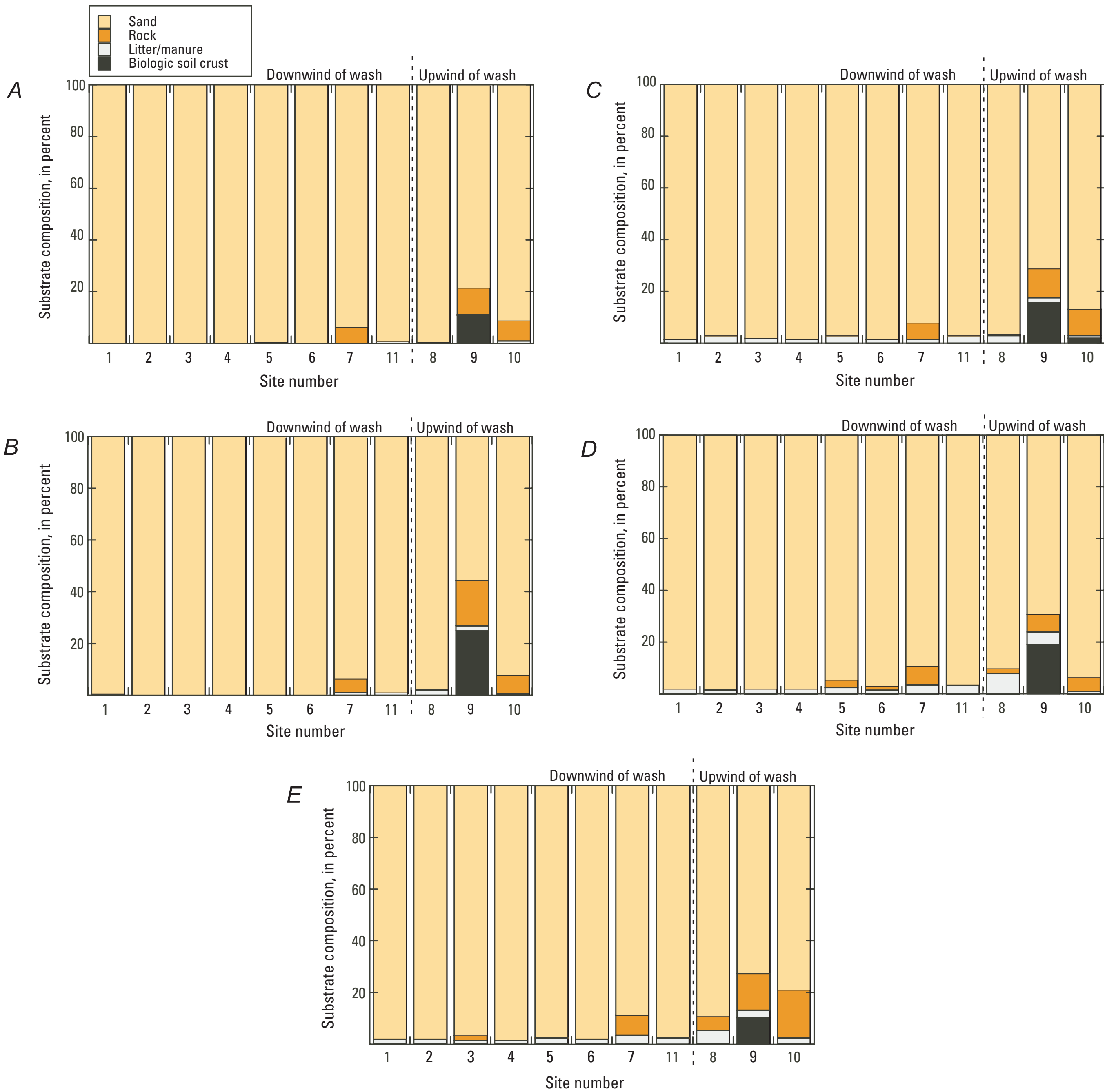

Figure 12. Substrate composition within circular plots of each pod, in *A*, March 2010; *B*, August 2010; *C*, March 2011; *D*, August 2011; and *E*, March 2012.

Table 2. Summary of major site characteristics measured in the study area near Teesto Wash, Navajo Nation, Arizona.

[Measurement uncertainty is estimated to be 5 percent of each value given below]

	Winter 2010	Summer 2010	Winter 2011	Summer 2011	Winter 2012
Total vegetation cover, in percent of area surveyed	14.1	32.6	19.4	15.9	16.5
Total Russian-thistle cover, in percent of area surveyed	0.37	4.30	2.64	1.36	0.74
Total other annual-plant cover, in percent of area surveyed	0	1.88	0.10	0.10	1.53
Total perennial-plant cover, in percent of area surveyed	13.7	26.4	16.7	14.4	14.2
Cumulative gap length, in centimeters, as median value for 11 sites	83.7	61.3	64.7	64.6	77.1
Basal gap length, in centimeters, as median of mean values for 11 sites	571	143	286	444	267
Total sand substrate, in percent of area surveyed	96.4	94.3	93.7	92.9	92.1
Total rock substrate, in percent of area surveyed	2.29	2.74	2.57	2.51	4.35
Total leaf litter substrate, in percent of area surveyed	0.30	0.68	2.10	2.84	2.56
Total biologic-soil-crust substrate, in percent of area surveyed	0.96	2.29	1.61	1.73	0.96

percent of annual-plant cover (fig. 9), with the rest made up of stickleaf and several other varieties of annual forbs (table 7). The winter 2012 survey was the only time during the study interval when no living Russian thistle was observed in the study area—all Russian thistle plants included in the survey (and others outside of the survey pods) were dead, and no green seedlings were observed, whereas live green seedlings of other annual plants, notably stickleaf, were abundant.

Discussion

The data presented here reflect conditions at the upwind edge of a dune field. In other, nearby areas with rapidly migrating sand dunes devoid or nearly devoid of vegetation, sand mobility and transport likely are much greater than in our study area. We have omitted such terrain from our study because rapid dune migration (more than 30 m during spring 2011; Redsteer and others, 2011) makes it impossible to deploy equipment in the field or to reoccupy the same sites for vegetation measurements. Instead, the present study has focused on conditions within a landscape where dunes are currently stable enough for people to live, work, and raise livestock. Relations discussed among vegetation cover and eolian sediment transport and erodibility on this Navajo Nation landscape are highly relevant also to other areas of the world with similar environmental problems (for example, Kurosaki and others, 2011; Okin and others, 2011).

Relative abundance of annual and perennial plants exerts an important control on eolian sand mobility and thus on landscape stability (Urban and others, 2009; Munson and others, 2011). Annual plants can germinate, mature, and disperse seeds with only one season of good rainfall, as occurred in the study area between March and August 2010 in response to adequate monsoon rains (tables 3, 4; figs. 9, 10). However, maintenance of and increase in perennial-plant cover requires sufficient moisture in multiple consecutive seasons, not only during the summer monsoon. Perennial plants generally have stiffer, more durable stems and roots and accumulate more leaf litter around their bases, protecting the land surface from wind erosion more efficiently than do annual plants (Belnap and others, 2009; Okin and others, 2011). Therefore, although a year with good monsoon rains and abnormally dry conditions in other seasons would cause short-term annual-plant growth, such as we measured in 2010, it would not reduce eolian sediment mobility in the long term because it would not enhance long-term growth of perennials. The disproportionate increase of such annuals as Russian thistle from a good summer monsoon season, such as in 2010 (fig. 9*A*), is unlikely to increase landscape stability. The windy season of the southwestern United States occurs in early spring before most annual plants have established. For this reason, and also because invasive exotic plants germinate earlier and crowd out slower-growing native plants, using water that otherwise could be available to perennials, the proliferation of Russian thistle may actually decrease landscape stability. Although both annual and perennial plants increased during the wetter summer of 2010, decreasing sand mobility well into the following year (figs. 6, 7), the subsequent loss of even perennial-plant cover in a dry year, such as occurred during 2011 (fig. 9*A*), poses a substantial risk to landscape stability in a setting prone to wind erosion. Previous research has shown that perennial-plant cover also has decreased elsewhere on the Colorado Plateau as mean annual temperatures have risen and precipitation has decreased over the past several decades, contributing to increased eolian sediment transport (Munson and others, 2011).

Among the 11 study sites where vegetation and substrate assemblage were measured, some differences were apparent between the sites upwind of Teesto Wash (sites 8–10; fig. 1*C*) and those downwind of the wash. Study sites 9 and 10 consistently had the lowest proportions of open sand substrate, with more area than at other sites occupied by rock and, especially at site 9, biologic soil crust (fig. 12). The greater proportion of open sand substrate at study sites downwind of the wash is consistent with observations from aerial photography of windblown sand originating from the ephemerally flowing streambed of Teesto Wash and moving downwind (figs. 1*B*, 1*C*). We infer that eolian sand thus effectively covers rock substrate and inhibits the growth of biologic crust downwind (northeast) of the wash. The sensitive organisms that compose biologic soil crust do not thrive when constantly abraded or buried by windblown sand, and extensive biologic crust growth is more commonly associated with areas where little eolian sand supply and transport occur (Lancaster, 1994; Draut, 2011, 2012). Although study site 8 is also upwind of the wash, ground cover there differs from that at other study sites because site 8 is affected strongly by livestock activity. Study site 8 is located just north of a water cistern visited frequently by cattle and horses (figs. 11*E*, 11*F*). This site had less overall plant diversity and less native-plant cover than did most other study sites, and instead contained abundant invasive Russian thistle and silverleaf nightshade (figs. 11*E*, 11*F*; tables 3–6). In the August 2010 survey, those two nonnative plant species accounted for most of the vegetation at study site 8, with Russian thistle and silverleaf nightshade composing 43 and 23 percent, respectively, of the total vegetation cover there (table 4). The disproportionately high abundance of those two plant types is attributed to livestock preferentially grazing on other, native plant species, and the ease with which Russian thistle and silverleaf nightshade colonize disturbed areas. Although livestock may eat Russian thistle when the plant is young and small, mature *Salsola* is thorny and unpalatable. Silverleaf nightshade is toxic to animals and is considered a noxious weed in many states, including Arizona, owing to its rapid spread in disturbed, sandy soils (Huisinga and others, 2006).

