Winterfat Decline and Halogeton Spread in the Great Basin

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Abstract—Winterfat (*Ceratoides lanata*) is a long-lived shrub with excellent drought tolerance and good to moderate tolerance for herbivory. It often occurs as near monocultures in deep fine-textured soils of alluvial fans and valley bottoms. Winterfat communities are second only to those of shadscale (*Atriplex confertifolia*) in dominance of the 16 million ha of salt-desert shrublands found in Western North America. In spite of improved grazing practices, winterfat is declining in many areas of the Great Basin. The Eurasian summer annual, halogeton (*Halogeton glomeratus*), is well adapted to the soils and climate associated with winterfat communities and is invasive, replacing winterfat on degraded sites. Recolonization of halogeton stands by winterfat is rare. Subsequently, distinct winterfat- and halogeton-dominated communities often occur side by side. At the Desert Experimental Range (Utah), episodic winterfat mortality at the ecotone has been observed particularly after flood events and periods of higher than average precipitation. The upward translocation and accumulation of cations, particularly sodium, in the soil by halogeton may account, at least in part, for the lack of winterfat establishment in halogeton stands. Other evidence suggests that a possible halogeton-induced change in soil microbiota may also be unfavorable for winterfat. The development of viable management options to restore winterfat communities will require a greater understanding of plant-soil interactions for these species.

Winterfat

Winterfat, or white sage (*Ceratoides lanata*), is a long-lived short- to medium-statured chenopod shrub with excellent drought tolerance (Chambers and Norton 1993) due in part to an extensive fibrous root system and deep penetrating taproot (Stevens and others 1977). It occurs in near monocultures on fine textured lacustrine deposits found in dry valley bottoms and as a more or less primary component of mixed communities on deep alluvium derived from calcareous substrate. Until recent decades, winterfat dominated the 'island' communities associated with rodent burrow clusters, which are scattered within otherwise mixed shrub/grass communities of valley alluvium (Kitchen and Jorgensen 1999).

Winterfat communities are second only to those of shadscale (*Atriplex confertifolia*) in dominance of the 16 million ha of North American salt-desert shrubland found primarily in the Great Basin (Blaisdell and Holmgren 1984). Common native associates include shadscale, budsage (*Artemisia spinescens*), low rabbitbrush (*Chrysothamnus greenei*), black sagebrush (*Artemisia nova*), Indian ricegrass (*Oryzopsis hymenoides*), galleta (*Hilaria jamesii*), and gooseberryleaf globemallow (*Sphaeralcea grossulariifolia*). Within the context of currently accepted models incorporating multiple stable states, successional pathways, and interstate thresholds (Friedel 1991; Laycock 1991), a species that is represented in multiple stable states might be safely considered late seral. Winterfat is such a species (Comstock and Ehleringer 1992). Consistent with a late seral strategy (Grime 1977; Tilman 1988) are winterfat traits of plant longevity (Chambers and Norton 1993), inconsistent seed production (Blaisdell and Holmgren 1984), and absence of seed dormancy mechanisms necessary to preserve a soil seed reserve (Stevens and others 1977; Kitchen and Jorgensen 1999). It is, therefore, no surprise that winterfat stands are slow to rebound following disturbance.

Winterfat is palatable and provides nutritious forage for wildlife and livestock in all seasons. Although moderately tolerant of herbivory (Harper and others 1990; Chambers and Norton 1993), significant Great Basin reductions in winterfat are attributed to abusive grazing practices by domestic livestock from the 1870s to the 1930s, and later in some locations (for example, Murdock and Welsh 1971). Winterfat is most susceptible to grazing damage during spring months when physiological activity is greatest (Blaisdell and Holmgren 1984; Harper and others 1990). On many locations, the condition of winterfat communities improved somewhat as grazing frequency and intensity were reduced consistent with implementation of the Taylor Grazing Act of 1934. However, despite improved grazing practices, Great Basin winterfat communities today show patterns of continued, or perhaps, renewed decline (Harper and others 1990; Alzerreca-Angelo and others 1998; Kitchen and Jorgensen 1999).

