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Impact of Nonindigenous Plants

ABSTRACT

Nonindigenous species play a dominant role in the vegetation of many ecosystems that adjoin or overlap the Sierra Nevada. Many of these habitats, such as the valley and foothills grasslands, appear to be saturated with these species. In contrast, the high elevations of the Sierra Nevada, like most high alpine regions, are not as heavily impacted by nonindigenous species. In between these extremes is a gradient of impact that is heavily influenced by the amount and extent of human disturbance of natural ecosystems. The most heavily affected regions within the Sierra Nevada are the foothill grassland and oak savanna habitats, infested with a diversity of Mediterranean annual grasses as well as herbaceous dicots; the riparian zones, infested by woody plants; and the eastern slope, which is strongly dominated by cheat grass. Infestation at middle elevations is most closely linked to disturbances such as clear-cuts and roadsides. Non-native species such as cheat grass, yellow star thistle, salt cedars, Russian olive, ailanthus, Himalayan blackberry, and Scotch broom affect ecosystem attributes such as grazing potential, forest regeneration, and water availability along stream courses. At the present time there are few restrictions on the importation of species that may, in the future, pose additional threats to the integrity and utility of the Sierra Nevada. This chapter recommends a series of actions, beginning with educational programs that may limit the sale of non-native species that are known problems. Programs from other states are profiled as models for potential importation restrictions that would be useful in protecting the integrity of the Sierra Nevada.

INTRODUCTION

Introduced weedy species present a disturbance to both natural ecosystems and managed habitats in ways that most citizens do not fully recognize. When one pauses to think about introduced species and how they affect our lives, from commerce to recreation, the evidence is abundant. Food that crosses international borders is inspected for potential pests and pathogens; the agrochemical industry has developed around the effort to reduce weedy pests (plants and animals) in agricultural systems; teams of scientists monitor the spread of plant pests such as the gypsy moth, killer bees, and disease agents that cause Dutch elm disease, oak wilt and white pine blister rust, to name a few.

Biological invasions have persistent and far-reaching consequences. Although plant invasions have often reduced biological diversity and the aesthetic value of natural lands, to humans these costs are often intangible, vary among individuals, or are difficult to measure. In contrast, the direct economic effects to agricultural systems are more easily assessed. A conservative estimate of the cumulative losses to the United States from selected harmful nonindigenous species from 1906 to 1991 is $97 billion (U.S. Congress, Office of Technology Assessment [OTA] 1993). This estimate includes only losses to agriculture, industry, and human health, and not the undocumented costs of the loss of native biological diversity, the disturbance of healthy forest ecosystems, and the loss of the recreation potential of habitats compromised by the presence of weedy pests (OTA 1993).

California, with respect to vascular plants, is one of the most biologically diverse regions of North America. Similarly, California has a greater diversity of problems regarding intro-

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duced species than most places. With its rich agricultural industry, California is arguably one of the most extreme examples of the costs associated with living with introduced species, including the Mediterranean fruit fly, Argentinean ants, killer bees, cheat grass, and star thistle. The list seems endless. Yet these problems are relatively recent. By definition, no nonindigenous plants had been introduced prior to European contact in 1769. By 1860 there were at least 134 established alien plant species (Raven 1990). By 1993 this number has grown to more than 1,000, or 15% of the entire flora (Hickman 1993). This century has seen exponential growth in the number of nonindigenous plant species (figure 47.1) as well as exponential growth in their impacts. Because problems with non-native species are typically less severe in the mountains, the Sierras are burdened with less of a problem with non-native species than is most of California. Nonetheless, the Sierras have a greater problem than most mountainous regions.

KEY QUESTIONS

This chapter addresses four key questions regarding non-native species:

1. Why are nonindigenous species problematic?
2. What habitats within the Sierra are most heavily affected by non-native species, and which species are responsible for these effects?
3. What disturbances, human generated or natural, exacerbate the non-native species problem, and in what ways do they do so?
4. What mechanisms can be implemented to minimize the risk associated with non-native plant species?

To answer these questions, we have divided this chapter into four parts. First, we define and describe nonindigenous weedy species and address attributes that contribute to the ability of certain species, once introduced, to spread uncontrollably and become management problems. Second, we describe habitats of the Sierra Nevada that are heavily disturbed as a result of non-native plants and discuss the specific ecology of some of the most problematic of these species. Third, we link the disturbances created by nonindigenous plants to other disturbance factors in the Sierra. Finally, we propose mechanisms to limit the potential for new damage by nonindigenous species and to remediate damage already inflicted upon the Sierra Nevada by the species that have already been introduced.

AN INTRODUCTION TO NONINDIGENOUS PLANTS

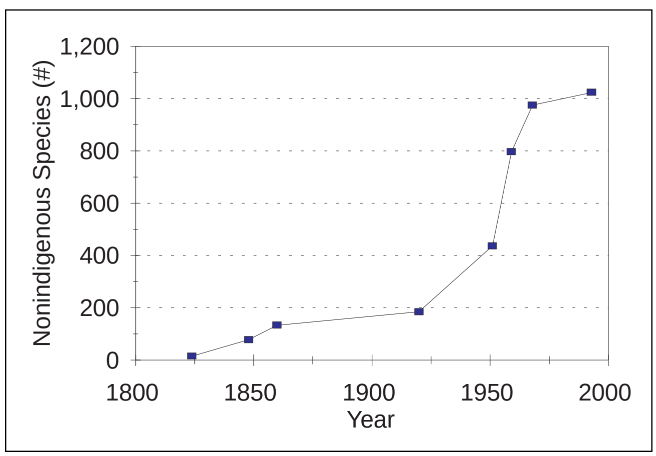
Terminology for defining non-native species has been somewhat unclear (Lukens 1994). Plants and animals have often been dispersed beyond their historic distribution limits through human activities. These species with human-enhanced distributions that become established (that is, that grow and reproduce without further human intervention) in their new environments are variously called "exotic," "non-native," "introduced," "alien," and "nonindigenous." A small but significant subset of invasive nonindigenous species experiences rapid and uncontrolled population growth. This chapter considers all plant species known to have been introduced, intentionally or unintentionally, to the flora of the Sierra Nevada since the time of European settlement to be nonindigenous.

The natural environment is a complex combination of biotic and abiotic interactions. Each species has numerous relationships with other organisms and its environment, some subset of which typically regulates population size. Predation, competition, disease, and unpredictable, harsh weather conditions can all limit the number of individuals in a population. Without regulation, populations of all species have the ability to grow exponentially (Silvertown and Doust 1993). When organisms are transported to a new habitat, they may experience a release from factors that typically limit their population growth. Such population expansions are frequently at the expense of native species that would otherwise occupy the space, but whose populations are regulated by their environment.

Researchers have tried to predict successful plant invaders, using life histories, genetics, and ecological traits. Baker (1974, 1986) addresses characteristics possessed by the hypo-

FIGURE 47.1

Number of nonindigenous plant species by date as reported in botanical treatments of the California flora.



thetical ideal weed (e.g., few germination requirements, rapid growth, continuous seed production, and strong competitive ability). Similarly, polyploidy (containing more than one full set of chromosomes) (Bazzaz 1986) and preadaptation to climate, nutrient levels, and the disturbance regime of the new area (Kruger et al. 1989) may also increase invasiveness. While this is interesting speculation, the value of such characterizations is questionable because biological systems are inherently complex (Noble 1989). The success of a plant species in a novel environment depends on the outcome of an undefined number of interactions with the abiotic and biotic environment. Hence, a plant possessing few "weedy" characteristics may succeed because one environmental factor may drive the ability of its population growth. Rejmanek (1989) has compiled a list of more than fifty species that invade "undisturbed" communities. After reviewing these species and their invaded communities, Rejmanek concludes, "While it seems to be possible to make some generalizations about successful invaders in disturbed and successionally young communities (Baker 1965; Heywood 1989), there is apparently nothing unifying for invaders of 'undisturbed' natural communities." Alternatively, Reed (1977) has generated a list, based on the plants' performance elsewhere, of plants not currently in the United States that, if introduced, could become invasive. Similarly, Rejmanek (1995) has identified potentially invasive pines by examining regeneration characteristics and past performance as an invader. Such lists could be successful in preventing the import of invasive species. Fewer than one-third of import protocols, however, require information on an organism's foreign performance (Ruesink et al. 1995).

The impact of nonindigenous plant species generally decreases with increasing elevation. While there are species (e.g., Kentucky bluegrass [Poa pratensis]) that invade high-elevation Sierra Nevada meadows, the number of these is few relative to lower elevations in the Sierras. The relative paucity of nonindigenous plants at higher elevations has led some to suggest that there is an elevational barrier to species introductions. The question remains as to whether the lower impact is due to a scarcity of invasive nonindigenous species that survive at higher elevations or to a lower frequency of introductions of high-elevation species. Evolution of high-elevation ecotypes from low-elevation nonindigenous species may eventually decrease this gradient. Populations of yellow star thistle (Centaurea solstitialis) in California have begun to differentiate as a result of differences in climatic conditions between the coast and inland areas (Maddox and Mayfield 1985).

