Invasive Exotic Plant Species in Sierra Nevada Ecosystems[1]

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Introduction

The Sierra Nevada is a topographically and floristically diverse region of the western United States. While it comprises only a fifth of the total land area of California, half of the native plant species in the state occur within the range. In addition, more than 400 plant species are endemic to the Sierra Nevada and many of these are listed as threatened or have other special conservation status (Shevock 1996). As in many areas of the world, the biodiversity of the Sierra Nevada region is undergoing change due to alterations in human uses and fire regimes, climate change, and invasions by non-native species. This paper provides an overview of invasive non-native plants and potential threats they pose to currently held values for Sierra Nevada ecosystems.

Throughout California, urban and suburban development, livestock, roads, and agriculture have been cited as the predominant causes of native plant population declines; however, on a local scale, the introduction and spread of non-native plants has also been implicated in the decline of numerous special status plant species (State of California 1992, www.dfg.ca.gov/hcpd/species/t_e__spp/ann_te_rpt.shtml). Exotic plant species can directly compete with natives and cause their local displacement. In addition, they may have a number of indirect impacts that can change the aesthetic values, biological diversity, and services of ecosystems. Potential impacts include alteration of disturbance regimes, changes in the food base for wildlife species, soil erosion and loss of soil carbon storage, decreases in range or forest productivity, and altered recreational or aesthetic values. Because a number of non-native plants species that are already established in California have had large ecological impacts, land managers in the Sierra Nevada have become increasingly interested in identifying these species and developing approaches to control and eradicate them.

This paper briefly assesses the potential threat of invasive non-native plant species to the Sierra Nevada and addresses the following points: (1) What exotic species are invading the Sierra Nevada region and what habitats are being most invaded? (2) Which species have the potential to dramatically reduce local native diversity or transform ecosystems? (3) What environmental conditions are likely to promote the spread of these species and consequent impacts? This information can ultimately help identify ecosystems at risk of invasion by potentially undesirable species and prevent further invasions.

General distribution patterns of non-native plant species in California and the Sierra Nevada

The distribution of California's exotic flora is described in detail in Randall and others (1998), who report that species richness of exotic plants is highest near the coast and declines toward the interior of the state and that the number of exotic species is greater at lower compared to

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[1] This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.
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higher elevations. For example, there are 77 non-indigenous plant species per 10 square kilometers ($km^{2)}$ in Sierra foothills, and 67 non-indigenous plant species in the same area in the higher Sierra Nevada (Randall and others 1998). Few exotics are reported above 1,800 meters (6,000 feet) elevation in the Sierra, and an extremely limited number of these are known to invade habitats above 2,600 meters (9,000 feet). Consistent with these general patterns, Keeley and others (2003) report that, in the greater Sequoia/King's Canyon (SEKI) area, the number and percent cover of exotic species decreases dramatically above 1,800 meters. The decrease in number of exotic species with elevation parallels the decline in native species with elevation, although it is steeper and more consistent (Keeley and others 2003).

What exotic species are invading the Sierra Nevada region and what habitats are being most invaded?

There is no thorough published plant list that describes the distributions of invasive, non-native species for the entire Sierra Nevada region. Such a list would likely include many species of minor ecological concern. The Sierra Nevada Forest Plan Amendment (2003, www.r5.fs.fed.us/sncf/eis/feis/) provides the best available list that describes potentially ecologically 'damaging' species. The list includes 59 noxious weeds or California Exotic Pest Plant Council (CalEPPC)-listed species and also provides estimates of areas covered by those species as of the late 1990s. Though not exhaustive, this list illustrates some interesting trends. For example, 71 percent of these invaders are forbs, and 50 percent of the species on the list are thistles and knapweeds. Grasses, shrubs, and trees each comprise approximately 12, 12, and 7 percent of the invaders listed, respectively (*table 1*).