Most climate models project that the southwestern United States will become increasingly warm and dry during the 21st century (for example, Seager and others, 2007a, b) and some suggest that intense storms and associated flooding may increase (Trenberth, 1998). In such a scenario, perennial streamflow would continue to decline on Navajo lands (Redsteer and others, 2010a), whereas stronger, more frequent episodic floods are possible. Because dry streambeds are sources of eolian sediment (fig. 1*B*), flash floods during storms could supply additional material that would be entrained by wind the following spring (cf. Muhs and Holliday, 1995; Lancaster, 1997; Clarke and Rendell, 1998; Bullard and McTainsh, 2003; Han and others, 2007). Such altered patterns of rainfall and streamflow could further increase sediment supply into the dunes downwind of dry streambeds that have become common on the Navajo Nation since the 1950s (Redsteer and others, 2010b). Increased eolian sediment transport in springtime also could destabilize vegetation that initially thrived under the previous fall monsoon rain, because windblown sand damages plants by abrasion and burial (Okin and others, 2006). We propose that a negative feedback cycle could develop whereby the summer–fall monsoon rain that promotes plant growth also supplies ephemeral washes with new sand, which damages those plants once it is mobilized by wind.

Increased eolian sand transport and dune activity in such a future climate regime would further compromise living conditions for those on the Navajo Nation, as well as elsewhere in the southwestern United States. Because many Navajo residents not only have strong traditional ties to these lands but also lack the economic means to relocate elsewhere, a future combination of climate change, greater sediment mobility, and growth of invasive plants that neither stabilize dunes nor serve a useful purpose for people or livestock would negatively impact residents in the long term.

Implications for the Rocky Mountains Snowpack

Eolian sediment transport in northeastern Arizona has consequences not only for human health and infrastructure but also for the snowpack in the Rocky Mountains of Colorado, on which millions of people depend for water supply. Satellite imagery has shown dust plumes originating repeatedly from Navajo lands in and near the study area during the time interval covered by this study (for example, fig. 13; U.S. Geological Survey, 2012). Windborne dust from the southwestern Colorado Plateau is known to settle on snow in the southern Rockies, reducing its albedo and leading to earlier spring melting (Painter and others, 2007, 2010; Colorado Dust-on-Snow Program, 2011; Phillips and Doesken, 2011).

Accelerated snowmelt poses a concern for resource managers, who anticipate that the demand for water will increase as warmer, drier conditions prompt a shift from snowfall toward rainfall and increase eolian sediment transport from the Colorado Plateau. This concern is particularly great during La Niña phases of the ENSO cycle—in La Niña years, northeastern Arizona generally sees higher wind velocities and less rainfall than during El Niño phases (Enloe and others, 2004; Phillips and Doesken, 2011), and as the data from this study suggest, less vegetation cover to stabilize sandy soils. Though dominated by very fine sand, the airborne sediment mobilized from our study area contains abundant silt and some clay-size material (fig. 14), indicating that sediment in the vicinity of the study area is certainly fine enough to be transported great distances downwind toward the Rocky Mountains.

Previous studies have indicated a link between strong winds in northeastern Arizona and dust events in the southern Rockies, with a daily average wind velocity higher than 6.7 m/s proposed as a threshold value for dust events (Phillips and Doesken, 2011), because dust particles commonly are mobilized by the impact of saltating sand grains (for example, Bagnold, 1941). The high springtime sediment transport and mobility measured in our study area in 2009 and 2010 are broadly consistent with the dust-on-snow deposition monitored in the San Juan Range of the southern Rocky Mountains (fig. 1*A*), where dust-on-snow mass was greater in spring 2009 than in any of the previous 7 years (Skiles and others, 2011). Making more specific connections between trends in eolian sand mobility in our study area and dust deposition in the southern Rocky Mountains is challenging because within the 350 km between the study area and the nearest snowpack downwind where dust events are recorded is such a large source area that even with a substantial reduction in sediment mobility in the vicinity of our study area, such as after substantial plant growth in a year with adequate rainfall, wind could still supply ample sediment to the San Juan Range. A longer record from the study area and elsewhere may clarify the connections between source-area eolian events and dust deposition in the mountains downwind.

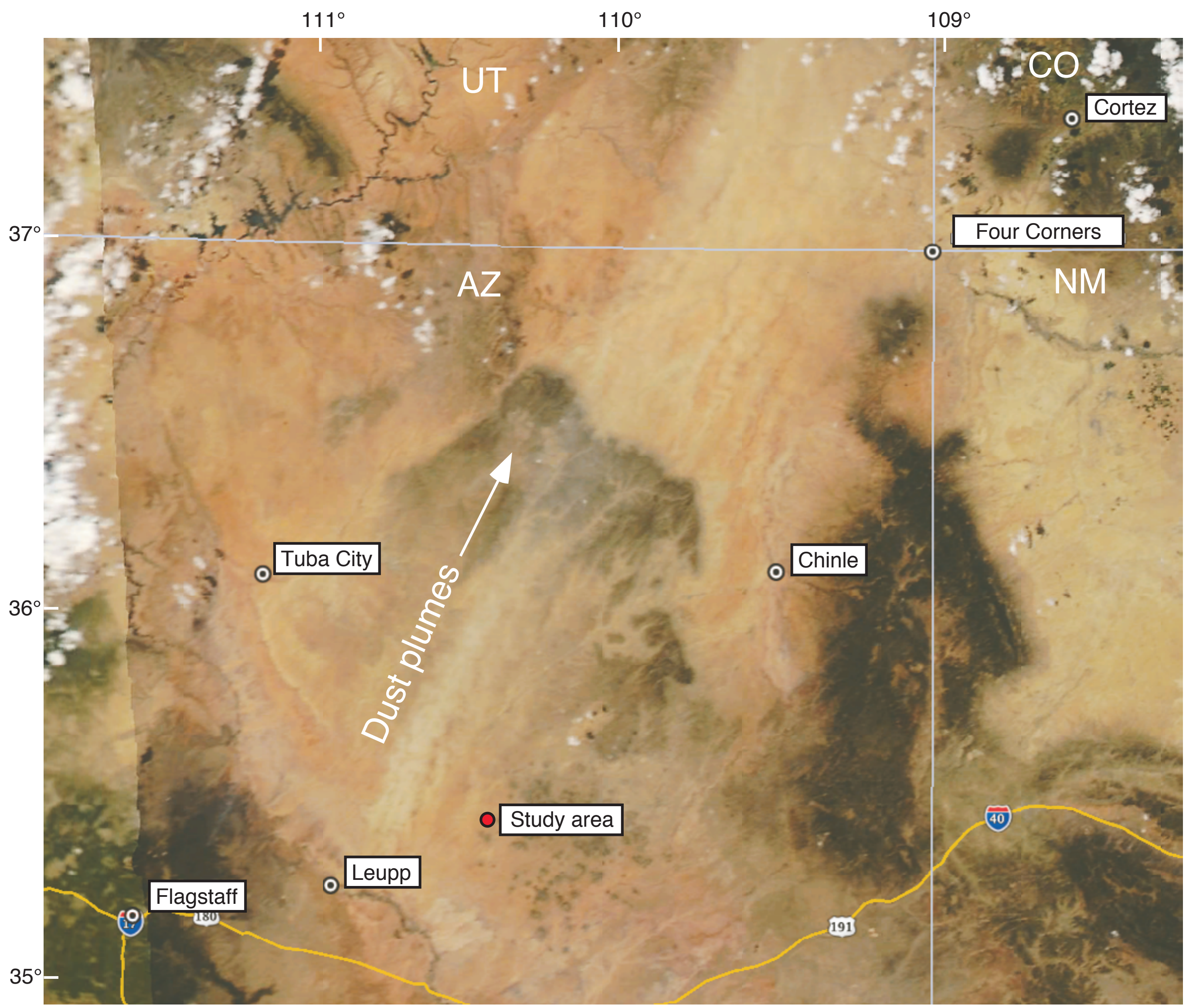

Figure 13. MODIS (Moderate Resolution Imaging Spectroradiometer) satellite image, showing eolian dust plumes that originated in northeastern Arizona, within the Navajo Nation, on the afternoon of May 29, 2011. From National Aeronautics and Space Administration, modified and posted online by the U.S. Geological Survey (2012).