In general, nonindigenous species are not randomly distributed with respect to biogeographic regions. Historically, regions with a mediterranean climate have been among those most affected by biological invasions. These regions, such as California, have cool, wet winters followed by hot, dry summers. A combination of a long potential growing season and a long human history of agriculture in the Mediterranean has resulted in numerous species that seem to be well adapted to invading human-disturbed habitats in such climates (Kruger et al. 1989; Groves 1986). The majority of successful invasives in other regions seem to come from Eurasia. The abundance of biological invasions in regions with a mediterranean climate is staggering. To cite a few examples,

- The invasive plant Mimosa pigra threatens to decimate waterbird populations and to reduce reptilian and mammalian diversity in Australia (Braithwaite et al. 1989).
- By 1977, more than 9 million hectares (22 million acres) of California grassland and woodland had been severely invaded by non-native plants (Heady 1977).
- Recent estimates show that 60% of South Africa's fynbos community (brushy, chaparrallike habitat) has been replaced by non-native woody invasives (Heywood 1989).
- Several dozen nonindigenous species have been deemed so serious as to be officially considered "plagues of agriculture" in Argentina (Mack 1989, citing Marcoza 1984).

In addition, a multitude of human-induced disturbances make communities more invasible. For example, agriculture (Mack 1989), clear-cutting (Heywood 1989), fire (Heywood 1989; Baird 1977; Groves 1986), road construction (Frenkel 1970), and urban expansion and grazing (Kruger et al. 1989; Orians 1986; Milchunas et al. 1988; Milchunas et al. 1989) have all historically been implicated or experimentally shown to facilitate plant invasion.

BIOLOGICAL INVASION OF THE SIERRA NEVADA

An examination of the nonindigenous plant species in the Sierra Nevada highlights three high-impact areas: valley grasslands and foothill oak woodland, riparian zones, and the eastern slope (table 47.1). Our treatment of nonindigenous plants focuses on highlighting general problems within these more heavily affected habitats, followed by a discussion of the autecology of key species. A separate, smaller section will follow, highlighting other problematic species for which we have less information. This survey of heavily affected sites and highly problematic species is not exhaustive (see, for example, table 47.1), but represents the status of a significant portion of the Sierra Nevada and is suggestive of the potential future of the region.

Sierra Nevada Valley Grassland and Foothill Oak Woodland

California has several extensively invaded plant communities. One of the most heavily affected is the Central Valley,

TABLE 47.1

A partial list of invasive nonindigenous plants of the Sierra Nevada, listed by habitat.

Valley Grasslands, Foothill Oak Woodlands	Riparian Zones	Eastern Slope Desert	General to Many Disturbed Habitats
Bull thistle *(Cirsium vulgare)*	Salt cedar *(Tamarix* spp.)	Klamath weed *(Hypericum perforatum)*	Kentucky bluegrass *(Poa pratensis)*
Cheat grass *(Bromus tectorum)*	Ailanthus *(Ailanthus altissima)*	Wild oats (*Avena* spp.)	Spanish broom *(Spartium junceum)*
Scotch broom *(Cytisus scoparius)*	Russian olive *(Eleagnus angustifolia)*	Fescue (*Festuca* spp.)	Tansy ragwort *(Senecio jacobaea)*
Yellow star thistle *(Centaurea solstitialis)*	Giant reed *(Arundo donax)*	Brome grass (*Bromus* spp.)	Spotted knapweed *(Centaurea maculosa)*
Wild oats (*Avena* spp.)	Harding grass *(Phalaris aquatica)*	Woolly mullein *(Verbascum thapsus)*	Leafy spurge *(Euphorbia esula)*
Fescue (*Festuca* spp.)	Eucalyptus (*Eucalyptus* spp.)	Camel thorn *(Alhagi camelorum)*	Canada thistle *(Cirsium arvense)*
Smooth brome *(Bromus inermis)*	English ivy *(Hedera helix)*		Bull thistle *(Cirsium vulgare)*
Artichoke thistle *(Cynara cardunculus)*	Himalayan blackberry *(Rubus discolor)*		Foxglove *(Digitalis purpurea)*
Wild fennel, anise *(Foeniculum vulgare)*	Periwinkle *(Vinca major)*		Woolly mullein *(Verbascum thapsus)*
Eucalyptus (*Eucalyptus* spp.)	Canada thistle *(Cirsium arvense)*		Halogeton *(Halogeton glomeratus)*
French broom *(Cytisus monspessulanus)*	Bull thistle *(Cirsium vulgare)*		Castor bean *(Ricinus communis)*
English ivy *(Hedera helix)*	Edible fig *(Ficus carica)*		
Fountain grass *(Pennisetum setaceum)*	Black locust *(Robinia pseudoacacia)*		
Himalayan blackberry *(Rubus discolor)*	Purple loosestrife *(Lythrum salicaria)*		
Periwinkle *(Vinca major)*	Lippia *(Phyla nodiflora)*		
Purple starthistle *(Centaurea calcitrapa)*			
Tansy ragwort *(Senecio jacobaea)*			
Spanish broom *(Spartium junceum)*			
Gorse *(Ulex europaeus)*			
Pennyroyal *(Mentha pulegium)*			
Harding grass *(Phalaris aquatica)*			
Smilo grass *(Piptatherum milaceium)*			
Castor bean *(Ricinus communis)*			
Camel thorn *(Alhagi camelorum)*			
Purple loosestrife *(Lythrum salicaria)*			
Giant plumeless thistle *(Carduus acanthoides)*			
Lippia *(Phyla nodiflora)*			
Tree tobacco *(Nicotiana glauca)*			

which has one of the worst problems with nonindigenous species in the world. The Central Valley, measuring 100 km (60 mi) wide and 650 km (400 mi) long, includes 15% of the state's total area. The original California grassland (pre-European settlement) was eliminated by the invasion of introduced annual species during the nineteenth century. Historical accounts of the area's vegetation are vague, but it is likely that two species of perennial bunchgrasses (Nassella cernua and N. pulchra) dominated in many areas (Barbour et al. 1993). In contrast, the present-day grassland is dominated by annual grasses, most of which are introduced. The first introductions began with the Spanish missionaries in about 1769. The effect of these earliest introductions is thought to have been minimal compared to the introductions by migrants moving to the West following the discovery of gold in 1848, who brought with them a huge number of livestock accompanied by contaminated seed lots, imported forage, and packing materials. The cattle and sheep also significantly intensified grazing pressure on native vegetation (figures 47.2 and 47.3). The perennial bunchgrasses, with their flowers and seeds high above the ground, were not well adapted for intense, year-around grazing pressure. It is thought that the native grasses disappeared rapidly with intense grazing and were replaced by grazing-tolerant non-native annual grasses (Mack 1989). In addition, widespread agriculture provided the disturbance and nutrients needed for many introduced plants to outcompete native plants (Mack 1989). Finally, woodland and chaparral communities were burned to make room for grazing and mining, thus changing the fire regime to one that favored annual grasses (Mack 1989).

The condition of the central valley grassland, which lies immediately to the west of the Sierra, has profound effects on the Sierra Nevada. Given the frequency with which land is cleared in the Central Valley, newly introduced plants have a good chance of becoming established and spreading. The Central Valley currently serves as a launching platform for nonindigenous plants, allowing them to ascend to higher elevations (figure 47.4). It may be only a matter of time before species introduced to the Central Valley move upslope into the Sierras. Species like Scotch broom (Cytisus scoparius) and yellow star thistle (Centaurea solstitialis) already exist in the middle-elevation ranges. Riparian areas transecting both the

Central Valley and the Sierra Nevada also provide corridors for possible invasion. The construction of dams and the associated disturbance of natural river flows also make riparian areas more susceptible to invasion (see the section on riparian areas, later in this chapter, for examples).

Oak woodlands form a large ellipse around the Central Valley, covering several million hectares. Three endemic trees dominate the community (blue oak [Quercus douglasii], valley oak [Q. lobata], and gray pine [Pinus sabiniana] [Griffin 1990]), along with interior live oak (Q. wislizenii var. wislizenii) and California buckeye (Aesculus californica). The oak woodlands support more than a hundred species of birds during the breeding season and sixty species of mammals (Barbour et al. 1993). Both black-tailed deer and the acorn woodpecker rely heavily on the acorns from oak trees (Barbour et al. 1993). In most sites, the understory of this community, as is the case in the Central Valley grassland, is dominated by non-native grasses. Within this matrix, additional weedy species are invading, making the habitat less suitable as forage for cattle (Menke et al. 1996). Further, the habitat itself is potentially threatened by the nonindigenous annual grasses. The characteristic overstory dominant blue oak is failing to regenerate within California oak woodlands (Momen et al. 1994). One hypothesis for the failure of blue oak is that it cannot compete with the annual grasses (Gordon et al. 1989; Welker et al. 1991; Gordon and Rice 1993; Rice et al. 1993).

Scotch Broom

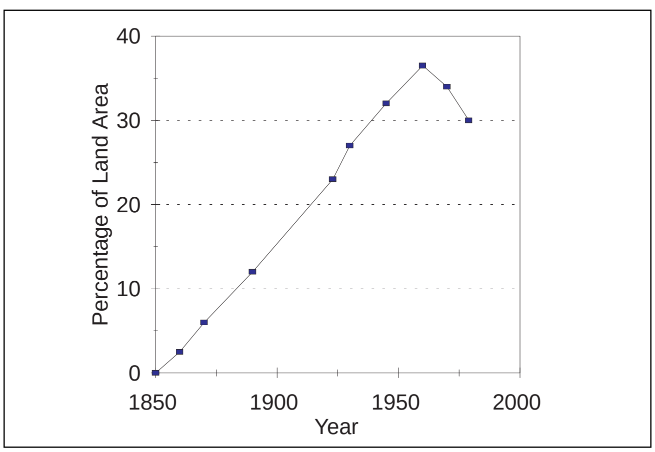
Scotch broom (Cytisus scoparius) presents one of the most severe threats to the oak woodlands of the Sierra foothills. Since its introduction in the 1850s, Scotch broom has spread in coastal and foothill regions and now covers more than 250,000 hectares (618,000 acres). Scotch broom has expanded up out of the oak woodlands to an elevation of 1,200 m (4,000 ft) (C. C. Bossard, telephone conversation with D. J. Porter, spring 1995). As an invasive nonindigenous species, Scotch broom aggressively displaces native vegetation (Andres 1979), making reforestation efforts more difficult (Bossard and Rejmanek 1994). Within the Sierra Nevada, Scotch broom is found in Plumas, Yuba, Butte, Sierra, Nevada, Placer, El Dorado, and Calaveras Counties, primarily around the ponderosa pine forest–chaparral transition, but also along roadsides across both of these habitat types.