Halogeton

Halogeton, (*Halogeton glomeratus*) is a succulent halophytic annual native to central and southwestern Asia and southeastern Europe. It is a prolific seed producer, even under drought stress (Eckert 1954). Tisdale and Zappetini (1953) reported yields of 25,000 seeds for larger plants and 800 seeds per plant in crowded stands where plant maturation height was only 76 mm. They found that vigorous stands

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produced from 220 to 450 kg of seed per ha. Halogeton seed are small (1 to 2 million per kg) and easily dispersed by wind, animal vectors, and vehicles. The production of both nondormant/short-lived black seed and dormant/long-lived brown seed (Cronin and Williams 1966) provides the means for both rapid spread and long-term persistence.

Although the timing and mode of introduction to the United States are unknown, the first documented collection of halogeton was made near Wells, Nevada, in 1934 (Dayton 1951). Although a weak competitor in perennial communities (Eckert 1954; Blaisdell and Holmgren 1984), this weed is well adapted to the soils and climate associated with salt-desert shrublands and is quick to invade disturbed sites, often resulting in near monocultures. Natural spread is facilitated by human-caused disturbances, in particular, the inadvertent creation of invasion corridors produced by road construction and maintenance activities (Dayton 1951; Stoddart and others 1951). After introduction, halogeton spread rapidly through the overgrazed rangelands of the semiarid West, infesting 4 million ha in the Western United States within 30 years of first collection (Cronin and Williams 1966). Once a salt-desert shrubland community is converted to halogeton, natural regeneration of native shrubs, such as winterfat, generally does not occur (Eckert 1954; Harper and others 1996).

The poisonous nature of halogeton for all classes of livestock, but more particularly for domestic sheep, was first recognized in 1942 (Dayton 1951). This awareness, in combination with the rapid rate of spread that was observed, captured the attention of the western range management community and resulted in substantial research effort on various aspects of halogeton biology during the 1940s and 1950s. One focus of that research was to examine the effect of halogeton litter on the chemical and physical properties of salt-desert soils. Eckert and Kinsinger (1960) conducted controlled studies using Nevada soils collected from three salt-desert community types and multiple levels of halogeton mulch. They demonstrated that the primary effect of halogeton leachate was an increase in cations, primarily sodium, at or near the soil surface with corresponding increases in soil pH and electrical conductivity. Secondary effects associated with the chemical changes included changes in soil physical properties, including increased crust strength and decreased percolation rate, and capillary rise of water associated with halogeton soils.

Today, halogeton stands are common on sites previously occupied by winterfat and are often found adjacent to remnant winterfat communities throughout the Great Basin. Using 1998 and 1999 road surveys in central and eastern Nevada and western Utah, we observed moderate to extensive displacement of winterfat by introduced annuals (primarily halogeton) in 16 central Great Basin drainage systems: specifically, Jakes, Monitor, Newark, Railroad, Spring, Steptoe, and White River Valleys of central and western Nevada, and Antelope, Escalante, Ferguson Desert, Pine, Rush, Sevier Desert, Snake, Tule, and Wah Wah Valleys of western Utah. Displacement had occurred in both low-diversity valley bottom communities and in the 'island' vegetation associated with rodent burrow clusters scattered in the more diverse alluvial community types. We concluded that the probability of surveying winterfat habitat in the Great Basin without observing significant displacement by halogeton was probably quite low. Goodrich (2000) reported a similar phenomenon in the Green River Basin of southwestern Wyoming, where halogeton is replacing stands of Gardner saltbush (*Atriplex gardneri*). It is apparent that a complete list of impacted communities will require additional reconnaissance.

Desert Experimental Range

In 1933, President Herbert Hoover set aside as an "agricultural range and experiment station" 22,500 ha (87 sections) located in western Millard County, Utah (Clary and Holmgren 1982). Pastures and reference areas of the Desert Experimental Range (DER), the Station's current name, were soon fenced for use in grazing and ecological studies, which continue to the present. Today, research and monitoring activities at the DER are coordinated by the Forest Service, Rocky Mountain Research Station, under the care of the Shrub Sciences Laboratory in Provo, Utah.