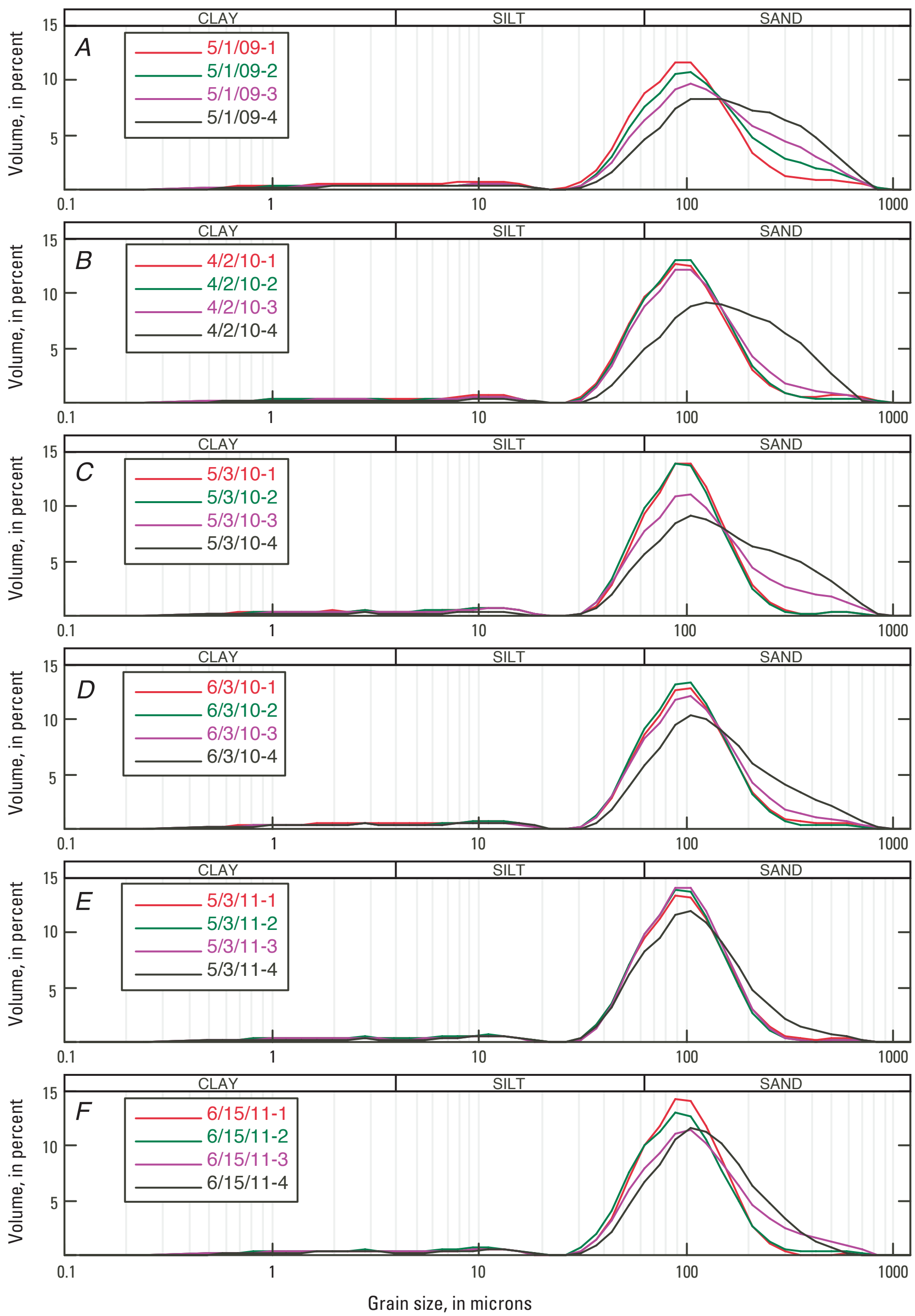

Figure 14. Particle-size data for 24 selected samples collected in Big Spring Number Eight (BSNE) sediment traps within the study area (fig. 1). All samples were obtained during spring, when wind speed is typically highest in this region. Samples were collected on *A*, May 1, 2009; *B*, April 2, 2010; *C*, May 3, 2010; *D*, June 3, 2010; *E*, May 3, 2011; and *F*, June 15, 2011. Numbers 1–4 after sample date indicate position of BSNE trap from which sample was collected, where 1 is uppermost and 4 is lowermost.

Conclusions

On the Navajo Nation, decreasing perennial streamflow and warming, drying trends have led to eolian sediment mobilization that affects air quality, housing, and transportation and potentially reduces the albedo of the Rocky Mountains snowpack downwind. Initial results of an intended long-term monitoring program in a 0.2-km^2 study area near Teesto Wash on the southern Navajo Nation indicate that sand mobility decreased substantially as one year (2010) with near-normal monsoon rainfall somewhat abated a decade-long drought, temporarily doubling vegetation cover. Perennial plants that grew during the same year with adequate monsoon rainfall died off rapidly during a subsequent dry year (2011). The proportion of bare, open sand area increased steadily after the short-term vegetation growth of summer 2010 began to die. Measurements in the study area have shown substantially greater vegetation cover during a year when the ENSO cycle was in the El Niño phase than during several years in the La Niña phase. Isolated seasonal increases in rainfall will not improve landscape stability in the long term because a sustained increase in perennial-plant cover, more effective than annual plants at stabilizing sand against wind erosion, requires multiple consecutive seasons of adequate rain. Climate projections suggest that warmer, drier conditions during the coming decades could potentially enhance eolian sediment supply after flash floods in otherwise dry, ephemeral washes. Such conditions could combine to decrease vegetation cover and increase eolian sediment transport and dune activity, worsening the present challenges to people living in this region.

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Appendix 1. Supplementary Information

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.

[Coverage is given in terms of area and percentage within five circles of radius 3 m, as shown in figure 3]

Site 1

Vegetation	Area, in square meters	Percentage
Unidentified perennial grass	5.51	3.90
Mojave indigobush (*Psorothamnus arborescens*)	3.25	2.30
Snakeweed (*Gutierrezia sarothrae*)	2.32	1.64
Rabbitbrush (*Ericameria nauseosus*)	0.71	0.50
Unidentified aster (*Asteraceae* family)	0.28	0.20
Saltbush (*Atriplex canescens*)	0.14	0.10
Unidentified shrub, dead	0.14	0.10
Narrowleaf yucca (*Yucca angustissima*)	0.06	0.04
Russian thistle (*Salsola* sp.)	0.03	0.02
Total vegetation cover	12.4	8.8
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		91.4
Mean basal gap length, in centimeters		1,000

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 2

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	11.3	8.00
Snakeweed (*Gutierrezia sarothrae*)	4.24	3.00
Unidentified perennial grass	2.54	1.80
Unidentified shrub, dead	1.58	1.12
Rabbitbrush (*Ericameria nauseosus*)	1.56	1.10
Basin wildrye (*Leymus cinereus*)	0.14	0.10
Russian thistle (*Salsola* sp.)	0.14	0.10
Total vegetation cover	21.5	15.2
Substrate	**Area, in square meters**	**Percentage**
Sand	141	99.9
Rock	0.08	0.06
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		89.5
Mean basal gap length, in centimeters		1,000

Site 3

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	11.5	8.10
Rabbitbrush (*Ericameria nauseosus*)	2.83	2.00
Unidentified perennial grass	2.77	1.96
Unidentified shrub, dead	1.19	0.84
Snakeweed (*Gutierrezia sarothrae*)	0.96	0.68
Russian thistle (*Salsola* sp.)	0.45	0.32
Total vegetation cover	19.7	13.9
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		75.2
Mean basal gap length, in centimeters		222

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 4

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	16.1	11.4
Snakeweed (*Gutierrezia sarothrae*)	1.75	1.24
Russian thistle (*Salsola* sp.)	1.05	0.74
Unidentified perennial grass	0.62	0.44
Rabbitbrush (*Ericameria nauseosus*)	0.51	0.36
Unidentified shrub, dead	0.14	0.10
Total vegetation cover	20.2	14.3
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		81.4
Mean basal gap length, in centimeters		500

Site 5

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	11.3	8.00
Mojave indigobush (*Psorothamnus arborescens*)	5.94	4.20
Snakeweed (*Gutierrezia sarothrae*)	3.96	2.80
Unidentified perennial grass	0.31	0.22
Unidentified shrub, dead	0.14	0.10
Russian thistle (*Salsola* sp.)	0.08	0.06
Total vegetation cover	21.7	15.4
Substrate	**Area, in square meters**	**Percentage**
Sand	140	99.3
Rock	1.02	0.72
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		83.8
Mean basal gap length, in centimeters		500

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 6

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	9.19	6.50
Rabbitbrush (*Ericameria nauseosus*)	4.24	3.00
Snakeweed (*Gutierrezia sarothrae*)	2.21	1.56
Unidentified perennial grass	1.13	0.80
Unidentified shrub, dead	0.85	0.60
Russian thistle (*Salsola* sp.)	0.74	0.52
Total vegetation cover	18.4	13.0
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0.03	0.02
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		83.7
Mean basal gap length, in centimeters		500

Site 7

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	23.9	16.9
Mojave indigobush (*Psorothamnus arborescens*)	10.0	7.10
Unidentified perennial grass	1.19	0.84
Russian thistle (*Salsola* sp.)	0.28	0.20
Snakeweed (*Gutierrezia sarothrae*)	0.25	0.18
Saltbush (*Atriplex canescens*)	0.20	0.14
Total vegetation cover	35.9	25.4
Substrate	**Area, in square meters**	**Percentage**
Sand	133	93.9
Rock	8.65	6.12
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		81.9
Mean basal gap length, in centimeters		1,000

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 8

Vegetation	Area, in square meters	Percentage
Unidentified perennial grass	3.39	2.40
Russian thistle (*Salsola* sp.)	2.69	1.90
Snakeweed (*Gutierrezia sarothrae*)	1.72	1.22
Total vegetation cover	7.80	5.52
Substrate	**Area, in square meters**	**Percentage**
Sand	141	99.4
Rock	0.11	0.08
Leaf litter	0.71	0.50
Biologic soil crust	0	0
Total gap length, in percent		95.8
Mean basal gap length, in centimeters		2,000

Site 9

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	12.2	8.60
Undifferentiated shrubs, live	6.22	4.40
Unidentified shrubs, dead	3.39	2.40
Rabbitbrush (*Ericameria nauseosus*)	0.42	0.30
Unidentified perennial grass	0.06	0.04
Snakeweed (*Gutierrezia sarothrae*)	0.03	0.02
Total vegetation cover	22.3	15.8
Substrate	**Area, in square meters**	**Percentage**
Sand	111	78.4
Rock	14.4	10.2
Leaf litter	1.13	0.80
Biologic soil crust	15.0	10.6
Total gap length, in percent		69.1
Mean basal gap length, in centimeters		571

Table 3. Vegetation cover and substrate measured in March 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 10

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	7.92	5.60
Mojave indigobush (*Psorothamnus arborescens*)	4.67	3.30
Unidentified shrubs, dead	0.85	0.60
Snakeweed (*Gutierrezia sarothrae*)	0.28	0.20
Unidentified perennial grass	0.11	0.08
Total vegetation cover	13.8	9.78
Substrate	**Area, in square meters**	**Percentage**
Sand	129	91.1
Rock	11.3	8.00
Leaf litter	1.33	0.94
Biologic soil crust	0	0
Total gap length, in percent		88.8
Mean basal gap length, in centimeters		489

Site 11

Vegetation	Area, in square meters	Percentage
Snakeweed (*Gutierrezia sarothrae*)	0.57	0.40
Unidentified perennial grass	0.08	0.06
Mojave indigobush (*Psorothamnus arborescens*)	3.68	2.60
Unidentified shrubs, dead	1.44	1.02
Undifferentiated shrubs, live	19.8	14.0
Russian thistle (*Salsola* sp.)	0.25	0.18
Total vegetation cover	25.8	18.3
Substrate	**Area, in square meters**	**Percentage**
Sand	140	98.9
Rock	0	0
Leaf litter	1.56	1.10
Biologic soil crust	0	0
Total gap length, in percent		75.3
Mean basal gap length, in centimeters		571

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.