Much of Scotch broom's success can be attributed to its weedy life history attributes and to continued habitat disturbance. Scotch broom lives up to seventeen years (M. Rejmanek, unpublished data, 1993) and produces a large number of seeds. It produces two types of seeds, which vary in average distance of dispersal, and maintains a long-lasting seed bank (Bossard 1990a). Scotch broom also has the ability to resprout after being cut or burned (Bossard and Rejmanek 1994), thus defying commonly used eradication methods. Scotch broom has the ability to colonize nitrogen-poor, seasonally dry, frequently disturbed soils (Bossard 1991; Williams 1981; Johnson 1982; Simandl and Kletecka 1989), a combination of edaphic characteristics that is commonly found along roadsides and other places. Frenkel (1970) conducted a survey of California vegetation along roadways and concluded that roads provided both the disturbance needed for establishment of Scotch broom and the corridors for it to spread. Bossard and Rejmanek (1994) found that in the Sierra Nevada, cutting of native vegetation and subsequent soil disturbance promoted the invasion of Scotch broom. Road construction, similarly, facilitates the spread of this plant.

Given the increasing rate of rural development and concomitant construction of roads, it seems likely that Scotch broom will continue to expand its range and zone of heavy impact. Further spread may have a number of ecological and economic impacts. Scotch broom, like many introduced species, provides little value for wildlife, and thus invasion rep-

FIGURE 47.2

Percentage of California land area used for grazing (redrawn from Mooney et al. 1989).



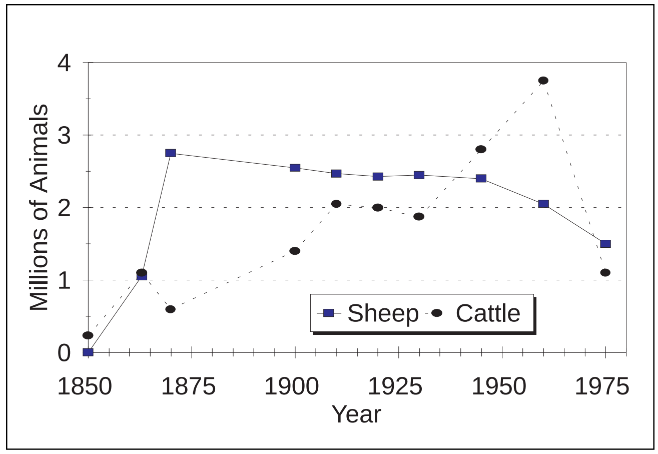


FIGURE 47.3

Sheep and cattle in California (redrawn from Mooney et al. 1989).

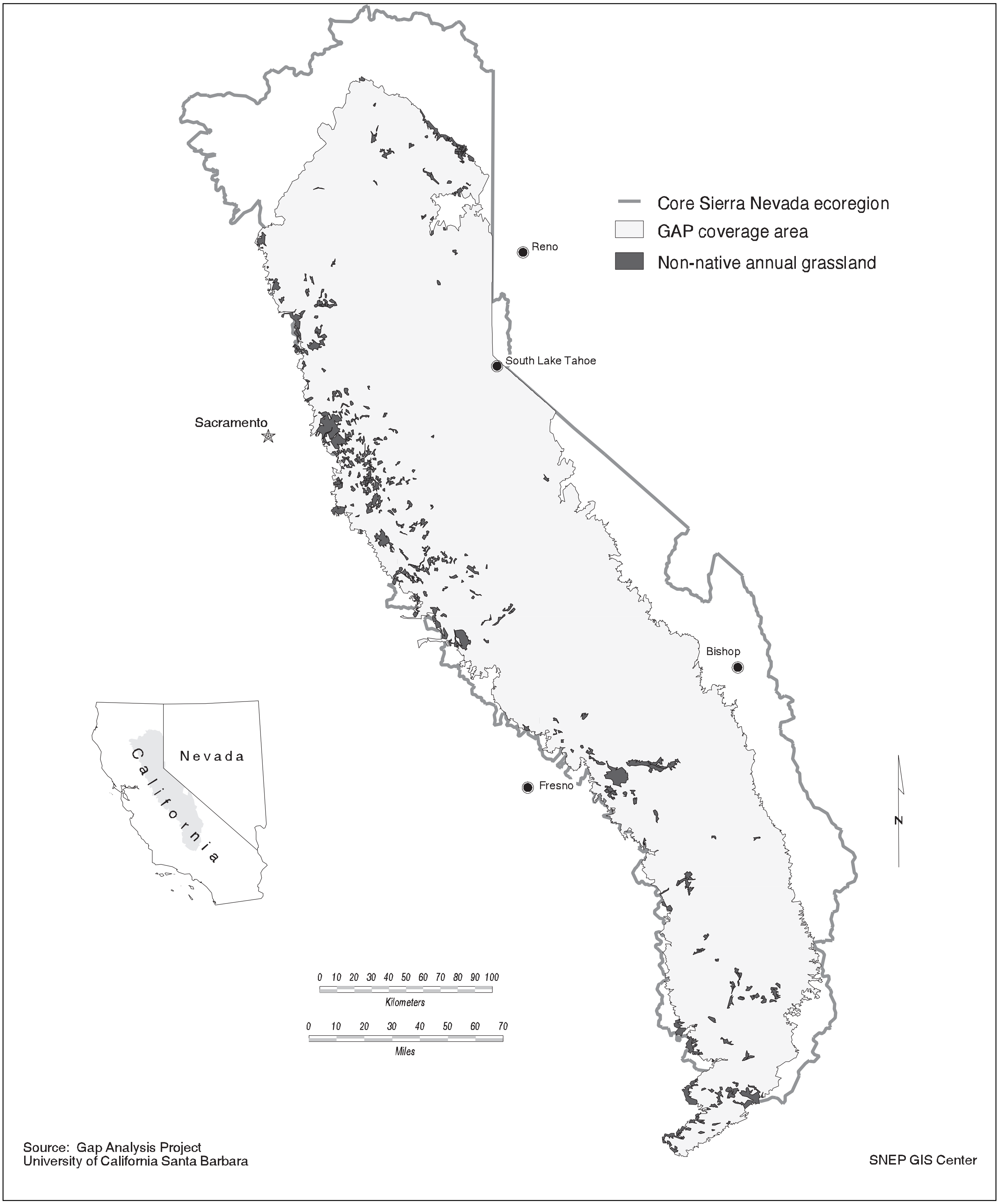


FIGURE 47.4

Non-native annual grassland coverage within the Sierra Nevada ecosystem. Darkly shaded areas represent habitats dominated by non-native grasslands. The *occurrence* of non-native grasses is much broader.

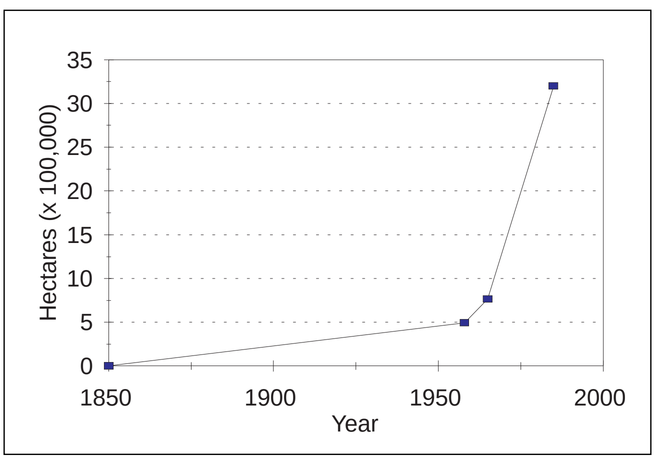
resents a loss of wildlife food resources. No bird or rodent has been observed eating Scotch broom seed, and experiments have shown that there is no significant granivory by vertebrates (Bossard 1990b; 1991). Scotch broom can also affect the survival of pine seedlings. For example, at one site 70% of ponderosa pine seedlings planted were killed following the invasion of Scotch broom (Bossard and Rejmanek 1994). A clear-cut recently conducted without the removal of the adjacent population of Scotch broom resulted in subsequent invasion of the cleared area, forming a dense monoculture and little regeneration of trees (C. C. Bossard, telephone conversation with the author, May 1995). A wide variety of landowners, from environmentalists to timber managers, must now include Scotch broom removal in their management plans.