The DER is located primarily within the northwest quarter of Pine Valley, a north/south trending closed basin with a bottom elevation of 1,547 m and with several surrounding peaks ranging from 2,400 to 2,900 m elevation. During the late Pleistocene, the valley held a small lake with a maximum size of approximately 10,600 ha and an upper shore line at about 1,570 m (Snyder and others 1964). A mostly barren playa and remnants of old shorelines are the most visible evidence of the lake.

Approximately 75 percent of the DER is coalescing alluvial fans, or bajadas, and valley bottom, including about half of the playa. The remainder is steeper uplands and outcrops made primarily of Paleozoic limestone and dolomite with lesser amounts of quartzite and early tertiary volcanics. Soils are mostly gravelly loams, sandy loams, and gravelly sandy loams (Aridisols and Entisols; Tew and others 1997). Soil series located on alluvium above ancient shorelines are deep to very deep, with rapid to moderate permeability, and moderate to well developed calcic horizons (Tew and others 1997). Soil series below these shorelines are very deep, with moderate to moderately slow permeability and high levels of exchangeable sodium (15 to 40 percent) in subsurface horizons (below 40 cm).

Precipitation at the DER is highly variable within and between years. Mean annual precipitation at the headquarters complex (1,600 m) for the period of 1934 to 1981 was 157 mm with approximately half occurring from October through April (Clary and Holmgren 1982). Annual precipitation for the last 25 years (1975 to 1999) averaged near 200 mm (Alzerreca-Angelo and others 1998; data on file at the U.S. Forest Service, Shrub Sciences Laboratory, Provo, Utah). Mean temperatures for January and July are –3.5 and 23.3 °C, respectively.

Vegetation on alluvial fans is salt-desert shrubland with shadscale, winterfat, low rabbitbrush, bud sagebrush, Nevada ephedra (*Ephedra nevadensis*), and various perennial grasses and forbs dominating. Multi-scaled patchiness in the vegetative matrix reveals variability in species dominance, a reflection of the heterogeneity in soil composition, structure, and disturbance. Valley bottom vegetation is less diverse than that found on alluvial fans (Kitchen and others 1999) and is comprised primarily of winterfat (sometimes in near monocultures), Indian ricegrass, gray molly (*Kochia americana*), Bonneville saltbush (*Atriplex bonnevillensis*), and halogeton. Black greasewood (*Sarcobatus vermiculatus*) and Nuttall saltbush (*Atriplex falcata*) are conspicuous additions on colonized portions of the playa.

Halogeton Research at the Desert Experimental Range

The early history of halogeton at the DER is recorded in unpublished documents on file at the U.S. Forest Service, Shrub Sciences Laboratory, Provo, Utah, and is summarized here. Halogeton was first observed at the DER in 1952 as a small (approximately 1 ha) patch near the playa. At the time, populations were known to exist in all basins surrounding Pine Valley. Although the means of seed transport to the DER is unknown, it was believed that seed might have come by way of contaminated bales of hay dropped as emergency feed in the winter of 1948 and 1949. A monitoring plan was developed to assess the condition of this population as well as to survey the remainder of the DER for new infestations in coming years. New populations were identified in 1953 both inside and near DER boundaries. Small plots with and without perennial vegetation were seeded to halogeton in June of 1954 to assess establishment with and without competition from perennials. Halogeton plants grew in all plots the same year. During the next 4 years, halogeton spread in Pine Valley from an increasingly greater number of source populations. Subsequently, by 1958 halogeton was widespread at the DER and surrounding lands. Within the DER, halogeton was concentrated mostly within the more open communities near the playa and on upland communities associated primarily with disturbance (rodent diggings, roads, and so forth).

Boundaries between nearly pure stands of winterfat and halogeton are generally well defined by a rather narrow ecotone. This results from the inability of winterfat to invade halogeton stands and the weak competitive attributes of halogeton in healthy perennial communities. At the DER, no natural regeneration of winterfat has occurred for up to 30 years following conversion to halogeton. However, halogeton advances have been observed following unexplained winterfat die-off events preceded by either summer flooding (Harper and others 1996) or extended periods of abnormally high precipitation.