[Coverage is given in terms of area and percentage within five circles of radius 3 m, as shown in figure 3]

Site 1

Vegetation	Area, in square meters	Percentage
Alkali sacoton (*Sporobolus airoides*)	11.5	8.10
Mojave indigobush (*Psorothamnus arborescens*)	3.78	2.68
Russian thistle (*Salsola* sp.)	3.78	2.68
Plains spring parsley (*Cymopterus acaulis*)	1.48	1.05
Indian ricegrass (*Oryzopsis hymenoides*)	1.45	1.03
Unidentified shrub, dead	1.27	0.90
Rabbitbrush (*Ericameria nauseosus*)	1.20	0.85
Sandhill muhly (*Muhlenbergia pungens*)	0.85	0.60
Stickleaf (*Mentzelia pumila*)	0.85	0.60
Purple three-awn (*Aristida purpurea*)	0.71	0.50
Narrowleaf yucca (*Yucca angustissima*)	0.57	0.40
Dicoria (*Dicoria canescens*)	0.35	0.25
Doveweed (*Croton texensis*)	0.18	0.13
Unidentified annual forb	0.14	0.10
Galleta grass (*Pleuraphis jamesii*)	0.14	0.10
Greene's rabbitbrush (*Chrysothamnus greenei*)	0.14	0.10
Snakeweed (*Gutierrezia sarothrae*)	0.07	0.05
Giant dropseed (*Sporobolus giganteus*)	0.07	0.05
Sand verbena (*Abronia fragrans*)	0.07	0.05
Milkweed (*Asclepias* sp.)	0.07	0.05
Total vegetation cover	28.6	20.3
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0.60	0.43
Biologic soil crust	0	0
Total gap length, in percent		57.3
Mean basal gap length, in centimeters		87

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 2

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	6.79	4.80
Unidentified shrub, dead	3.78	2.68
Russian thistle (*Salsola* sp.)	3.25	2.30
Stickleaf (*Mentzelia pumila*)	2.69	1.90
Rabbitbrush (*Ericameria nauseosus*)	1.84	1.30
Indian ricegrass (*Oryzopsis hymenoides*)	1.41	1.00
Plains spring parsley (*Cymopterus acaulis*)	1.34	0.95
Sandhill muhly (*Muhlenbergia pungens*)	1.17	0.83
Alkali sacoton (*Sporobolus airoides*)	0.99	0.70
Galleta grass (*Pleuraphis jamesii*)	0.57	0.40
Doveweed (*Croton texensis*)	0.49	0.35
Snakeweed (*Gutierrezia sarothrae*)	0.46	0.33
Dicoria (*Dicoria canescens*)	0.42	0.30
Bindweed heliotrope (*Heliotropium convolvulaceum*)	0.21	0.15
Unidentified annual forb	0.14	0.10
Wire lettuce (*Stephanomeria pauciflora*)	0.14	0.10
Total vegetation cover	25.7	18.2
Substrate	**Area, in square meters**	**Percentage**
Sand	141	99.9
Rock	0	0
Leaf litter	0.18	0.13
Biologic soil crust	0	0
Total gap length, in percent		65.3
Mean basal gap length, in centimeters		125

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 3

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	16.5	11.7
Russian thistle (*Salsola* sp.)	6.29	4.45
Rabbitbrush (*Ericameria nauseosus*)	5.02	3.55
Stickleaf (*Mentzelia pumila*)	2.90	2.05
Sandhill muhly (*Muhlenbergia pungens*)	2.26	1.60
Giant dropseed (*Sporobolus giganteus*)	2.23	1.58
Plains spring parsley (*Cymopterus acaulis*)	1.41	1.00
Unidentified shrub, dead	1.27	0.90
Indian ricegrass (*Oryzopsis hymenoides*)	0.59	0.42
Doveweed (*Croton texensis*)	0.57	0.40
Dicoria (*Dicoria canescens*)	0.30	0.21
Snakeweed (*Gutierrezia sarothrae*)	0.28	0.20
Galleta grass (*Pleuraphis jamesii*)	0.18	0.13
Alkali sacoton (*Sporobolus airoides*)	0.14	0.10
Globemallow (*Sphaeralcea sp.*)	0.14	0.10
Unidentified annual grass	0.11	0.08
Total vegetation cover	40.2	28.5
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0.14	0.10
Biologic soil crust	0	0
Total gap length, in percent		62.4
Mean basal gap length, in centimeters		121

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 4

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	19.4	13.7
Russian thistle (*Salsola* sp.)	10.6	7.50
Stickleaf (*Mentzelia pumila*)	9.19	6.50
Rabbitbrush (*Ericameria nauseosus*)	2.26	1.60
Doveweed (*Croton texensis*)	1.41	1.00
Silverleaf nightshade (*Solanum elaeagnifolium*)	1.20	0.85
Bindweed heliotrope (*Heliotropium convolvulaceum*)	1.15	0.81
Unidentified forb, dead	1.13	0.80
Indian ricegrass (*Oryzopsis hymenoides*)	0.98	0.69
Plains spring parsley (*Cymopterus acaulis*)	0.95	0.67
Unidentified annual grass	0.71	0.50
Snakeweed (*Gutierrezia sarothrae*)	0.57	0.40
Globemallow (*Sphaeralcea sp.*)	0.49	0.35
Unidentified perennial grasses	0.49	0.35
Dicoria (*Dicoria canescens*)	0.23	0.16
Sandhill muhly (*Muhlenbergia pungens*)	0.14	0.10
Unidentified shrubs, dead	0.14	0.10
Spike dropseed (*Sporobolus contractus*)	0.07	0.05
Galleta grass (*Pleuraphis jamesii*)	0.04	0.03
Total vegetation cover	51.2	36.2
Substrate	**Area, in square meters**	**Percentage**
Sand	141.32	99.96
Rock	0.06	0.04
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		64.0
Mean basal gap length, in centimeters		143

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 5

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	13.3	9.40
Stickleaf (*Mentzelia pumila*)	11.2	7.90
Rabbitbrush (*Ericameria nauseosus*)	7.63	5.40
Silverleaf nightshade (*Solanum elaeagnifolium*)	6.29	4.45
Snakeweed (*Gutierrezia sarothrae*), dead	3.89	2.75
Plains spring parsley (*Cymopterus acaulis*)	3.82	2.70
Doveweed (*Croton texensis*)	3.34	2.36
Russian thistle (*Salsola* sp.)	2.47	1.75
Bindweed heliotrope (*Heliotropium convolvulaceum*)	1.41	1.00
Unidentified perennial grass	0.85	0.60
Indian ricegrass (*Oryzopsis hymenoides*)	0.59	0.42
Unidentified annual grass	0.54	0.38
Snakeweed (*Gutierrezia* sp.)	0.49	0.35
Dicoria (*Dicoria canescens*)	0.11	0.08
Unidentified annual forb	0.08	0.06
Total vegetation cover	56.0	39.6
Substrate	**Area, in square meters**	**Percentage**
Sand	141	100
Rock	0	0
Leaf litter	0	0
Biologic soil crust	0	0
Total gap length, in percent		61.3
Mean basal gap length, in centimeters		267

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 6

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	23.5	16.6
Stickleaf (*Mentzelia pumila*)	11.6	8.20
Russian thistle (*Salsola* sp.)	10.9	7.70
Plains spring parsley (*Cymopterus acaulis*)	7.35	5.20
Doveweed (*Croton texensis*)	3.25	2.30
Rabbitbrush (*Ericameria nauseosus*)	3.25	2.30
Indian ricegrass (*Oryzopsis hymenoides*)	1.34	0.95
Unidentified annual forb	1.27	0.90
Unidentified dead plant	0.92	0.65
Sand dropseed (*Sporobolus cryptandrus*)	0.71	0.50
Giant dropseed (*Sporobolus giganteus*)	0.14	0.10
Alkali sacoton (*Sporobolus airoides*)	0.07	0.05
Galleta grass (*Pleuraphis jamesii*)	0.04	0.03
Total vegetation cover	64.3	45.5
Substrate	**Area, in square meters**	**Percentage**
Sand	141.1	99.8
Rock	0	0
Leaf litter	0.28	0.20
Biologic soil crust	0	0
Total gap length, in percent		61.7
Mean basal gap length, in centimeters		148