Yellow Star Thistle

The genus Centaurea is noted for its invasive abilities, with twelve species introduced to the state, three of which are listed as noxious weeds (Hickman 1993). The genus includes purple star thistle (C. calcitrapa), Iberian star thistle (C. iberica) and spotted knapweed (C. maculosa), all found within the Sierra Nevada region. Also within the genus, yellow star thistle (C. solstitialis) is a highly invasive plant now found in most parts of the world (Maddox and Mayfield 1985). Yellow star thistle typically invades grasslands, orchards, agricultural fields, and oak woodlands. Since its introduction in the mid to late 1800s, yellow star thistle has run rampant across U.S. rangelands, displacing native vegetation and reducing forage quality. Surveys were conducted between 1958 and 1985 to assess changes in the coverage of yellow star thistle in California (figure 47.5), with the foothills of the Sierra Nevada among the most heavily invaded regions. Maddox and Mayfield (1985) estimated that nearly 8 million acres were infested in California, with more than 75% of this acreage located in drainage regions of the Sierra Nevada.

FIGURE 47.5

Total acreage estimates of yellow star thistle infestation in California (redrawn from Maddox and Mayfield 1985).



Yellow star thistle has several characteristics conducive to its behavior as an invasive weed. It has broad ecological tolerance and can be found (1) from sea level to 2,500 m (8,200 ft); (2) in deep, well-drained soils or shallow, rocky soils; and (3) in areas that receive between 25 and 100 cm (10 and 40 in) annual precipitation (Maddox et al. 1985). Once established, yellow star thistle populations may expand quickly. The plant produces abundant seeds in many heads, each with 50 to 100 seeds. The seed is dimorphic, with the inner seeds being smaller and bearing a pappus that facilitates wind dispersal as well as secondary dispersal by being caught on animals (Roche 1991). The outer seeds are larger and bear no pappus; they stay in the heads longer and tend not to be dispersed as far. Remaining in the seed heads may allow these larger seeds to have different germination requirements and seed longevity, diversifying the life history strategies and hence enhancing the potential success of this species. The plants also appear to produce toxins that exclude the establishment of other species (Maddox et al. 1985). Sharp spines around the flower heads deter grazers (Roche 1991). Intense grazing provides the disturbance and removal of competing vegetation needed for yellow star thistle to colonize, spread, and dominate an area (Maddox and Mayfield 1985).

The impact of yellow star thistle on ranching operations and recreational use of lands is substantial. Nearly all of the semiarid to subhumid rangeland in the western United States is susceptible to yellow star thistle invasion (Callihan et al. 1982). Although cattle will graze on yellow star thistle in early spring, when the spines are not well developed, the nutritional value is low, and cattle lose weight on a sole diet of yellow star thistle (Maddox et al. 1985). Later in the year cattle will not normally use the plant for forage. The thistle also causes a neurological disorder in horses commonly referred to as “chewing disease” in which loss of mouth control prevents horses from eating, eventually causing them to starve. Further, yellow star thistle invades many additional habitats in the Sierra: grainfields, orchards, vineyards, cultivated crops, pastures, roadsides, trails, and wastelands (Maddox et al. 1985). The thistle spines are as unpleasant to humans as they are to cattle, resulting in a loss of recreational value in infested land. Methods of control are numerous, ranging from mechanical to chemical. Recent studies indicate that carefully timed grazing of yellow star thistle during the bolting, prespiny stage, followed by three subsequent grazing events can significantly reduce populations (Thomsen et al. 1993).

Riparian Areas of the Sierra Nevada

Riparian communities contain more plant and animal species than any other California community type (Schoenherr 1992). Riparian communities extend from high-elevation snowmelts down to the ocean, spanning a wide range of environmental conditions. A long walk along a river or stream from the Sierran crest to the Pacific would reveal a number of unique vegetation types described as riparian communities. High-elevation riparian zones are dominated by quaking aspen, willows, and deciduous shrubs (Schoenherr 1992). Valley oak dominates in the foothills, followed by cottonwoods, box elders, and willows, with an understory of coyote bush, California grape, and poison oak toward the Central Valley (Barbour et al. 1993). The low-elevation riparian communities are threatened primarily by habitat loss because their fertile soil and relatively level profile make valuable agricultural land. Some of California's most expensive agricultural property is former riparian woodland (Barbour et al. 1993). Currently, less than 10% of the original 900,000 acres of Central Valley riparian woodland exists, and more than half of this is degraded (Barbour et al. 1993). Much of this degradation is due to invasion by nonindigenous plants.

Salt Cedar

The salt cedars (Tamarix chinesis, T. ramosissima, T. parviflora) are invasive trees that can transform arid riparian communities into monocultures with diminished ecological and agricultural value. Because of its preference for arid environments, salt cedar is invading mostly in the southern and eastern portions of the Sierra Nevada. Salt cedars have a number of properties that make spread likely and eradication difficult:

- Seed production is prolific: a single tree can produce half a million seeds a year.
- Seed production is prolonged: salt cedars mature seed long into the dry season after co-occurring native species have stopped (Brothers 1981).
- The seeds are small and are distributed widely by wind.
- The seeds germinate where soil remains moist (Neill 1993).
- The plants are fast growing, highly competitive, and drought tolerant, the roots often penetrating deeper to obtain water where native species do not (Griffin et al. 1989).

Salt cedars will often outgrow native species before the drought season and then continue to grow while natives are dormant (Neill 1993). The salt cedars are so invasive that, under optimal conditions, a desert riparian area containing only a few trees can be converted to an impenetrable thicket in less than ten years (Neill 1993).

Salt cedars may also alter the natural flood regime of riparian areas. Native plants are typically swept out of floodplains by seasonal floods, allowing natural regeneration. In contrast, salt cedars grow quickly enough to withstand the seasonal floods. In the Green River of Utah, Tamarix ramosissima has been observed to stabilize riparian soils and induce increased sedimentation, causing a 13% to 57% reduction in channel width (Macdonald et al. 1989, citing Graf 1978). Similarly, artificial changes in the flood regime may promote the establishment of salt cedars. The construction of the Los Angeles aqueduct changed the flow of the Owens River (Inyo County) and the frequency of floods such that the river level was high for most of the year; both flood magnitude and frequency were decreased. Native species have had difficulty becoming established in such conditions, while T. chinesis has established itself and continues to spread (Brothers 1981). Salt cedars may also consume water (via transpiration) faster than other native riparian species, representing a significant pathway for water loss from reservoirs (Brothers 1981). The invasion of salt cedars into Death Valley's Eagle Borax Spring was followed by the complete disappearance of water from what used to be a large marsh. Following the removal of the salt cedars, the water returned (Vitousek 1986; Neill 1983).

Salt cedars continue to spread through Sierra Nevada, particularly at low elevations along stream courses in the northern Sacramento valley, southern San Joaquin valley, the south fork of the Kern River, and near the mouths of streams draining from the east side of the Sierra into the Owens Valley. The potential impact of salt cedars on the Sierra Nevada is substantial. Once established, salt cedars are among the most difficult plants to eradicate. Fire, ground-level cutting, and application of herbicide are ineffective in isolation; all result in vigorous resprouting of the crown (Neill 1993). Successful removal involves combinations of cutting and herbicide application in a labor-intensive program that has proved impractical over large infected areas (Neill 1993).

Russian Olive

Introduced during the colonial period, Russian olive (Elaeagnus angustifolia) has spread to all of the western states. It is an introduced tree with a dense growth form and edible fruit (Olson and Knopf 1986). It can germinate and survive in a wide range of temperature, soil, and moisture conditions (Olson and Knopf 1986; Borell 1976; Elias 1980). Within a ten-year period (1964–74), Russian olive became one of the dominant trees in Arizona's Canyon de Chelly National Monument (Harlan and Dennis 1976). Currier (1982) reports that Russian olive has the ability to decrease site suitability for native cottonwood germination, thus slowing the recovery of degraded riparian areas. Currier (1982) also postulates that Russian olive may increase overbank deposition, eventually transforming a site to a relatively dry upland with Russian olive as the climax species. Russian olive interferes with farming operations and wildlife refuge management efforts by forming dense, monospecific stands that are hard to remove (Olson and Knopf 1986). Once established, it is also difficult to control and virtually impossible to eradicate (Olson and Knopf 1986). Mowing seedlings, cutting, burning, spraying, girdling, and bulldozing have all been used to remove Russian olive, with limited success (Olson and Knopf 1986). Like the salt cedars, Russian olive may also tolerate changes in river flow due to aqueduct construction better than native species (Brothers 1981). In contrast to most nonindigenous plants, Russian olive provides good food and cover for a number of species such as sharp-tailed grouse, fox squirrels, whitetailed deer, and non-game birds like northern flickers and black-headed grosbeaks. Knopf and Olson (1984) report that the spread of Russian olive may widen some riparian woodlands and benefit the avian species that depend on tall shrubs.

Russian olive currently presents a threat to the Sierra Nevada ecosystem in three areas: the Mojave River bed near Victorville, a small area near Antioch, and along Lone Pine Creek in Inyo County (Olson and Knopf 1986). Detailed accounts from Olson and colleagues note that Inyo County is the only area in California where Russian olive infestations are extensive; however, the species has been reported near Oroville (northern California) and along the Cosumnes and Mokelumne Rivers (near Sacramento) (Olson and Knopf 1986, citing unpublished reports by D. Barbe, B. Bartholomew, O. Clark, T. Combs, M. DeDecker, G. Levi, and W. Wisura). Given the lack of information on community effects and the persistent nature of this species, we recommend that Russian olive be watched carefully and eradicated where resources are available.