Table 1 was used as a basis to query the Cal Flora Database (www.calflora.org) to evaluate where these species have been found within counties of the Sierra Nevada region. Occurrence records were classified as being from disturbed sites if the collection locale was a roadside, ditch, disturbed pasture or field, or was near human structures or part of a fuel break. Of the species on the list, 100 percent were associated with disturbance in at least one of their listed records (note, however, not all records describe the habitat from which the specimen was collected). For 80 percent of the species, where habitat was described, all collection sites could be classified as disturbed habitats (*table 1*). Thus, there appears to be a strong association of exotic plant species with disturbed circumstances, as described inbroad literature surveys from elsewhere (for example, Hobbs and Huenneke 1993, D'Antonio and others 1999).

Also classified was species elevation range, based on either CalFlora or collection site data. Lower elevation (below 1,800 meters) meadows and foothill woodland-grasslands had the most potential invaders from this list, while intact conifer forest areas and higher elevation (above 1,800 meters) meadows had the fewest invaders. This pattern was again consistent with surveys of Keeley and others (2003) who report that coniferous forest habitats in the SEKI region have consistently low abundance and richness of exotics. They found exotic species richness was higher in mid-elevation chaparral and low-elevation oak savanna, and that exotic richness generally paralleled native richness in these lower elevation habitats.

Consistent with these elevation trends, in a pilot survey of 32 high elevation (2,205 to 3,440 meters) meadows in SEKI, the authors found exotic species to be rare. Preliminary results suggest exotic plants occurred in only 12 percent of the meadows, and in all cases of occurrence, exotic plant species were rare (less than 5 percent cover). The most frequent non-native plant species present were the perennial grass *Poa pratensis* and the forb *Taraxacum officinale*. Interestingly, in contrast to the extremely low abundance of exotic species in these high-elevation meadows, 60 percent of the meadows surveyed contained saplings of the native lodgepole pine (*Pinus contorta* ssp. *murrayana*). These pine saplings were observed in a range

Table 1— *Invasive non-native plant species occurrence in Sierra Nevada National Forest (modified from SNFPA, 1999). † = where estimates exist. ‡ = all species records from disturbed habitat; more specific habitat types are listed.*

Scientific name	Common name	Life form	Estimated area infested (acres)	Upper elevation boundary (ft)	Habitat‡
Acroptilon repens	Russian knapweed	Forb		6,200	Fields, roadsides
Aegilops cylindrica	Jointed goatgrass	Grass (a)		4,900	Fields, roadsides, foothills, grasslands
Aegilops triuncialis	Barbed goatgrass	Grass (a)		3,280	Foothills, grasslands
Ailanthus altissima	Tree of heaven	Tree	111	4,100	Ditches, fields
Brassica nigra	Black mustard	Forb	700	4,921	
Bromus tectorum	Cheatgrass	Grass (a)	280,000	7,000	Many
Cardaria drabalpubescens	Hoary cress/whitetop	Forb	5	3,940	Fields, saline
Carduus acanthoides	Plumeless thistle	Forb	10	4,265	Fields
Carduus nutans	Musk thistle	Forb	1010		Fields
Carduus pycnocephalus	Italian thistle	Forb	600	3,281	Fields
Carthamus baeticus	Smooth distaff thistle	Forb		1,640	
Carthamus lanatus	Wooly distaff thistle	Forb		3,609	
Centaurea calcitrapa	Purple star-thistle	Forb		3,281	
Centaurea iberica	Iberian starthistle	Forb		3,281	
Centaurea diffusa	Diffuse knapweed	Forb	2000	7,546	Fields
Centaurea maculosa	Spotted knapweed	Forb	1584	6,562	Fields
Centaurea melitensis	Tocalote	Forb	1400	7,118	Woodlands and fields
Centaurea solstitialis	Yellow star-thistle	Forb	27,830	4,265	Fields, woodlands
Centaurea squarrosa	Squarrose knapweed	Forb	1050	1,969	
Chondrilla juncea	Rush skeletonweed	Forb		4,593	
Cirsium arvense	Canada thistle	Forb	625	5,006	
Cirsium ochrocentrum	Yellowspine thistle	Forb	10	10,000+	Yellow pine forest; PJ, sagebrush scrub
Cirsium undulatum	Wavyleaf thistle	Forb		5,249	
Cirsium vulgare	Bull thistle	Forb	16,625	7,546	