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 7

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	22.3	15.8
Mojave indigobush (*Psorothamnus arborescens*)	5.94	4.20
Sandhill muhly (*Muhlenbergia pungens*)	5.09	3.60
Stickleaf (*Mentzelia pumila*)	4.17	2.95
Russian thistle (*Salsola* sp.)	3.65	2.58
Plains spring parsley (*Cymopterus acaulis*)	2.40	1.70
Doveweed (*Croton texensis*)	2.33	1.65
Giant dropseed (*Sporobolus giganteus*)	1.41	1.00
Indian ricegrass (*Oryzopsis hymenoides*)	1.17	0.83
Alkali sacoton (*Sporobolus airoides*)	0.85	0.60
Unidentified dead plants	0.71	0.50
Sand dropseed (*Sporobolus cryptandrus*)	0.65	0.46
Unidentified annual grass	0.57	0.40
Ephedra (*Ephedra* sp.)	0.42	0.30
Saltbush (*Atriplex canescens*)	0.42	0.30
Dicoria (*Dicoria canescens*)	0.14	0.10
Snakeweed (*Gutierrezia sarothrae*)	0.08	0.06
Total vegetation cover	52.3	37.0
Substrate	**Area, in square meters**	**Percentage**
Sand	132	93.6
Rock	7.49	5.30
Leaf litter	1.56	1.10
Biologic soil crust	0	0
Total gap length, in percent		48.4
Mean basal gap length, in centimeters		103

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 8

Vegetation	Area, in square meters	Percentage
Silverleaf nightshade (*Solanum elaeagnifolium*)	22.5	15.9
Russian thistle (*Salsola* sp.)	11.9	8.40
Sand dropseed (*Sporobolus cryptandrus*)	10.0	7.10
Doveweed (*Croton texensis*)	6.36	4.50
Unidentified dead plants	0.99	0.70
Unidentified perennial grass	0.57	0.40
Pigweed (*Amaranthus* sp.)	0.14	0.10
Sandhill muhly (*Muhlenbergia pungens*)	0.14	0.10
Bindweed heliotrope (*Heliotropium convolvulaceum*)	0.04	0.03
Total vegetation cover	52.6	37.2
Substrate	**Area, in square meters**	**Percentage**
Sand	138	97.7
Rock	0.28	0.20
Leaf litter	2.97	2.10
Biologic soil crust	0	0
Total gap length, in percent		58.7
Mean basal gap length, in centimeters		108

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 9

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	17.8	12.6
Rabbitbrush (*Ericameria nauseosus*)	9.61	6.80
Unidentified annual forbs	6.22	4.40
Stickleaf (*Mentzelia pumila*)	4.81	3.40
Unidentified dead plants	3.53	2.50
Unidentified dead shrub	1.27	0.90
Doveweed (*Croton texensis*)	0.95	0.68
Unidentified annual grass	0.68	0.48
Russian thistle (*Salsola* sp.)	0.52	0.37
Plains spring parsley (*Cymopterus acaulis*)	0.14	0.10
Globemallow (*Sphaeralcea sp.*)	0.10	0.07
Total vegetation cover	45.7	32.3
Substrate	**Area, in square meters**	**Percentage**
Sand	78.8	55.8
Rock	24.3	17.2
Leaf litter	3.25	2.30
Biologic soil crust	35.0	24.8
Total gap length, in percent		6.28
Mean basal gap length, in centimeters		444

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 10

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	15.6	11.0
Stickleaf (*Mentzelia pumila*)	7.35	5.20
Mojave indigobush (*Psorothamnus arborescens*)	6.64	4.70
Unidentified dead shrubs	3.11	2.20
Russian thistle (*Salsola* sp.)	2.12	1.50
Plains spring parsley (*Cymopterus acaulis*)	1.27	0.90
Unidentified perennial grass	0.85	0.60
Unidentified dead plants	0.71	0.50
Unidentified annual forb	0.42	0.30
Unidentified annual forb (second)	0.42	0.30
Snakeweed (*Gutierrezia sarothrae*)	0.28	0.20
Indian ricegrass (*Oryzopsis hymenoides*)	0.14	0.10
Doveweed (*Croton texensis*)	0.14	0.10
Pigweed (*Amaranthus* sp.)	0.07	0.05
Milkvetch (*Astragalus* sp.)	0.07	0.05
Total vegetation cover	39.2	27.7
Substrate	**Area, in square meters**	**Percentage**
Sand	130	92.1
Rock	10.5	7.40
Leaf litter	0.71	0.50
Biologic soil crust	0	0
Total gap length, in percent		13.0
Mean basal gap length, in centimeters		666

Table 4. Vegetation cover and substrate measured in August 2010 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 11

Vegetation	Area, in square meters	Percentage
Unidentified annual forb	14.1	10.0
Stickleaf (*Mentzelia pumila*)	12.2	8.60
Russian thistle (*Salsola* sp.)	11.5	8.10
Mojave indigobush (*Psorothamnus arborescens*)	9.90	7.00
Unidentified annual forb (second)	3.39	2.40
Unidentified dead plants	2.54	1.80
Plains spring parsley (*Cymopterus acaulis*)	1.34	0.95
Indian ricegrass (*Oryzopsis hymenoides*)	0.85	0.60
Unidentified perennial grass	0.57	0.40
Bindweed heliotrope (*Heliotropium convolvulaceum*)	0.35	0.25
Sand dropseed (*Sporobolus cryptandrus*)	0.14	0.10
Total vegetation cover	56.8	40.2
Substrate	**Area, in square meters**	**Percentage**
Sand	139.8	98.9
Rock	0	0
Leaf litter	1.56	1.10
Biologic soil crust	0	0
Total gap length, in percent		61.6
Mean basal gap length, in centimeters		200

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.

[Coverage is given in terms of area and percentage within five circles of radius 3 m, as shown in figure 3]

Site 1

Vegetation	Area, in square meters	Percentage
Galleta grass (*Pleuraphis jamesii*)	13.9	9.80
Mojave indigobush (*Psorothamnus arborescens*)	2.54	1.80
Russian thistle (*Salsola* sp.)	1.91	1.35
Stickleaf (*Mentzelia pumila*)	1.63	1.15
Sandhill muhly (*Muhlenbergia pungens*)	0.85	0.60
Indian ricegrass (*Oryzopsis hymenoides*)	0.83	0.59
Rabbitbrush (*Ericameria nauseosus*)	0.71	0.50
Snakeweed (*Gutierrezia sarothrae*), live	0.61	0.43
Snakeweed (*Gutierrezia sarothrae*), dead	0.57	0.40
Narrowleaf yucca (*Yucca angustissima*)	0.42	0.30
Saltbush (*Atriplex canescens*)	0.42	0.30
Sand dropseed (*Sporobolus cryptandrus*)	0.20	0.14
Unidentified perennial grass, dead	0.14	0.10
Sand verbena (*Abronia fragrans*)	0.08	0.06
Unidentified forb	0.07	0.05
Total vegetation cover	24.8	17.6
Substrate	**Area, in square meters**	**Percentage**
Sand	139.1	98.4
Rock	0.00	0.00
Leaf litter	2.26	1.60
Biologic soil crust	0.00	0.00
Russian-thistle litter	0.71	0.50
Total gap length, in percent		70.1
Mean basal gap length, in centimeters		133

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 2

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	12.6	8.90
Russian thistle (*Salsola* sp.)	4.59	3.25
Rabbitbrush (*Ericameria nauseosus*)	3.68	2.60
Sandhill muhly (*Muhlenbergia pungens*)	3.32	2.35
Indian ricegrass (*Oryzopsis hymenoides*)	2.12	1.50
Stickleaf (*Mentzelia pumila*)	1.89	1.34
Snakeweed (*Gutierrezia sarothrae*), dead	1.70	1.20
Galleta grass (*Pleuraphis jamesii*)	1.41	1.00
Unidentified shrub, dead	1.27	0.90
Unidentified perennial forb	0.71	0.5
Giant dropseed (*Sporobolus giganteus*)	0.61	0.43
Snakeweed (*Gutierrezia sarothrae*), live	0.48	0.34
Total vegetation cover	34.4	24.3
Substrate	**Area, in square meters**	**Percentage**
Sand	137	97.0
Rock	0	0
Leaf litter	4.24	3.00
Biologic soil crust	0	0
Russian-thistle litter	2.83	2.00
Total gap length, in percent		79.4
Mean basal gap length, in centimeters		222

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 3

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	16.7	11.8
Russian thistle (*Salsola* sp.)	5.80	4.10
Rabbitbrush (*Ericameria nauseosus*)	4.03	2.85
Indian ricegrass (*Oryzopsis hymenoides*)	2.33	1.65
Stickleaf (*Mentzelia pumila*)	2.12	1.50
Sandhill muhly (*Muhlenbergia pungens*)	1.84	1.30
Giant dropseed (*Sporobolus giganteus*)	1.29	0.91
Unidentified plant	0.64	0.45
Galleta grass (*Pleuraphis jamesii*)	0.57	0.40
Snakeweed (*Gutierrezia sarothrae*)	0.28	0.20
Total vegetation cover	35.6	25.2
Substrate	**Area, in square meters**	**Percentage**
Sand	138	97.8
Rock	0	0
Leaf litter	3.11	2.20
Biologic soil crust	0	0
Russian-thistle litter	4.67	3.30
Total gap length, in percent		52.2
Mean basal gap length, in centimeters		118

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 4

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	22.1	15.6
Russian thistle (*Salsola* sp.)	8.91	6.30
Stickleaf (*Mentzelia pumila*)	3.24	2.29
Indian ricegrass (*Oryzopsis hymenoides*)	1.07	0.76
Rabbitbrush (*Ericameria nauseosus*)	0.85	0.60
Snakeweed (*Gutierrezia sarothrae*), dead	0.28	0.20
Spike dropseed (*Sporobolus contractus*)	0.28	0.20
Plains spring parsley (*Cymopterus acaulis*)	0.03	0.02
Globemallow (*Sphaeralcea* sp.)	0.03	0.02
Total vegetation cover	36.7	26.0
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.3
Rock	0	0
Leaf litter	2.40	1.70
Biologic soil crust	0	0
Russian-thistle litter	10.3	7.30
Total gap length, in percent		58.6
Mean basal gap length, in centimeters		286