Ailanthus, or Tree of Heaven

Ailanthus (Ailanthus altissima) was first introduced to the United States in 1784 from Asia (Heisey 1990). Since its early introduction, ailanthus has invaded most of North America, quickly gaining a reputation for its persistence in harsh, urban environments, where it withstands drought, poor soil, and pollution. Even under such poor conditions, ailanthus can grow to 15 to 18 m (50 to 60 ft) tall with a dense canopy. The potential to transform desolate and barren city streets into shaded urban forests was immediately recognized, and ailanthus has frequently been used as a street tree (Newton 1986). Ailanthus vegetatively reproduces well from long lateral roots, sending up sprouts as far as 15 m (45 ft) away from the original tree (Hunter et al. 1993). The cutting of unwanted stems often results in resprouting. It is likely that ailanthus was brought to California's Sierra Nevada foothills by Chinese immigrants working in the gold mines in about 1850 (McClintock 1981). A number of trees were planted near the Placer mining camps and from there spread to the surrounding areas (McClintock 1981). By 1936, ailanthus had spread throughout much of California, so much so that it has been referred to as the only tree in California that is "aggressively spontaneous" (McClintock 1981).

Ailanthus is a fast-growing tree, with seedling growths of 1 to 2 m (3 to 7 ft) in the first year (Miller 1965) and vegetative sprout growths of 3 to 4 m (10 to 13 ft) in a year (Miller 1965). Ailanthus competes well above ground by overtopping many of the surrounding trees and below ground with an extensive and adaptable root system. It has the ability to send out fibrous lateral roots in search of water, and can form a long taproot to extract water from deeper sources (Miller 1965; Newton 1986; J. Hunter, University of California, Davis, conversation with the author, May 1995). Further, ailanthus is allelopathic (produces toxins that exclude the establishment of other species) on more than thirty-five species of hardwoods and thirty-four species of conifers (Miller 1965). The seeds (samaras) of ailanthus are small, wind dispersed, and numerous (more than 1 million per tree) (Hunter 1995). The seeds often remain on the tree and are dispersed throughout the winter (J. Hunter, conversation with the author, May 1995). The expansion of ailanthus appears to be limited by a closed forest canopy (ailanthus is shade intolerant) (Miller 1965). Further, wind, snow, and hard freezes seem to kill the tops of seedlings, possibly excluding ailanthus from higher elevations. It has, however, been known to sprout vegetatively in shaded areas and to resprout following wind, snow, or freeze damage (Miller 1965).

Data describing the current distribution of ailanthus are sparse, but large populations are known to exist in several regions, for example, at Angels Camp in San Andreas County (Robbins et al. 1951). Ailanthus is known to invade riparian zones of the Sierra Nevada foothills (McClintock 1981; J. Hunter, conversation with the author, May 1995; M. Rejmanek, University of California, Davis, conversation with the author, May 1995). It does not seem to invade much above 1,000 m (3,280 ft) (M. Rejmanek, conversation with the author, May 1995). Scientists and land managers generally agree that the problems associated with ailanthus invasion have just begun. Although very little is known about the effects of ailanthus on community diversity, most people familiar with the tree agree that without action it will expand in riparian systems.

The Eastern Slope of the Sierra Nevada

Owing to the rain shadow created by the Sierra Nevada, there is a sharp environmental gradient from the relatively moist crest of the Sierra down the eastern slope to some of the most arid environments in North America. Desert regions in California are, in general, common and cover close to 28 million acres, or approximately 28% of the state (Barbour et al. 1993). The desert communities of California, often severely degraded by mineral extraction, water diversion, military training, suburb expansion, and motorized recreation, recover very slowly (on the order of hundreds of years) (Barbour et al. 1993). Exacerbating the current pressures on desert communities are a number of aggressive nonindigenous plants introduced by early European settlers.

The vegetation of the eastern slope varies considerably with altitude and latitude (Barbour and Major 1988) . The slope vegetation of the Great Basin desert is dominated by a mixture of woody shrubs such as Great Basin sagebrush, rabbitbrush, and bitterbrush. In pristine, ungrazed sites, native perennial grasses make up the understory of this two-layer landscape, but in most places non-native grasses have replaced the native species. In the southern Sierra, the Mojave slope vegetation is dominated by an overstory of evergreen creosote bush, burro bush, and brittle bush. The understory of native annual and perennial species has also been largely replaced by nonindigenous plants. The problems caused by introduced plants in this habitat are exemplified by one single species that is the most widespread and pervasive of all weeds in these arid grasslands: cheat grass.

Cheat Grass

Cheat grass (Bromus tectorum), being indigenous to Central Asia, has a long association with human occupation and disturbance. Cheat grass is well adapted to frequent burning, intense grazing, and agriculture, and so it spreads rapidly in disturbance-dominated landscapes. In its native range, cheat grass thrives in chronically disturbed grasslands (Pierson and Mack 1990a, citing Hess et al. 1967). Like with many of the early introductions, cheat grass probably came to the western United States via contaminated seed lots in the mid to late 1800s (Mack 1989). When introduced to western North America, cheat grass encountered an equitable climate, ample disturbance, and a landscape free of its associated pests and pathogens. Its spread was rapid, filling more than 200,000 km^2 (80,000 mi^2) of the intermountain west in just forty years (Mack 1989). Cheat grass now dominates much of the arid western United States and the eastern slope of the Sierra Nevada, having both negative ecological and negative economic impacts. It and a related species, B. rubens, now dominate much of the annual flora in California and the Mojave desert (Hunter 1991).

In presettlement times native ungulates browsed on overstory shrubs, which resprout following herbivory, leaving the native understory grasses relatively untouched. Cattle and sheep, in contrast, prefer understory grasses. The mass introduction of livestock completely changed the local grassland grazing regime. Large areas of ground were cleared and disturbed. Successful pioneer species, such as cheat grass, do well in these situations because they exploit the available resources quickly. Cheat grass has an efficient seed dispersal mechanism, making colonization of recently grazed sites more probable (Ellner and Shmida 1981; Levin et al. 1984). Further, cheat grass is an efficient competitor for several potentially limiting resources in arid environments: (1) it rapidly sequesters nitrogen, which is typically seasonally depleted to the point that it limits plant growth in arid desert environments; (2) it appears to grow its root system faster than native species (a proposed mechanism by which it competitively displaces the native Agropyron spicatum [Harris 1967]); and (3) it has the ability to grow under shrubs, where soil is relatively fertile (Hunter 1991, citing Soholt and Irwin 1976).

One of the principal negative impacts of cheat grass has been to promote wildfire (Macdonald et al. 1989; Macdonald et al. 1988). Most perennial grasses of North America mature slowly and do not dry out until after the fire season has passed (Macdonald et al. 1989). In contrast, cheat grass matures in early June and dries one to two weeks after maturity (Macdonald et al. 1989). Earlier drying and high biomass production increase fuel loads and increase fire hazard. After a fire, cheat grass quickly germinates, recolonizes, and expands, resulting in stand domination (Macdonald et al. 1989). The ubiquitous nature of cheat grass makes revegetation with native species impractical (Barbour et al. 1993). From an economic standpoint, cheat grass has several disadvantages as a forage grass: it grows slowly in the spring, has a short "green feed" period, is highly flammable in the summer, and has a highly erratic yield from year to year (Melgoza et al. 1990). Poor-quality food means that ranchers require more land to support the same number of cattle and sheep than if they had native grass pastures available. Cheat grass has also reduced agricultural yields in the Great Basin desert (Hunter 1991, citing Morrow 1984).

While cheat grass peaks in abundance in grassland communities, it is also found in forest communities, even in subalpine zones (Hess et al. 1967). Sheep and cattle bring cheat grass seeds into Sierran forest communities, although these forest populations do not persist (Pierson and Mack 1990a). Deep forest litter appears to inhibit the germination and growth of cheat grass (Pierson and Mack 1990b). The species also seems to be more apparent in forest communities, making it highly susceptible to grazing by small native mammals (Pierson and Mack 1990b). Finally, shading limits populations of cheat grass (Pierson et al. 1990). In relatively sparse forests, such as those dominated by ponderosa pine and Douglas fir, cheat grass can establish populations with understory disturbance, but in denser forests, such as those dominated by fir and cedar, simultaneous disturbance of both the understory and the overstory is required for establishment. Current fire-suppression policies have minimized the amount of understory disturbance, resulting in a dense understory. Crown wildfires, as well as prescribed burning, however, could promote the invasion of grass species.

Other Problematic Invasive Plants of the Sierra Nevada

A large number of additional species also pose problems in the Sierra Nevada. Himalayan blackberry (Rubus discolor) infests riparian and moist areas below 1,600 m (5,280 ft). When present, Himalayan blackberry forms dense thickets. It is favored by rats for food and shelter, providing additional ecological problems (Hickman 1993). Mullein (Verbascum thapsus), Canada thistle (Cirsium arvense) and bull thistle (Cirsium vulgare) infest middle-elevation Sierran meadows, including those in Yosemite Valley, as well as clear-cuts in the Eldorado National Forest. Canada thistle is a rhizomatous plant that has become very difficult to control; stems are easily killed, but individuals are not. Foothill grasslands are literally inundated with additional Mediterranean annual grasses (Avena fatua, A. barbata, Bromus diandrus, B. mollis, Hordeum spp., Lolium multiflorum, and Taneatherum caput medusae, to name a few), in addition to cheat grass and a wide range of herbaceous species (e.g., Elodea canadensis, Lythrum salicaria, etc). This overview has merely given a synopsis of the worst species in the most heavily infested habitats, and is by no means an exhaustive discussion of the problem.