Convolvulus arvensis	Field bindweed	Forb	150	4,921	Orchards, gardens
Crupina vulgaris	Bearded creeper	Forb	200	1,000	Grasslands
Cynodon dactylon	Bermuda grass	Grass (p)	100	3,000	Disturbed, wet
Cytisus scoparius	Scotch broom	Shrub	7,711	3,281	Forests
Elaeagnus angustifolius	Russian olive	Tree		5,000	Riparian
Elytrigia repens	Quackgrass	Grass (p)	200	5,905	Fields
Euphorbia esula	Leafy spurge	Forb		4,600	Grasslands, old fields
Euphorbia oblongata	Oblong spurge	Forb	5	<1,000	
Foeniculum vulgare	Fennel	Forb	5	<1,200	Grasslands
Genista monspessulana	French broom	Shrub	200	<2,000	Conifer, grass, woodland
Halogeton glomeratus	Halogeton	Forb	20	6,000	Saline, shrubland, flats
Hydrilla verticillata	Hydrilla	Forb		<1,000	Water, wetlands
Hypericum perforatum	Klamath weed	Forb	4,010	4,500	Forest, fields
Isatis tinctoria	Dyer's Woad	Forb	10,010	3,281	Fields
Iva axillaris	Poverty weed	Forb		6,700	Saline
Lepidium latifolium	Perennial pepperweed	Forb	70	6,234	Saline, roadsides, riparian, wet meadows
Leucanithemum vulgare	Ox-eye daisy	Forb	233	6,562	Mountain meadows, fields
Linaria genistifolia ssp *dalmatica*	Dalmation toadflax	Forb	2,004	3,280	Grasslands
Lythrum salicaria	Purple loosestrife	Forb	5	4,000	Wet meadows, riparian
Myriophyllum spicatum	Eurasian milfoil	Forb		500	Water
Onopordum acanthium	Scotch thistle	Forb	30,680	5,250	
Robinia pseudoacacia	Black locust	Tree	<20	6,233	Springs, riparian
Rubus discolor	Himalayan blackberry	Shrub	4,220	5,250	Riparian, uplands, moist
Salsola paulsenii	Tumbleweed	Forb	50	5,900	
Salsola tragus	Russian thistle	Forb	110	8,858	Shrubland
Salvia aethiopis	Mediterranean sage	Shrub	2,000		Roadsides
Silybum marianum	Milk thistle	Forb	20	1,640	
Solanum elaeagnifolium	White horsenettle	Forb	10	3,940	Dry areas; fields

Sorghum halepense	Johnson grass	Grass (p)	50	2,624	Ditches, roadsides
Spartium junceum	Spanish broom	Shrub	700	2,000	
Taeniatherum caputmedusae	Medusahead	Grass (a)	5,270		Many
Tamarix chinensis	Tamarisk	Tree	175		
Tribulus terrestris	Puncture vine	Forb	55	3,280	
Ulex europaeus	Gorse	Shrub		1,300	Pastures, fields
Verbascum thapsus	Woolly mullein	Forb	11,050	15,000	Open

of conditions, from trailside disturbances, dry disturbed soil, and de-watered meadows near erosion gullies, to relatively undisturbed areas and boggy meadows. The authors' work on large meadows of the Kern Plateau in the southern Sierra Nevada also suggests that, while exotic invaders are rare, native woody invaders (in this case, largely *Artemisia rothrockii*) are widespread and can rapidly invade many high elevation meadows (Bauer and others 2002, Berlow and others 2002, 2003). The authors believe that these native woody species have greater potential to affect forage production, wildlife, native species diversity, and other ecosystem characteristics than do the current suite of non-native plant species likely to enter most high elevation areas.