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 5

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	10.5	7.40
Mojave indigobush (*Psorothamnus arborescens*)	9.75	6.90
Stickleaf (*Mentzelia pumila*)	1.84	1.30
Russian thistle (*Salsola* sp.)	1.77	1.25
Snakeweed (*Gutierrezia sarothrae*), live	1.63	1.15
Snakeweed (*Gutierrezia sarothrae*), dead	0.57	0.40
Unidentified annual forb	0.49	0.35
Unidentified plant	0.42	0.30
Giant dropseed (*Sporobolus giganteus*)	0.28	0.20
Indian ricegrass (*Oryzopsis hymenoides*)	0.23	0.16
Silverleaf nightshade (*Solanum elaeagnifolium*)	0.07	0.05
Unidentified perennial grass	0.03	0.02
Plains spring parsley (*Cymopterus acaulis*)	0.03	0.02
Total vegetation cover	27.6	19.5
Substrate	**Area, in square meters**	**Percentage**
Sand	137	97.1
Rock	0	0
Leaf litter	3.96	2.80
Biologic soil crust	0	0
Russian-thistle litter	5.23	3.70
Total gap length, in percent		67.1
Mean basal gap length, in centimeters		400

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 6

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	8.48	6.00
Rabbitbrush (*Ericameria nauseosus*)	7.21	5.10
Russian thistle (*Salsola* sp.)	2.32	1.64
Stickleaf (*Mentzelia pumila*)	2.12	1.50
Sand dropseed (*Sporobolus cryptandrus*)	0.99	0.70
Giant dropseed (*Sporobolus giganteus*)	0.98	0.69
Indian ricegrass (*Oryzopsis hymenoides*)	0.68	0.48
Unidentified annual forb	0.57	0.40
Unidentified perennial forb	0.31	0.22
Rabbitbrush (*Ericameria nauseosus*), dead	0.28	0.20
Snakeweed (*Gutierrezia sarothrae*), dead	0.23	0.16
Unidentified plant	0.14	0.10
Grama grass (*Bouteloua sp.*)	0.08	0.06
Sandhill muhly (*Muhlenbergia pungens*)	0.07	0.05
Total vegetation cover	24.5	17.3
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.5
Rock	0	0
Leaf litter	1.98	1.40
Biologic soil crust	0	0
Russian-thistle litter	2.40	1.70
Total gap length, in percent		69.1
Mean basal gap length, in centimeters		400

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 7

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	13.9	9.80
Russian thistle (*Salsola* sp.)	4.21	2.98
Mojave indigobush (*Psorothamnus arborescens*)	3.96	2.80
Galleta grass (*Pleuraphis jamesii*)	3.39	2.40
Unidentified plant	0.85	0.60
Indian ricegrass (*Oryzopsis hymenoides*)	0.75	0.53
Sandhill muhly (*Muhlenbergia pungens*)	0.71	0.50
Ephedra (*Ephedra* sp.)	0.65	0.46
Giant dropseed (*Sporobolus giganteus*)	0.64	0.45
Stickleaf (*Mentzelia pumila*)	0.57	0.40
Sand dropseed (*Sporobolus cryptandrus*)	0.42	0.30
Saltbush (*Atriplex canescens*)	0.34	0.24
Snakeweed (*Gutierrezia sarothrae*)	0.14	0.10
Total vegetation cover	30.5	21.6
Substrate	**Area, in square meters**	**Percentage**
Sand	130	92.2
Rock	8.77	6.20
Leaf litter	2.26	1.60
Biologic soil crust	0	0
Russian-thistle litter	6.50	4.60
Total gap length, in percent		52.5
Mean basal gap length, in centimeters		222

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 8

Vegetation	Area, in square meters	Percentage
Sand dropseed (*Sporobolus cryptandrus*)	6.43	4.55
Russian thistle (*Salsola* sp.)	4.67	3.30
Galleta grass (*Pleuraphis jamesii*)	1.70	1.20
Unidentified plant	0.99	0.70
Unidentified perennial grass	0.57	0.40
Unidentified perennial forb	0.42	0.30
Silverleaf nightshade (*Solanum elaeagnifolium*)	0.28	0.20
Unidentified annual forb	0.14	0.10
Indian ricegrass (*Oryzopsis hymenoides*)	0.06	0.04
Globemallow (*Sphaeralcea* sp.)	0.06	0.04
Snakeweed (*Gutierrezia sarothrae*), dead	0.06	0.04
Total vegetation cover	15.4	10.9
Substrate	**Area, in square meters**	**Percentage**
Sand	137	96.6
Rock	0.59	0.42
Leaf litter	4.24	3.00
Biologic soil crust	0	0
Russian-thistle litter	1.84	1.30
Total gap length, in percent		75.3
Mean basal gap length, in centimeters		148

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 9

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	13.7	9.70
Rabbitbrush (*Ericameria nauseosus*)	2.26	1.60
Stickleaf (*Mentzelia pumila*)	1.87	1.32
Unidentified shrub, dead	1.13	0.80
Russian thistle (*Salsola* sp.)	0.85	0.60
Rabbitbrush (*Ericameria nauseosus*), dead	0.71	0.50
Grama grass (*Bouteloua* sp.)	0.49	0.35
Total vegetation cover	21.0	14.9
Substrate	**Area, in square meters**	**Percentage**
Sand	100	71.1
Rock	15.8	11.2
Leaf litter	2.90	2.05
Biologic soil crust	22.2	15.7
Russian-thistle litter	2.40	1.70
Total gap length, in percent		41.0
Mean basal gap length, in centimeters		1333

Site 10

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	11.7	8.30
Mojave indigobush (*Psorothamnus arborescens*)	6.36	4.50
Stickleaf (*Mentzelia pumila*)	1.98	1.40
Russian thistle (*Salsola* sp.)	1.41	1.00
Rabbitbrush (*Ericameria nauseosus*), dead	0.42	0.30
Ephedra (*Ephedra* sp.), dead	0.42	0.30
Indian ricegrass (*Oryzopsis hymenoides*)	0.20	0.14
Unidentified shrubs, dead	0.14	0.10
Total vegetation cover	22.7	16.0
Substrate	**Area, in square meters**	**Percentage**
Sand	123	86.9
Rock	14.4	10.2
Leaf litter	1.27	0.90
Biologic soil crust	2.83	2.00
Russian-thistle litter	0.71	0.50
Total gap length, in percent		58.5
Mean basal gap length, in centimeters		2000

Table 5. Vegetation cover and substrate measured in March 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 11

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	17.2	12.2
Russian thistle (*Salsola* sp.)	4.61	3.26
Stickleaf (*Mentzelia pumila*)	2.71	1.92
Rabbitbrush (*Ericameria nauseosus*)	2.26	1.60
Indian ricegrass (*Oryzopsis hymenoides*)	0.85	0.60
Unidentified forbs	0.37	0.26
Giant dropseed (*Sporobolus giganteus*)	0.28	0.20
Snakeweed (*Gutierrezia sarothrae*), dead	0.28	0.20
Sand dropseed (*Sporobolus cryptandrus*)	0.14	0.10
Unidentified aster (*Asteraceae* family)	0.08	0.06
Total vegetation cover	28.8	20.4
Substrate	**Area, in square meters**	**Percentage**
Sand	137	97.0
Rock	0	0
Leaf litter	4.10	2.90
Biologic soil crust	0.08	0.06
Russian-thistle litter	4.67	3.30
Total gap length, in percent		64.7
Mean basal gap length, in centimeters		444

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.

[Coverage is given in terms of area and percentage within five circles of radius 3 m, as shown in figure 3]

Site 1

Vegetation	Area, in square meters	Percentage
Unidentified perennial grass, dead	11.3	8.00
Mojave indigobush (*Psorothamnus arborescens*)	5.51	3.90
Sand dropseed (*Sporobolus cryptandrus*)	1.84	1.30
Sandhill muhly (*Muhlenbergia pungens*)	1.41	1.00
Russian thistle (*Salsola* sp.)	0.92	0.65
Saltbush (*Atriplex canescens*)	0.57	0.40
Narrowleaf yucca (*Yucca angustissima*)	0.57	0.40
Rabbitbrush (*Ericameria nauseosus*)	0.57	0.40
Stickleaf (*Mentzelia pumila*)	0.42	0.30
Indian ricegrass (*Oryzopsis hymenoides*)	0.42	0.30
Snakeweed (*Gutierrezia sarothrae*)	0.39	0.28
Unidentified shrub, dead	0.35	0.25
Alkali sacoton (*Sporobolus airoides*)	0.28	0.20
Snakeweed (*Gutierrezia* sp.), dead	0.14	0.10
Total vegetation cover	24.7	17.5
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.0
Rock	0	0
Leaf litter	2.83	2.00
Biologic soil crust	0	0
Russian-thistle litter	0.28	0.20
Total gap length, in percent		79.5
Mean basal gap length, in centimeters		129

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 2

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	9.90	7.00
Rabbitbrush (*Ericameria nauseosus*)	3.11	2.20
Sandhill muhly (*Muhlenbergia pungens*)	2.97	2.10
Unidentified perennial grass	1.91	1.35
Unidentified shrub, dead	1.13	0.80
Indian ricegrass (*Oryzopsis hymenoides*)	0.75	0.53
Russian thistle (*Salsola* sp.)	0.57	0.40
Stickleaf (*Mentzelia pumila*)	0.51	0.36
Snakeweed (*Gutierrezia sarothrae*)	0.39	0.28
Giant dropseed (*Sporobolus giganteus*)	0.35	0.25
Spike dropseed (*Sporobolus contractus*)	0.21	0.15
Unidentified perennial forb	0.14	0.10
Snakeweed (*Gutierrezia sarothrae*), dead	0.14	0.10
Unidentified perennial forb, dead	0.06	0.04
Total vegetation cover	22.1	15.7
Substrate	**Area, in square meters**	**Percentage**
Sand	138	97.8
Rock	0.85	0.60
Leaf litter	2.26	1.60
Biologic soil crust	0	0
Russian-thistle litter	1.98	1.40
Total gap length, in percent		74.1
Mean basal gap length, in centimeters		400