Harper and others (1996) observed changes in soil chemistry associated with halogeton conversion at the DER similar to those observed in Nevada (Eckert and Kinsinger 1960). They also found evidence that halogeton conversion had altered the soil microbial community as was predicted by Eckert and Kinsinger. In greenhouse experiments using treated (methyl bromide fumigation) and untreated soils collected from the halogeton and winterfat communities, winterfat seedling survival in treated halogeton soil (50.3 percent) was significantly higher than that for untreated halogeton soil (36.6 percent) and not significantly different than that of treated (55.9 percent) and untreated (47.4 percent) winterfat soils. These results suggest possible enhanced pathogenic activity associated with halogeton soils.

In 1998, additional soil samples were taken at four DER sites near the playa. Samples were collected from adjoining winterfat and halogeton stands, the ecotone between the stands, and bare areas (<1 percent cover) located within halogeton stands. These bare areas had supported solid stands of halogeton in 1997 as determined by the condition of standing litter. Three replicated samples were taken from the top 10 cm for each site/plant community combination (n = 12). Increases in sodium associated with halogeton (table 1) were consistent with that reported by Eckert and Kinsinger (1960) and Harper and others (1996). Halogeton-related increases in potassium and magnesium were also significant. Our results also show that, although exchangeable concentrations of these cations were not significantly higher at the ecotone than in the winterfat community, they were trending upward and clearly were being affected by halogeton litter. Change in cation concentration between halogeton and winterfat soils, when expressed as a ratio, was greater for sodium (3.7:1) than for potassium (2.3:1) or magnesium (1.3:1). Eckert and Kinsinger (1960) suggested that disproportionate increases in sodium could cause reduced uptake of other cations resulting in nutrient stress for affected plants. Whether by the direct affect of increased sodium on plant growth, negative alteration of the physical properties of soils, disruption of soil micro flora, changes of cation ratios, or some combination of the above, halogeton is clearly effective at rendering intolerable, soils previously occupied by winterfat.

Because of the cumulative nature of these soil-chemistry changes, it seems reasonable to assume that the length of time a site is occupied by halogeton and the chemical, physical, and perhaps biological condition of that soil as it pertains to winterfat growth are inversely related. We believe that this is largely true, at least until conditions are so poor that halogeton growth also becomes restricted. It is possible that this occurred on the bare areas we observed at the DER in 1998. Cation concentrations were clearly greater in these soils than in other soils tested, including those associated with dense halogeton stands (table 1). Interestingly, a full and vigorous stand of halogeton grew on the previously bare areas in 1999. The 1998 boundary between the halogeton stand and bare ground remained clearly visible due largely to greater stand vigor (height, color, biomass) associated with previously bare areas. This would

Table 1—Exchangeable concentrations (ppm) for four cations in top 10 cm of soil in adjoining winterfat and halogeton communities, ecotone, and bare areas at four sites on the Desert Experimental Range, Millard County, Utah (1998). Within columns, means followed by the same letter are not significantly different at the $p < 0.05$ level (SNK).

Community type	Ca	Mg	K	Na
			ppm	
Winterfat	8,736a	490c	636c	102c
Ecotone	8,359b	509c	793c	149c
Halogeton	8,371b	650b	1,455b	373b
Bare	8,644a	725a	1,633a	450a

seem to suggest that halogeton rendered these sites unfavorable for halogeton (or most any other species present), and that it remained so until soil conditions improved. For example, the above average precipitation that occurred in 1998 (215 mm) could have been sufficient to partially leach salts from near the soil surface, improving conditions on bare soils. At the same time, such improvements might not have occurred on soils with active halogeton stands due to the extra halogeton biomass (and, therefore, salted litter) produced in response to abundant soil water. Research that could document and quantify this hypothesis has not been done.

Conclusion

Winterfat decline is widespread in Great Basin salt-desert communities. Presently, our knowledge of the processes by which introduced annuals, particularly halogeton, displace and exclude winterfat is deficient. Before we can assess the probable effectiveness of potential management strategies in preventing continued expansion of halogeton and in restoring winterfat community stability, a more complete understanding of interactions among winterfat and halogeton and associated soils and soil microbiota must first be developed. Failure to respond to this challenge will likely result in further degradation of winterfat-dominated communities in the Great Basin.

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