RELATIONSHIPS BETWEEN PLANT INVASIONS AND ANTHROPOGENIC DISTURBANCE

Human Land Use

The single most influential factor allowing one to predict problems with nonindigenous plant species in the Sierras is estimating development pressure. Development pressure creates potential invasion problems through increases in: (1) the extent of habitat disturbance through road and other types of construction; (2) the amount of plant material sold through horticulturalists; (3) the quantity of nonnatural habitats (yards, pastures, etc.) that support populations of potentially problematic species; (4) the importation of landfill that may carry seeds of invasive nonindigenous species; and (5) the movement of humans and their domesticated animals that may be bearing seeds of invasive weedy species. This list provides just a few of the examples by which human presence directly increases the risk of creating an ecologically harmful and potentially expensive nonindigenous plant problem. Quite simply, increased human presence means increased risk of plant invasion. Beyond these obvious mechanisms, however, there are several less obvious ways in which human alteration of the natural landscape has made it possible for nonindigenous species to invade natural habitats.

Fire

Fire can promote the invasion of nonindigenous plants by creating open space for new seed germination. Humans influence the amount and types of fire that occur on a landscape. In the early twentieth century, the United States adopted a stringent policy of fire suppression to prevent the destruction of forests and property. This policy did not recognize the importance of forest ground fires. Prior to fire suppression, frequent ground fires maintained an open understory and an intact overstory. With fire suppression, the plant density of the forest understory has increased, making catastrophic fire more likely (Skinner and Chang 1996). In addition, vegetation changes such as the increased dominance of white fir increase the likelihood of ground fires being transported to the canopy and turning into stand-clearing crown fires. Fire frequency in chaparral communities has been reduced to protect property, allowing fuel loads to build. Crown fires and intense chaparral fires frequently leave behind expanses of bare ground, which favor the invasion and establishment of new species, including nonindigenous plants. Nonindigenous plants are typically characterized by efficient seed-dispersal mechanisms that allow them rapidly to colonize newly opened sites. Aggressive species, such as those described earlier, once established, competitively exclude native understory plants and hinder the establishment of trees and other native species.

Nitrogen Deposition Pollutants

The nitrogen cycle, upon which plants and animals depend, is being augmented by human activities. Nitrogen is an essential building block of all proteins, as well as the predominant atmospheric gas. (Approximately 80% of the atmosphere is nitrogen.) Animals acquire nitrogen, directly or indirectly, through plants. Plants, however, can utilize nitrogen only when it is found in the soil in one of two compounds, ammonium or nitrate. These compounds are seasonally depleted in most soils, and nitrogen availability often limits plant growth in natural habitats. Currently, society produces mass quantities of fixed nitrogen (mostly for fertilizer, but also as a pollutant emitted by cars and as industrial waste), effectively fertilizing the earth's surface. The added nitrogen disrupts the natural cycle and changes the relationships between plants and animals. Anthropogenic nitrogen fixation has risen steadily throughout the twentieth century and currently exceeds the combined natural nitrogen fixation of plants and microorganisms. Vitousek (1994) estimates that approximately 50% of all industrial nitrogen fertilizer used in human history through 1992 has been applied since 1982.

Nonindigenous plants often compete well in artificially enriched sites (witness the preponderance of pest plants in agricultural settings). A number of experimental studies have shown that artificial augmentation of soil nitrogen can promote the invasion of introduced plants. Huennecke et al. (1990) confirm that increased nutrient availability, without physical disturbance of soil or native vegetation, can favor the invasion and success of introduced weeds in an ecosystem where natural levels of resources are low. Heil et al. (1987) have shown that small increases in soil ammonium were sufficient to change the competitive relationships among species in favor of the faster-growing, nonindigenous weeds. While the relationship between nitrogen deposition and plant invasion has not been studied specifically in the Sierra Nevada, there are observations and data that may help guide further research.

Cahill et al. (1996) summarizes the biological effects of air pollution, including nitrification, in the Sierra Nevada. The Sierra Nevada serves as a sink for atmospheric nitrogen. (Miller 1995). Over time, increased deposition rates could lead to altered nutrient cycling and eventually to nitrogen saturation. Already water from the San Gabriel Mountains exceeds federal standards for nitrogen content in drinking water, and nitrate levels in the southern Sierra Nevada and San Bernardino Mountains are among the highest in the nation. Cahill et al. (1996) also notes that nitrogen accumulation appears to be a distinct characteristic of California wildlands exposed to photochemical smog. Nitrogen deposition in the Sierra is an ongoing problem and, while more chronic in close proximity to urban areas, is likely to have long-term negative effects on native species in the Sierra by increasing the importance of nonindigenous species.

Carbon Dioxide

Increased levels of CO_2 associated with human combustion of fossil fuels is well documented. Like nitrogen, CO_2 is often a limiting resource for plants, and its enhancement increases biomass production (Melillo et al. 1990). Increases in CO_2 are also likely to change the competitive abilities of plants (Melillo et al. 1990). Plants are divided into three broad categories, based on their photosynthetic pathway. The three pathways are similar but differ physiologically in ways that are important to the plants' survival. C_3 plants are the largest group of plants and include many introduced pest plants. These plants, in general, respond more to increased CO_2 levels than the other two groups (C_4 and CAM) of plants (Bazzaz 1990; Poorter 1993, Melillo et al. 1990). In addition, species with rapid growth rates (a common characteristic of nonindigenous invasive species) may be more responsive to added CO_2 than species with slower growth rates (Hunt et al. 1990; Poorter 1993).

MECHANISMS TO LIMIT NONINDIGENOUS SPECIES AND REMEDIATE CURRENT DAMAGE

Overview of the Current Status of Regulations

The regulation of introduced pest species is a loose patchwork of federal, state, and local laws and ordinances. Regulation efforts focus on economically important industries such as agriculture, aquaculture, and forestry, giving minimal attention to the protection and restoration of natural areas. For example, in 1992, more than $100 million was spent on agricultural quarantine and port inspection for introduced species, compared to $3 million spent on port inspection for species posing threats to natural areas (OTA 1993). Most regulatory organizations, like the Animal and Plant Health Inspection Service (APHIS), lack the funding and technical expertise to handle the problems and research associated with introduced species. In fact, the Office of Technology Assessment's survey of state fish and wildlife agencies found that a clear majority (63%) favored an increased federal role in addressing problems with introduced species (OTA 1993). The decentralized approach to introduced species, coupled with the lack of funding, has both short-term and long-term consequences. Currently, nonindigenous species that are known to be problematic are still legally imported. Education on the nonindigenous species problem is typically ranked as a low priority in most state and federal agencies and private organizations involved with natural resources, receiving less than 1% of their budgets (OTA 1993). The California Exotic Pest Plant Council (EPPC) is using voluntary restrictions and education as its primary tools to limit the potential hazard of additional problems with nonindigenous species in California. An in-depth discussion of all the laws, ordinances, and local efforts is beyond the scope of this report. The Office of Technology Assessment's report (OTA 1993) provides a thorough treatment of this subject. A few of the federal laws pertaining to nonindigenous plants, some model state ordinances and organizations, and the regulatory bodies of California are briefly highlighted in the paragraphs that follow.

APHIS does much of the current risk assessment for introduced species primarily using two federal laws (the Federal Noxious Weed Act [FNWA] and the Federal Seed Act) to prevent the import of potentially invasive plants. The FNWA prohibits the importation of listed noxious weeds and provides the authority to quarantine species entering the country. There are, however, a number of problems with the implementation of the act. The major problem is the cumbersome nature of the listing process. In eight years, APHIS has placed 93 species on the current list of federal noxious weeds, even though more than 750 weeds meeting the act's definition remain unlisted (OTA 1993). There is no emergency mechanism in the FNWA to allow rapid action in cases of unlisted species known to have large negative effects, despite a recognized backlog. Another major problem associated with this act is APHIS's narrow interpretation of the interstate transport sections of the FNWA. Section 4 of the FNWA requires a permit for moving listed species between states. APHIS interprets this section as applying only to species for which a specific quarantine has been issued under Section 5 and has issued only one such quarantine in eighteen years. As a result, at least nine known noxious weeds were sold in interstate commerce as of 1990 (OTA 1993). The proposed 1990 Farm Bill, which did not become law, included several amendments to the FNWA that would have required each Federal and land management agency to establish and fund an "undesirable plant management program" for lands under their jurisdiction (OTA 1993). A proposed 1995 Farm Bill contains many of the same amendments.

The Federal Seed Act provides for accurate labeling and purity standards (or impurity tolerance standards) for seeds in commerce (OTA 1993). By 1993, only twelve species had been listed under this act, only one of which is also among the ninety-three noxious weeds listed by the FNWA. Clearly, the issue of whether seeds of FNWA-listed species should be banned is not resolved at this time. Both FNWA and the Federal Seed Act are barely effective in preventing the introduction and transport of agricultural weeds, and neither mentions nonagricultural nonindigenous plants. Natural communities are also not recognized in most of the local protocols regarding unplanned introductions of nonindigenous species (Ruesink et al. 1995).

A thorough review of state regulations by the Office of Technology Assessment (OTA 1993) highlights some exemplary state efforts. Georgia has addressed what may be the most ill-founded principle in the species introduction issue, burden of proof of safety. Currently, APHIS takes full responsibility for assessing the risk of incoming species. The agency generally treats unregulated imports under the presumption "that everything is enterable until we (APHIS) determine it should not be" (OTA 1993). Given that we have yet to successfully eradicate any nonindigenous species other than the smallpox virus, the burden of proof would, logically, lie in proving a species safe prior to importation. Georgia treats the importation and release of nonindigenous plants as a privilege to be granted only upon "clear demonstration" that review criteria are met (OTA 1993).