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 3

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	9.61	6.80
Sandhill muhly (*Muhlenbergia pungens*)	3.68	2.60
Rabbitbrush (*Ericameria nauseosus*)	2.97	2.10
Russian thistle (*Salsola* sp.)	2.76	1.95
Unidentified perennial grass	2.33	1.65
Indian ricegrass (*Oryzopsis hymenoides*)	1.06	0.75
Stickleaf (*Mentzelia pumila*)	0.85	0.60
Giant dropseed (*Sporobolus giganteus*)	0.57	0.40
Unidentified shrub, dead	0.14	0.10
Snakeweed (*Gutierrezia sarothrae*)	0.13	0.09
Spike dropseed (*Sporobolus contractus*)	0.07	0.05
Total vegetation cover	24.2	17.1
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.2
Rock	0	0
Leaf litter	2.54	1.80
Biologic soil crust	0	0
Russian-thistle litter	2.54	1.80
Total gap length, in percent		64.6
Mean basal gap length, in centimeters		191

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 4

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	20.4	14.4
Russian thistle (*Salsola* sp.)	3.60	2.55
Rabbitbrush (*Ericameria nauseosus*)	1.15	0.81
Stickleaf (*Mentzelia pumila*)	1.03	0.73
Indian ricegrass (*Oryzopsis hymenoides*)	0.49	0.35
Unidentified perennial grass	0.20	0.14
Snakeweed (*Gutierrezia sarothrae*), dead	0.07	0.05
Globemallow (*Sphaeralcea* sp.)	0.03	0.02
Total vegetation cover	26.9	19.1
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.0
Rock	0	0
Leaf litter	2.83	2.00
Biologic soil crust	0	0
Russian-thistle litter	3.11	2.20
Total gap length, in percent		70.1
Mean basal gap length, in centimeters		562

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 5

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	11.3	8.00
Mojave indigobush (*Psorothamnus arborescens*)	7.35	5.20
Russian thistle (*Salsola* sp.)	0.75	0.53
Snakeweed (*Gutierrezia sarothrae*)	0.57	0.40
Snakeweed (*Gutierrezia sarothrae*), dead	0.42	0.30
Silverleaf nightshade (*Solanum elaeagnifolium*)	0.37	0.26
Indian ricegrass (*Oryzopsis hymenoides*)	0.25	0.18
Unidentified perennial grass, dead	0.21	0.15
Giant dropseed (*Sporobolus giganteus*)	0.14	0.10
Stickleaf (*Mentzelia pumila*)	0.07	0.05
Unidentified perennial grass	0.04	0.03
Total vegetation cover	21.5	15.2
Substrate	**Area, in square meters**	**Percentage**
Sand	134	94.5
Rock	4.38	3.10
Leaf litter	3.32	2.35
Biologic soil crust	0	0
Russian-thistle litter	3.96	2.80
Total gap length, in percent		75.1
Mean basal gap length, in centimeters		571

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 6

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	9.19	6.50
Rabbitbrush (*Ericameria nauseosus*)	4.24	3.00
Russian thistle (*Salsola* sp.)	0.93	0.66
Unidentified perennial grass	0.89	0.63
Snakeweed (*Gutierrezia sarothrae*)	0.85	0.60
Unidentified shrub, dead	0.71	0.50
Unidentified annual plants, dead	0.57	0.40
Giant dropseed (*Sporobolus giganteus*)	0.17	0.12
Indian ricegrass (*Oryzopsis hymenoides*)	0.16	0.12
Snakeweed (*Gutierrezia sarothrae*), dead	0.14	0.10
Stickleaf (*Mentzelia pumila*)	0.10	0.07
Total vegetation cover	17.9	12.7
Substrate	**Area, in square meters**	**Percentage**
Sand	137	97.2
Rock	1.98	1.40
Leaf litter	1.98	1.40
Biologic soil crust	0	0
Russian-thistle litter	2.33	1.65
Total gap length, in percent		63.8
Mean basal gap length, in centimeters		444

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 7

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	9.19	6.50
Rabbitbrush (*Ericameria nauseosus*)	9.19	6.50
Unidentified perennial grass	1.70	1.20
Russian thistle (*Salsola* sp.)	1.34	0.95
Unidentified annual plants, dead	0.85	0.60
Sandhill muhly (*Muhlenbergia pungens*)	0.42	0.30
Saltbush (*Atriplex canescens*)	0.42	0.30
Sand dropseed (*Sporobolus cryptandrus*)	0.42	0.30
Snakeweed (*Gutierrezia sarothrae*)	0.42	0.30
Ephedra (*Ephedra* sp.)	0.35	0.25
Giant dropseed (*Sporobolus giganteus*)	0.35	0.25
Indian ricegrass (*Oryzopsis hymenoides*)	0.28	0.20
Total vegetation cover	25.0	17.7
Substrate	**Area, in square meters**	**Percentage**
Sand	126	89.3
Rock	10.7	7.55
Leaf litter	4.52	3.20
Biologic soil crust	0	0
Russian-thistle litter	5.51	3.90
Total gap length, in percent		57.6
Mean basal gap length, in centimeters		400

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 8

Vegetation	Area, in square meters	Percentage
Sand dropseed (*Sporobolus cryptandrus*)	8.62	6.10
Russian thistle (*Salsola* sp.)	8.34	5.90
Unidentified perennial grass	3.68	2.60
Silverleaf nightshade (*Solanum elaeagnifolium*)	1.29	0.91
Total vegetation cover	21.9	15.5
Substrate	**Area, in square meters**	**Percentage**
Sand	127	90.1
Rock	3.28	2.32
Leaf litter	10.7	7.60
Biologic soil crust	0	0
Russian-thistle litter	0.14	0.10
Total gap length, in percent		88.7
Mean basal gap length, in centimeters		167

Site 9

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	14.6	10.3
Rabbitbrush (*Ericameria nauseosus*)	2.83	2.00
Russian thistle (*Salsola* sp.)	0.23	0.16
Unidentified shrub, dead	2.54	1.80
Unidentified perennial forb, dead	0.14	0.10
Stickleaf (*Mentzelia pumila*)	0.28	0.20
Total vegetation cover	20.6	14.6
Substrate	**Area, in square meters**	**Percentage**
Sand	97.7	69.1
Rock	10.2	7.20
Leaf litter	6.64	4.70
Biologic soil crust	26.9	19.0
Russian-thistle litter	2.40	1.70
Total gap length, in percent		34.6
Mean basal gap length, in centimeters		2000

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 10

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	8.48	6.00
Rabbitbrush (*Ericameria nauseosus*)	7.86	5.56
Russian thistle (*Salsola* sp.)	1.19	0.84
Stickleaf (*Mentzelia pumila*)	0.57	0.40
Unidentified shrub, dead	0.57	0.40
Unidentified perennial grass	0.03	0.02
Globemallow (*Sphaeralcea sp.*)	0.03	0.02
Indian ricegrass (*Oryzopsis hymenoides*)	0.31	0.22
Snakeweed (*Gutierrezia* sp.)	0.14	0.10
Total vegetation cover	19.2	13.6
Substrate	**Area, in square meters**	**Percentage**
Sand	132	93.4
Rock	7.63	5.40
Leaf litter	1.70	1.20
Biologic soil crust	0	0
Russian-thistle litter	2.12	1.50
Total gap length, in percent		51.2
Mean basal gap length, in centimeters		571

Table 6. Vegetation cover and substrate measured in August 2011 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 11

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	18.5	13.1
Stickleaf (*Mentzelia pumila*)	1.22	0.86
Russian thistle (*Salsola* sp.)	1.22	0.86
Indian ricegrass (*Oryzopsis hymenoides*)	0.62	0.44
Unidentified shrub, dead	0.57	0.40
Rabbitbrush (*Ericameria nauseosus*)	0.28	0.20
Giant dropseed (*Sporobolus giganteus*)	0.28	0.20
Unidentified perennial grass, dead	0.17	0.12
Unidentified aster (*Asteraceae* family)	0.08	0.06
Total vegetation cover	23.0	16.2
Substrate	**Area, in square meters**	**Percentage**
Sand	137	96.6
Rock	0	0
Leaf litter	4.81	3.40
Biologic soil crust	0	0
Russian-thistle litter	1.98	1.40
Total gap length, in percent		62.2
Mean basal gap length, in centimeters		500

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.

[Coverage is given in terms of area and percentage within five circles of radius 3 m, as shown in figure 3]

Site 1

Vegetation	Area, in square meters	Percentage
Unidentified perennial grass	8.91	6.30
Mojave indigobush (*Psorothamnus arborescens*)	4.24	30.00
Sandhill muhly (*Muhlenbergia pungens*)	2.46	1.74
Stickleaf (*Mentzelia pumila*)	0.91	0.64
Rabbitbrush (*Ericameria nauseosus*)	0.64	0.45
Snakeweed (*Gutierrezia sarothrae*)	0.57	0.40
Narrowleaf yucca (*Yucca angustissima*)	0.57	0.40
Unidentified shrub, dead	0.49	0.35
Russian thistle (*Salsola* sp.), dead	0.48	0.34
Indian ricegrass (*Oryzopsis hymenoides*)	0.37	0.26
Saltbush (*Atriplex canescens*)	0.14	0.10
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	trace	trace
Total vegetation cover	19.8	14.0
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.0
Rock	0	0
Leaf litter	2.83	2.00
Biologic soil crust	0	0
Russian-thistle litter		0.20
Total gap length, in percent		82.8
Mean basal gap length, in centimeters		114