Which exotic species have the potential to reduce local diversity or transform ecosystems?

Exotic plant species that managers should focus on for control and prevention are those than can either greatly reduce local native biological diversity and/or substantially alter Sierra Nevada ecosystems. Richardson and others (2000) formalized use of the term "transformer species" to describe those species with potential to form monotypic stands, and greatly alter resource availability, trophic structure, ecosystem productivity, and/or disturbance regimes. Some potential non-native transformer plant species invading the Sierra Nevada include: cheatgrass (*Bromus tectorum*), medusahead (*Taniatherum caputmedusae*), yellow star thistle (*Centaurea solsticialis*), spotted, diffuse and Russian knapweed (*Centaurea maculosa*, *C. diffusa*, and *Acroptilon repens* respectively), perennial pepperweed (also called tall whitetop-*Lepidium latifolium*), purple loosestrife (*Lythrum salicaria*), Dalmation toadflax (*Linaria genistifolia* var. *dalmatica*), leafy spurge (*Euphorbia esula*), broom species (including gorse-*Ulex europaea*, striated broom-*Cytisus striatus*, french broom-*Genista monspessulana*, scotch broom-*Cytisus scoparius*, and spanish broom-*Spartium junceum*), Himalayan blackberry (*Rubus discolor*), Russian olive (*Eleagnus angustifolia*), and saltcedar (*Tamarix parviflora*, and *T. ramosissima*). A few of these species are already widely distributed, but many are still relatively restricted within the Sierra Nevada (see Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement 2001). These should be top-priority species for early detection and rapid response eradication efforts. Some species, such as the riparian invaders (*Tamarix, Eleagnus* and *Lythrum*), are restricted in their habitat requirements so search and local eradication can be targeted. Others, such as the grasses *B. tectorum* and *T. caputmedusae*, occur over broad areas, have wide habitat tolerances, and will be very difficult to control. Rather than discuss the distribution and potential threat for each of these, highlighted here are a few species about which much is already known regarding their impacts elsewhere.

Bromus tectorum (cheatgrass) is considered to be a transformer species because it has greatly altered disturbance regimes throughout the Intermountain West with a variety of effects on species diversity and ecosystem function (see Whisenant 1990, D'Antonio and Vitousek 1992). The invasion of cheatgrass, for example, has allowed fires to burn across larger areas and at higher frequencies, resulting in communities with fewer shrubs and more cheatgrass over time. Cheatgrass has been observed in most Sierra Nevada counties (Calflora database), and is fueling fires in northeastern California and along the eastern Sierra Nevada and Carson Range near Reno, Nevada. While it is not yet abundant in the majority of Sierra Nevada locations, cheatgrass has been observed at elevations up to 2,800 meters on eastern slopes of the range adjacent to shrublands and pinyon/juniper woodlands. It has also become an element of bitterbrush (*Purshia tridentata*)/sagebrush (*Artemisia tridentata*) shrublands below Mammoth Lake, near Carson City, and at southeastern Lake Tahoe, where it has the potential to alter fire frequency with as yet unknown consequences. Cheatgrass has also invaded the understory of ponderosa pine (*Pinus ponderosa*) forests in SEKI (McGinnis and others, this volume).

The highly competitive yellow star thistle might also be considered a transformer species because it can become quite abundant, reduce water availability for native species (Gerlach and others 1998), and decrease recreational, livestock, and aesthetic values (Jetter and others [in press]). It has been observed in flower in Tuolumne Meadows (at 2,600 meters) in Yosemite National Park (Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement, 2001), and is forming increasingly large populations near Reno and along the eastern Sierra Nevada. However, the majority of yellow star thistle populations occur on the western slope of the Sierra Nevada (for current distribution see http://pi.cdfa.ca.gov/map_yst/).