State regulation, like overall regulation, is a patchwork of groups with significant gaps. Some states, like Hawaii, have conducted thorough reviews of their organizations to find such gaps. After its review, Hawaii found that no organization was addressing the problem of weeds entering forest communities. As a result, Hawaii has written an interagency agreement to research the biological control of forest weeds (OTA 1993). Other state groups have filled similar gaps. The Exotic Pest Plant Council (EPPC) of Florida is a collection of agency officials, botanists, and other environmentalists who focus on nonagricultural introduced plants that threaten biodiversity. This council has succeeded in passing the only model local law that addresses introduced plant species. The law combines the eradication of nonindigenous pest plants with land development. Predevelopment removal of introduced plants and tax reductions for property owners who remove them are two ways this law promotes responsible development. In California, a similar organization based on the Florida model was formed in 1992.

Proposed Responses within the Sierra Nevada

Seven steps can be identified that would help limit the flow of nonindigenous species into the Sierra Nevada (table 47.2). The least stringent of these responses would be to seek voluntary compliance from nurseries and horticulturalists in stopping the sale and planting of recognized problem species within the Sierra. A proposed list has been provided by the California Exotic Plant Pest Council and is summarized in table 47.1. Lacking sufficient state and federal legislation, California's EPPC has adopted this strategy.

In assembling this report we conducted a survey of nursery operators and their customers in El Dorado County. Appendix 47.1 contains a full description of the methods, questions asked, and frequencies of responses to the survey. Eighteen nursery owners and thirty-eight customers participated in the survey. Although it does not represent a random sample of merchants and residents of the Sierra, and despite the small sample size, the survey is informative because it suggests that the implementation of simple educational programs could substantially reduce the risk of nonindigenous species in the Sierra. We found that most nursery owners are fairly knowledgeable regarding problematic nonindigenous plants. The typical nursery owner would not be willing to restrict the product lines sold to only native species, but would shift away from selling nonindigenous species that invade natural habitats and would be willing not to sell them. Owners typically do not track the proportion of their sales of native species to non-native ones.

The second recommended step is to increase educational programs and horticultural incentives to plant native species. In our survey we found that most nursery customers are substantially less well informed than the nursery owners but just as well intentioned. That is, they would forgo purchasing a plant product that was viewed as problematic, but for the most part they lack the information they need to act as environmentally friendly consumers.

These two steps alone would help alleviate many problems, because the intentional planting of problematic exotic species is one of the major driving forces of our expanding problems with exotic pest plants. The third step is to create a legislative constraint similar to the Georgia model that places the burden of proof for the introduction of any additional nonindigenous species upon the importer. Those who wish to market new plant products would need to demonstrate clearly that a species proposed to be introduced is not invasive in Sierran habitats. These first three recommendations could be implemented with relatively little direct cost and little impact on commerce.

Our fourth recommended step is to adequately fund eradication programs for species whose spread and impact we have a chance to contain (e.g., ailanthus and Scotch broom). This process of attacking the vanguard of spreading populations is most likely to be effective in controlling problem plants, but is somewhat counterintuitive. Our impulse is to fund a massive program to eradicate a clearly widespread problem like cheat grass. It may be more effective and more economical, however, to eradicate new and currently sparse populations of species that, if let go, may become the next cheat grass.

Fifth, we recommend funding specific research programs in biological control, or natural herbicides, for those species such as cheat grass and yellow star thistle that are already chronic problems. Sixth, land managers can identify sites that are currently relatively free from exotic pest plants and maintain them as "clean" sites. These latter three steps require expenditures.

Our seventh recommendation is to restrict the sale of nonnative plant species that are recognized as problems. This seems like an obvious and necessary first step in the control of nonindigenous plant species, but it has proven very difficult to implement because of resistance from nurserymen's associations.

CODA

Despite a recognized threat and seemingly adequate restrictions, the Asian gypsy moth was recently accidentally im-

TABLE 47.2

Seven steps proposed to limit the impact of nonindigenous plants in the Sierra Nevada.

Cost and Impact of Program	Steps
A. Programs for which there would be little direct cost or direct impact on commerce.	1. Seek voluntary compliance in stopping the sale and planting of recognized exotic weed problem species within the Sierra. 2. Increase educational programs regarding the cost of exotic species introductions, and provide incentives to plant native species. 3. Legislate constraints that place the burden of proof for the introduction of species not currently propagated or sold in the Sierra upon the importer, who would need to demonstrate clearly that the proposed species is not invasive.
B. Programs for which there would be a substantial direct cost but no negative (and possibly a positive) impact on commerce.	4. Adequately fund eradication programs. 5. Fund research into biological control, or natural herbicides, for chronic pest plants such as yellow star-thistle and cheat grass. 6. Identify "safe site" regions and maintain them free from exotic pest plants.
C. Programs for which there may or may not be a direct negative impact on commerce.	7. Cease and desist the sale of recognized problematic non-native pest plant species.

ported to the Pacific Northwest, resulting in an emergency eradication effort costing $14 million to $20 million. Further, while habitat management stops at political boundaries, fluxes of water, particulates, and organisms do not (Saunders et al. 1991). Likewise, legislative boundaries are not biological boundaries. Restrictions can not safeguard against the next yellow star thistle or cheat grass to invade the Sierra. Luckily, relatively few high-elevation species have been introduced into California. However, the expansion of human populations into higher elevations, bringing with them a desire for new horticultural varieties, is likely to result in additional species that the Sierra will be saddled with forever. While there can be no absolute safeguard from nonindigenous pest plants, there are several constraints that could easily be invoked that would limit the likelihood of introducing a particularly severe problem. Lest we think that by this point in the twentieth century the Sierra is saturated with exotic pest plants, we should bear in mind that zebra mussels, the Asian gypsy moth, and tiger mosquitoes have all been introduced to the United States within the past decade, and all already cost millions of dollars in control efforts. The curve of increasing numbers of introduced species in the California flora appears exponential and shows no tendency toward leveling off. With the current level of control, it is only a matter of time before we will be paying, in real dollars, for the impact of yet another new nonindigenous pest plant.

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APPENDIX 47.1

Survey of the Opinions of Nursery People and Their Customers Concerning the Use and Spread of Nonindigenous Plant Species in El Dorado County, California

Introduction

Purpose: These surveys were conducted to learn about the opinions and awareness of professional nursery people and their customers on the issues surrounding the use and spread of non-native and invasive species. El Dorado county was chosen as a geographical location for the survey as it is within the SNEP project boundaries, spans diverse rural and urban areas and is easily accessed from Davis, CA.

General Methods: The survey questions were designed to gain descriptive information about public opinions; in other words, to elucidate what people thought, not why. For this reason no demographic questions were included in the surveys. In addition, questions of a personal nature were avoided so that people felt comfortable when administering and completing the survey. Guidelines developed by deVaus (1990) were used in the survey design.

Nursery Surveys

Methods: Managers or owners of 18 nurseries (Table 1) were surveyed by phone. The surveys consisted of 11 questions (Figure 1). Nurseries were chosen from either the directory of the California Association of Nurserymen or the El Dorado county phone book.

Table 1

Participating Businesses (Business and Customer [c] Surveys)	
Add Growers (Rescue)	Frontyard Nursery & Landscape (Placerville)
Anderson Backhoe & Trucking (Camino)	Georgetown Divide Supply, Inc. (Greenwood) **(c)**
Blue Oak Growers (Rescue)	Gold Hill Nursery (Placerville)
Camino Garden Center (Camino)	Green Valley Nursery & Landscape (Rescue) **(c)**
Carter's Garden & Pet Supply (Placerville)	Hall's Pleasant Valley Supermarket (Rescue)
Clifton & Warren (Placerville)	Homebuilder's Outlet (Placerville)
Divide Nursery (Cool) **(c)**	Maple Leaf Nursery (Placerville)
Dusty Creek Lumber (El Dorado Hills)	Pollock Pine True Value Hardware (Pollock Pines)
Foothill Nursery (Shingle Springs) **(c)**	Red Bed Farms (Georgetown)

<u>Results:</u> The one nursery owner in the Tahoe region with whom we were in contact consistently failed to return our calls. Therefore, all nurseries surveyed are in the western foothills of the Sierra Nevadas near Placerville and Auburn. Although the owner of the Lotus Valley Nursery & Gardens

Figure 1

Nursery Survey with Results
(n=18, % response to question found in parenthesis)

1. Are you familiar with any of the following plants that are considered to be invasive in your area? (check boxes)	☐ Scotch broom (*Cystisus scoparius*) (94%) ☐ Cheat grass (*Bromus tectorum L.*) (22%) ☐ Tree of heaven (*Ailanthus altissima*) (61%) ☐ Gum tree (*Eucalyptus*) (89%) ☐ Russian olive (*Elaeagnum angustifolius L.*) (56%) ☐ Bull thistle (*Cirsium vulgare*) (61%) ☐ Kentucky Blue Grass (*Poa pratensis*) (94%) ☐ Yellow star-thistle (*Centaurea solistitialis L.*) (100%) ☐ Salt cedar (*Tamarix*) (56%) ☐ None (0%)
2. Approximately what percentage of your inventory is made of these plants? (Circle your answer from the following choices)	0% (56%) 20-39% (0%) 60-79% (0%) 1-19% (44%) 40-59% (0%) 80-100% (0%) DNK (0%)
3. Would your business suffer if you could not sell one or more of these species?	YES (0%) NO (100%) DNK (0%)
4. Can you name any plants in your inventory, not mentioned above, that you suspect to be invasive out of a garden setting? (Please list)	
5. Do you maintain records of the number of native and non-native species in your inventory?	YES (17%) NO (83%)
6. If not, have you considered maintaining these sorts of records?	YES (17%) NO (67%) N/A(17%)
7. Approximately what percentage of your inventory is in native species?	0% (11%) 20-39% (17%) 60-79% (0%) 1-19% (39%) 40-59% (6%) 80-100% (6%) DNK (22%)
8. Do some of your customers distinguish between native and non-native species?	YES/occasionally (61%) If no, go to #10
9. Which do they request more often?	NATIVE (6%) NON-NATIVE (56%) DNK (0%)
10. If you had access to the appropriate information would you sell only non-invasive species?	YES (78%) NO (11%) DNK (11%)
11. If you do not already, would you consider selling only native species?	YES (6%) NO (83%) DNK/NA (11%)

refused to participate in the survey, all others were very cooperative.