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 2

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	10.9	7.70
Sandhill muhly (*Muhlenbergia pungens*)	5.94	4.20
Rabbitbrush (*Ericameria nauseosus*)	2.83	2.00
Indian ricegrass (*Oryzopsis hymenoides*)	2.26	1.60
Shrub, unidentified, dead	1.63	1.15
Russian thistle (*Salsola* sp.), dead	1.36	0.96
Snakeweed (*Gutierrezia sarothrae*)	0.81	0.57
Unidentified perennial grass	0.79	0.56
Stickleaf (*Mentzelia pumila*)	0.62	0.44
Giant dropseed (*Sporobolus giganteus*)	0.11	0.08
Milkvetch (*Astragalus* sp.)	0.02	0.01
Unidentified annual forb	0.01	0.004
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.01	0.004
Total vegetation cover	27.3	19.3
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.0
Rock	0	0
Leaf litter	2.83	2.00
Biologic soil crust	0	0
Russian-thistle litter	2.04	1.44
Total gap length, in percent		86.3
Mean basal gap length, in centimeters		267

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 3

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	15.7	11.1
Rabbitbrush (*Ericameria nauseosus*)	7.63	5.40
Stickleaf (*Mentzelia pumila*)	3.87	2.74
Russian thistle (*Salsola* sp.), dead	1.13	0.80
Unidentified perennial grass	0.99	0.70
Snakeweed (*Gutierrezia sarothrae*), dead	0.99	0.70
Indian ricegrass (*Oryzopsis hymenoides*)	0.78	0.55
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.44	0.31
Giant dropseed (*Sporobolus giganteus*)	0.28	0.20
Unidentified shrub, dead	0.17	0.12
Unidentified annual forb	0.12	0.08
Plains spring parsley (*Cymopterus acaulis*)	0.003	0.002
Total vegetation cover	32.1	22.7
Substrate	**Area, in square meters**	**Percentage**
Sand	137	96.7
Rock	2.83	2.00
Leaf litter	1.84	1.30
Biologic soil crust	0	0
Russian-thistle litter	2.01	1.42
Total gap length, in percent		68.9
Mean basal gap length, in centimeters		211

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 4

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	22.9	16.2
Stickleaf (*Mentzelia pumila*)	5.51	3.90
Rabbitbrush (*Ericameria nauseosus*)	3.39	2.40
Russian thistle (*Salsola* sp.), dead	3.14	2.22
Indian ricegrass (*Oryzopsis hymenoides*)	1.10	0.78
Unidentified shrub, dead	0.28	0.20
Unidentified perennial grass	0.20	0.14
Giant dropseed (*Sporobolus giganteus*)	0.14	0.10
Globemallow (*Sphaeralcea sp.*)	0.11	0.08
Plains spring parsley (*Cymopterus acaulis*)	0.10	0.07
Snakeweed (*Gutierrezia sarothrae*), dead	0.07	0.05
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.07	0.05
Unidentified annual forb	0.06	0.04
Bindweed heliotrope (*Heliotropium convolvulaceum*)	trace	trace
Total vegetation cover	37.1	26.2
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.3
Rock	0	0
Leaf litter	2.40	1.70
Biologic soil crust	0	0
Russian-thistle litter	1.84	1.30
Total gap length, in percent		83.9
Mean basal gap length, in centimeters		250

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 5

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	8.20	5.80
Rabbitbrush (*Ericameria nauseosus*)	5.80	4.10
Sandhill muhly (*Muhlenbergia pungens*)	2.26	1.60
Stickleaf (*Mentzelia pumila*)	1.84	1.30
Unidentified perennial grass	1.61	1.14
Russian thistle (*Salsola* sp.), dead	1.13	0.80
Indian ricegrass (*Oryzopsis hymenoides*)	0.7	0.52
Snakeweed (*Gutierrezia sarothrae*)	0.57	0.40
Unidentified shrub, dead	0.28	0.20
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.15	0.10
Unidentified annual forb	0.01	0.01
Total vegetation cover	22.6	16.0
Substrate	**Area, in square meters**	**Percentage**
Sand	138	97.3
Rock	0.28	0.20
Leaf litter	3.53	2.50
Biologic soil crust	0	0
Russian-thistle litter	2.88	2.04
Total gap length, in percent		77.1
Mean basal gap length, in centimeters		222

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 6

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	6.64	4.70
Stickleaf (*Mentzelia pumila*)	2.12	1.50
Rabbitbrush (*Ericameria nauseosus*)	1.56	1.10
Giant dropseed (*Sporobolus giganteus*)	1.07	0.76
Unidentified shrub, dead	0.71	0.50
Russian thistle (*Salsola* sp.), dead	0.42	0.30
Indian ricegrass (*Oryzopsis hymenoides*)	0.33	0.23
Unidentified perennial grass	0.28	0.20
Plains spring parsley (*Cymopterus acaulis*)	0.17	0.12
Unidentified annual forb	0.14	0.10
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.06	0.04
Total vegetation cover	13.5	9.6
Substrate	**Area, in square meters**	**Percentage**
Sand	139	98.2
Rock	0.14	0.10
Leaf litter	2.46	1.74
Biologic soil crust	0	0
Russian-thistle litter	0.14	0.10
Total gap length, in percent		73.8
Mean basal gap length, in centimeters		333

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 7

Vegetation	Area, in square meters	Percentage
Rabbitbrush (*Ericameria nauseosus*)	19.7	13.9
Mojave indigobush (*Psorothamnus arborescens*)	8.62	6.10
Unidentified perennial grass	2.21	1.56
Ephedra (*Ephedra* sp.)	1.41	1.00
Russian thistle (*Salsola* sp.), dead	1.27	0.90
Saltbush (*Atriplex canescens*)	0.79	0.56
Sandhill muhly (*Muhlenbergia pungens*)	0.71	0.50
Indian ricegrass (*Oryzopsis hymenoides*)	0.57	0.40
Giant dropseed (*Sporobolus giganteus*)	0.42	0.30
Snakeweed (*Gutierrezia sarothrae*)	0.23	0.16
Stickleaf (*Mentzelia pumila*)	0.20	0.14
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.12	0.08
Plains spring parsley (*Cymopterus acaulis*)	0.06	0.04
Total vegetation cover	36.3	25.6
Substrate	**Area, in square meters**	**Percentage**
Sand	125	88.7
Rock	10.9	7.70
Leaf litter	5.09	3.60
Biologic soil crust	0	0
Russian-thistle litter	5.09	3.60
Total gap length, in percent		73.4
Mean basal gap length, in centimeters		400

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 8

Vegetation	Area, in square meters	Percentage
Unidentified perennial grass	11.10	7.85
Russian thistle (*Salsola* sp.), dead	1.81	1.28
Unidentified forb, dead	0.06	0.04
Silverleaf nightshade (*Solanum elaeagnifolium*), dead	0.03	0.02
Globemallow (*Sphaeralcea* sp.)	0.03	0.02
Indian ricegrass (*Oryzopsis hymenoides*)	0.01	0.01
Total vegetation cover	13.0	9.2
Substrate	**Area, in square meters**	**Percentage**
Sand	126	89.2
Rock	7.69	5.44
Leaf litter	7.63	5.40
Biologic soil crust	0	0
Russian-thistle litter	0	0
Total gap length, in percent		93.7
Mean basal gap length, in centimeters		333

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 9

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	10.0	7.10
Unidentified shrub, dead	2.26	1.60
Stickleaf (*Mentzelia pumila*)	2.08	1.47
Rabbitbrush (*Ericameria nauseosus*), dead	1.98	1.40
Rabbitbrush (*Ericameria nauseosus*), live	0.99	0.70
Unidentified perennial grass	0.14	0.10
Russian thistle (*Salsola* sp.), dead	0.14	0.10
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.08	0.06
Indian ricegrass (*Oryzopsis hymenoides*)	0.06	0.04
Unidentified perennial forb	0.03	0.02
Unidentified annual forb	0.003	0.002
Total vegetation cover	17.8	12.6
Substrate	**Area, in square meters**	**Percentage**
Sand	103	72.6
Rock	19.8	14.0
Leaf litter	4.24	3.00
Biologic soil crust	14.7	10.4
Russian-thistle litter	3.53	2.50
Total gap length, in percent		75.9
Mean basal gap length, in centimeters		1,330

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 10

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	6.50	4.60
Rabbitbrush (*Ericameria nauseosus*)	6.08	4.30
Stickleaf (*Mentzelia pumila*)	2.97	2.10
Unidentified shrub, dead	0.85	0.60
Russian thistle (*Salsola* sp.), dead	0.42	0.30
Unidentified perennial grass	0.14	0.10
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.12	0.09
Indian ricegrass (*Oryzopsis hymenoides*)	0.03	0.02
Unidentified perennial forb	0.01	0.01
Total vegetation cover	17.1	12.1
Substrate	**Area, in square meters**	**Percentage**
Sand	112	79.2
Rock	26.0	18.4
Leaf litter	3.39	2.40
Biologic soil crust	0	0
Russian-thistle litter	0.14	0.10
Total gap length, in percent		77.6
Mean basal gap length, in centimeters		167

Table 7. Vegetation cover and substrate measured in March 2012 in the study area near Teesto Wash, Navajo Nation, Arizona.—Continued

Site 11

Vegetation	Area, in square meters	Percentage
Mojave indigobush (*Psorothamnus arborescens*)	13.3	9.40
Stickleaf (*Mentzelia pumila*)	1.92	1.36
Rabbitbrush (*Ericameria nauseosus*)	1.70	1.20
Unidentified shrub, dead	1.41	1.00
Indian ricegrass (*Oryzopsis hymenoides*)	0.99	0.70
Giant dropseed (*Sporobolus giganteus*)	0.42	0.30
Russian thistle (*Salsola* sp.), dead	0.14	0.10
Unidentified aster (*Asteraceae* family), dead	0.11	0.08
Unidentified annual forb; pigweed (*Amaranthus* sp.)?	0.06	0.04
Unidentified perennial forb	0.03	0.02
Total vegetation cover	20.1	14.2
Substrate	**Area, in square meters**	**Percentage**
Sand	138	97.3
Rock	0	0
Leaf litter	3.53	2.50
Biologic soil crust	0.28	0.20
Russian-thistle litter	2.12	1.50
Total gap length, in percent		66.7
Mean basal gap length, in centimeters		333

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