On the eastern slope of the Sierra Nevada, *Lepidium latifolium* (perennial pepperweed or tall whitetop) has invaded many areas and is widely recognized as a problem in wet meadows, riparian zones, and saline sinks where it forms monospecific stands to the exclusion of all native species. It is also abundant in portions of California's Central Valley so entry points for invasion into the Sierra Nevada could come from either side of the range. It is currently found primarily below 5,000 feet, but that could soon change. Blank (2002) found that perennial pepperweed dramatically alters soil fertility characteristics with potentially great consequences for revegetation efforts in affected areas. It is extremely difficult to control, even with herbicides. Thus, the best control is preventing establishment of or obliterating new populations.

Another wet area invader of potential concern is *Lythrum salicaria* (purple loosestrife, for current distribution see http://pi.cdfa.ca.gov/purpleloosestrife/). This species is a widely distributed pest throughout the eastern and central United States (U.S. Congress Office of Technology Assessment, 1993) where it clogs waterways, excludes native species, and is the target of biological control efforts. Biocontrol has been successful in Canada and some northern states, including Oregon (Hight and others 1995). This species is currently restricted to lower elevation sites on both western and eastern slopes of the Sierra Nevada. Biological control is a potential option, but its overall efficacy in environments like those of the Sierra Nevada remains unknown.

Other potentially important riparian invaders include Russian olive, a tree widely planted for the berries it provides for wildlife, and *Tamarix* (saltcedar). Both these species invade riparian areas on arid landscapes and spread rapidly. *Tamarix* can form dense thickets, change water flow patterns in streams, and alter wildlife habitat. The high economic costs of not controlling *Tamarix* have been estimated (Zavaleta 2000), and it is currently the target of biological control efforts in California, including the Owen's Valley. Although biocontrol agents have been released in California (Dudley and others 2001), none have yet been successfully established.

What environmental conditions are likely to promote the spread and consequent impacts of exotic species in the Sierra Nevada?

Natural disturbances (fire and animal activity) and human-caused disturbances (such as logging, fire and fuels management) will undoubtedly play a role in the future spread of exotics into intact, or as yet uninvaded, plant communities. These disturbances may affect the current resistance of the conifer zone, high elevation areas, and alpine meadows to invasion. Fuel breaks may act as dispersal corridors for exotics, and fires themselves may temporarily provide a window of opportunity for species establishment. In a series of controlled burns in SEKI, Keeley and others (2003) found that non-native species respond positively to fire in conifer forests, and this response is greater under higher intensity fires. It is unknown whether these invaders will persist and delay the re-establishment of conifers, or promote more rapid fire return intervals, and how invasions will affect the timing of burns and age of stands subject to fire.

Research on processes influencing invasion of the native woody invader, Rothrock's sagebrush (*Artemisia rothrockii)*, into herb-dominated meadows suggests that climate, soil moisture, local soil disturbance, seed supply, and potentially livestock grazing all play roles in the ongoing woody species invasion of mesic montane meadows. Despite the fact that *A. rothrockii* is a native species, its takeover of meadow communities is generally viewed as undesirable. Natural recruitment of sagebrush seedlings in mesic herbaceous meadows occurs most frequently on rodent disturbances, and establishment of shrub patches is higher in years following heavier spring snow packs (Bauer and others 2002, Berlow and others 2002). When the authors mimicked livestock grazing by clipping background vegetation combined with soil disturbance, they observed the highest rates of sagebrush seedling survival and fastest times to reproduction (*table 2*). The data suggest that an understanding of the interaction of climate with disturbances (grazing and gopher activity) and seed dispersal is essential to understanding vegetation change in these sites.