Question #1: All 18 business people surveyed were familiar with yellow star-thistle and 17 (94%) were familiar with scotch broom and Kentucky Blue Grass (Figure 2). Familiarity with Eucalyptus was also noteworthy at 89%.

Figure 2

Question #1 Customer and Business Surveys		
plant name	% familiar (customers) (n=38)	% familiar (businesses) (n=18)
Scotch broom	82	94
Cheat grass	03	22
Tree of heaven	37	61
Gum tree	26	89
Russian olive	13	56
Bull thistle	37	61
Kentucky Blue Grass	32	94
Yellow star-thistle	82	100
Salt cedar	08	56

Question #2: Fifty-six percent sold none of the species listed in question #1. The remainder either sold one of the brooms, Eucalyptus, russian olive or a grass as part of a grass mix. The manager at the Green Valley Nursery and Landscape added that they were sure to warn their customers about potential problems with those species that were notoriously invasive. However, invasiveness seems to be more troublesome to nursery people and their customers within a gardening context.

Question #3: One-hundred percent of those surveyed answered that their business would not suffer if they could not sell the species listed in question #1.

Question #4: Species stated to be potential invasives outside of garden settings were:

- *Oenothera* (spp?)
- Ivy
- *Ceanothus* (spp?)
- *Baccharis* (spp?)
- other Brooms
- *Euphorbia* (spp?)
- Poplar
- Black Locust
- *Vinca* (spp?)
- Blackberries
- Bamboos
- *Convolvulus* (spp?)
- Honey Suckle

Question #5: Eighty-three percent answered that they did not maintain records of the number of natives and non-natives in their inventory. One of those that answered "yes" also stated that they "maintained records on everything".

Question #6: Ten of the 15 that answered no to #5 (that they do not maintain records on the number of natives in their inventory) have not considered maintaining these sorts of records. Five said that they had considered it.

Question #7: Thirty-nine percent said that their inventory consisted of between 1 and 19% natives. Eleven and 17% said that their inventory consisted of 0% and 20-39%, respectively. Hall's Pleasant Valley Supermarket/Nursery said their inventory consisted of between 80-100% natives. Twenty-two percent did not know how much of their inventory was in natives.

Question #8: Sixty-one percent of those surveyed said that their customers occasionally distinguished between natives and non-native species. The remainder said that their customers did not.

Question #9: Of the eleven that answered "yes" to #8, ten answered that their customers request non-natives most often. The one business that answered "natives" to the question is Blue Oak Growers, a nursery specializing in natives.

Question #10: Seventy-eight percent answered that they would sell only non-invasive species if they had access to the appropriate information. Eleven percent (or two businesses) answered that they would not sell only non-invasives and another two that they did not know.

Question #11: Eighty-three percent said that they would not consider selling only native species. Six percent (1 business) answered "yes" and 11% did not know.

Discussion: Most of those surveyed conveyed a feeling of concern for the problem with invasive species in their area. All, save Lotus Valley Nursery and Garden, responded favorably to our request for their time and were willing to discuss some of their feelings after the survey was conducted. Some were amused when asked if they were familiar with species such as yellow star-thistle and scotch broom. Lotus Valley Nursery and Garden felt very strongly about their right to import and sell exotic species and gave us a leaflet, written by seedsman J.L. Hudson, to further express their views.

Question #5 on occasion seemed to elicited default responses. Some assumed that if they maintained records on all species they automatically had records on the native/non-native status of those species. No explanation of the meaning of the question was offered so that standardization could be maintained. Most did not want to bother keeping these types of records.

Blue Oak Growers was the only business in the survey that specialized in native species. On question #7 they answered that their inventory consisted of between 40-59% natives. The owner mentioned that she would like to sell more but that people generally did not use only natives and that to stay in business she had to sell some non-natives. On the other hand, Hall's Pleasant Valley Supermarket and Nursery answered 80-100% on this question. While this may be true, it is rather dubious in light of the substantially lower percentage sold by a native specialty nursery. It is interesting and instructive that Blue Oak Growers answered that they would not consider carrying an entirely native inventory.

The definition of non-native did become vague at times in both the nursery and customer surveys. Those surveyed sometimes assumed that if the plant grew vigorously in the area and was deer proof it was therefore native. This added confusion to the surveys that was not anticipated.

As mentioned before, most of the owners and managers were concerned about the invasive species in their area. Although not asked directly it seems that they would be responsive to educating themselves and their customers on this issue and a campaign to eliminate the sale or propagation of invasive exotic species; however, they seem generally skeptical of legislation and scientists

Customers Surveys

Methods: Customer survey questions were constructed as were the business survey questions. Surveys were hand delivered with explicit verbal and written instructions to ten cooperating nurseries. A contact person was established by phone prior to our arrival. Each nursery was given fifty surveys consisting of four questions (Figure 3). Pencils were provided. The contact was instructed to place the surveys on the counter for two weeks in a place where the customers could complete them leisurely. A SASE was left with each nursery.

Results: Of the 500 surveys delivered, 38 were completed and returned by 4 businesses ([c] Table 1). Therefore, 40% of the businesses were compliant and 13% of the surveys delivered were returned to us completed by customers. All of the contact persons that did not return the survey were called until they either sent the surveys or were convinced that the surveys were lost.

Question #1. Thirty-four percent of the people surveyed were familiar with three of the plants in the list. Sixteen and 18% were familiar with 1 and 2 plants respectively. Eighty-two percent were familiar with scotch broom and yellow star-thistle, thirty-seven with tree of heaven and bull thistle, thirty-two with Kentucky Blue Grass and 26% with Eucalyptus.

Question #2 Eighty-two percent would buy native (versus non-native) if the plants were clearly designated. Sixteen percent would not and three did not know.

Question #3 Eighty-two percent would not buy a plant if it were considered to be invasive.

Thirteen would and five did not know.

Question #4 Eleven percent of the customers want rural development to increase in their area. Sixty-one percent favor no change and 24% would like to see development decrease.

Figure 3

Customer Survey
(n=38, % response to answer found in parenthesis)

1. Are you familiar with any of the following plants that are considered to be invasive in your area? (check boxes)	☐ Scotch broom (*Cystisus scoparius*) (82%) ☐ Cheat grass (*Bromus tectorum L.*) (3%) ☐ Tree of heaven (*Ailanthus altissima*) (37%) ☐ Gum tree (*Eucalyptus*) (26%) ☐ Russian olive (*Elaeagnum angustifolius L.*) (13%) ☐ Bull thistle (*Cirsium vulgare*) (37%) ☐ Kentucky Blue Grass (*Poa pratensis*) (32%) ☐ Yellow star-thistle (*Centaurea solistitialis L.*) (82%) ☐ Salt cedar (*Tamarix*) (8%) ☐ None (0%)
2. Would you make a conscious choice to buy native (versus non-native) if the plants were clearly designated as such in the nursery?	YES (82%) NO (16%) DNK (3%)
3. If you knew a species was considered to be invasive would you purchase it?	YES (82%) NO (13%) DNK (5%)
4. Do you feel the rate of rural development (i.e., building of houses, businesses, roads) in your area should	INCREASE (11%) DECREASE (24%) STAY THE SAME (61%)

Discussion: A positive correlation was found between questions #2 and 3. Seventy-one percent of those customers surveyed answered that they would buy native (Q#2) but not buy invasive (Q#3). Seventy-seven percent of those (or 55% of the total) said they preferred that development either decrease or stay the same (Q#4). Half of the six that would not buy natives said that they would buy invasive species.

Perhaps the question concerning the purchase of natives should have clearly indicated that the available native plants would serve the same purpose in the garden as the non-natives. According to many business owners (even the one that specialized in natives), customers prefer the highly horticultural non-native species to the natives and it would be difficult to maintain a completely native inventory.

It is surprising, considering its leading nature, that anyone would answer "yes" to question #3. In order to understand better what the customer was thinking it would have been more informative to word the question to suggest that we were referring to plants that would be invasive in habitats outside of the garden. There was no trend with regard to the number or type of species with which people were familiar and how they answered questions #2-4.

Participation on customer surveys was disappointingly low. Better participation and standardization would have been achieved if the public surveys were administered either similarly with more extensive follow-up or directly.

Conclusion

A more extensive survey of this sort should be conducted not only to more definitively determine the opinions of these people but to also raise awareness on the issue.

Exotic species introduction threatens all native habitats in California and they are definitively finding their way into the Sierra Nevadas. Awareness on the part of the people living in these areas is important in order to elicit their help in controlling the more invasive exotic species. Although these surveys are not completely conclusive they do give us an idea of what people think and raised awareness on the issue.

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