Table 2— *Effect of clipping background vegetation and disturbing soils on four-year survival and reproduction of Artemesia rothrockii in Mulkey Meadow, CA (from Berlow et al. 2002).*

Treatment	Soil condition	Percent survival	Percent reproductive
Herbs clipped	Soils Undisturbed	40	0
Herbs unclipped	Soils Undisturbed	0	0
Herbs clipped	Soils Disturbed	100	40
Herbs unclipped	Soils Disturbed	40	0

Conclusions and Recommendations

Species change has been the norm for plant communities in North America throughout the Pleistocene era (Davis 1986, Delcourt and Delcourt 1992). Even within the last few centuries, climate change has influenced vegetation change in the Sierra Nevada (see papers on climate from this symposium). Thus, the invasion of species into the Sierra Nevada (or range expansion of species already present) is not an unexpected phenomenon, and it should increase in intensity or rate as climate continues to change.

An initial conclusion, particularly if one compares the Sierra Nevada to the California coastal ranges and Central Valley, is that invasions by many potentially problematic plant species in the Sierra Nevada are still at a relatively early stage. This does not mean, however, that managers can put aside thinking about them. Indeed, targeting species for removal at an early stage of invasion is essential to their successful control; hence, early detection is a critical monitoring challenge. More knowledge is needed regarding pathways of introduction and dispersal, including the roles (and effects) of logging, roads, trails, human visitation, cars, heavy equipment, pack animals, and livestock. This knowledge would aid in understanding where to look for incipient outbreaks and identifying vegetation communities that will be most vulnerable to full scale invasion. While programs such as Weed Free Feed have been instituted (http://www.extendinc.com/weedfreefeed/ and http://pi.cdfa.ca.gov/weed/wff/) in an effort to reduce the potential entry of weeds into backcountry habitats, better documentation of pathways on a species-by-species basis will help target control efforts. Coordinated region-wide early detection and rapid response systems need to be developed.

Second, the extensive conifer forests of the Sierra Nevada are currently less invaded than adjacent lower elevation habitats. This may be due to ecological resistance as a result of the dense shade in the conifer forest understory, or relatively low seed supply to these vast areas (see Keeley and others 2003). Because activities such as logging and controlled burning can eliminate ecological processes that might otherwise make communities resistant to invasion (D'Antonio and others 1999), a better understanding of how changing land uses, logging roads, and fire management will influence invasion of these habitats is needed. In particular, research is needed to evaluate the effects of the interaction of disturbances and climate on the spread of potential transformer species. Species that are likely to invade the conifer forest belt (such as Himalayan blackberry and several broom species) may not persist as conifers re-establish but this temporal dimension of invasion needs greater attention, particularly as political pressure mounts to do more forest clearing and fire control.

Third, in establishing priorities for control efforts, it is essential to ascertain which species (a) are moving from disturbed corridors into wildland habitat and (b) pose the greatest ecological threats once they become established. To what extent will movement depend on propagule buildup on the corridor, climatic fluctuation, fire or other natural disturbances off the corridors?

Fourth, the threat posed to endemic or rare native species by invasive exotics needs to be evaluated. Initially, a distribution matching approach, whereby the distribution of problematic species is overlain with that of threatened species, could be used. This would require landscape-scale (spatial) analyses. Shevock (1996) provides a reasonable description of the distribution of endemic and threatened species in the Sierra Nevada.

Lastly, managers will benefit from systematic surveys of distribution and abundance of the main problem invaders, with coordination for monitoring and control efforts at a regional scale. Over the past decade, great strides have been made in this area. Interactive web-based databases, such as the CRISIS Weed Map and Data Server (http://cain.nbii.gov/cgibin/mapserv?map=../html/cain/crisis/crisismaps/crisis.map&mode=browse&layer=state&layer=county), are now available that allow users to input occurrence data and download distribution maps. The national parks in the Sierra Nevada have at least preliminary information on the occurrence and distribution of problem species within their jurisdictional boundaries. Information sharing between managers and owners of lands throughout the Sierra Nevada will be an essential part of successful regional scale management.

Acknowledgements

The authors would like to thank the USDA-ARS lab in Reno Nevada for feedback on early versions of the presentation from which this manuscript was derived. Dr. James Young provided valuable feedback on an earlier draft. The authors thank the National Park Service for support for the SEKI survey.

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