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Native grass stand rarity, threat, and structure in the central coast ranges

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**NATIVE GRASS STAND RARITY, THREAT, AND STRUCTURE
IN THE CENTRAL COAST RANGES**

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

by

Cort Johnson

December 2001

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ABSTRACT

NATIVE GRASS STAND RARITY, THREAT, AND STRUCTURE IN THE SANTA CRUZ MOUNTAIN PRESERVES

By Cort R. Johnson

Native grasses are a rare and mostly unknown component of California's grasslands. Approximately 3000 hectares of grasslands in twenty-seven preserves were surveyed for native grass stands. One hundred and forty native grass stands were sampled and two canonical correlations run to determine vegetation structure. Historical reviews were done to determine if cultivation or landscape conversion had occurred.

Native grass stands occupy approximately 1.7% of grassland area. Three of the 17 native grasses found occupy approximately 90% of the stand area. Less than 2% of native grass stands held >70% of native grass stand area. Thirteen distinct vegetation assemblages including twelve native grasses were identified. Invasive species frequently occur in the regions native grass stands.

Grasslands converted from other vegetation types had few or no native grass stands. Native grasses in mesic habitats in the coastal and montane regions have been able to re-invade previously cultivated sites.

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PART ONE
LITERATURE REVIEW

CHAPTER ONE

INTRODUCTION AND RESEARCH QUESTIONS

Introduction

Grasslands are among the most threatened vegetation types worldwide. Often occurring in rich, productive, lowland environments, they have traditionally borne the brunt of agricultural and development activities. In California (and elsewhere), they continue to be converted to agriculture or urban uses at high rates (Keeley 1990, 1991). Eleven of the twenty-six most critically endangered ecosystems (>98% loss) in the United States are grasslands (Noss et. al. 1998).

Native grassland decline in the western United States is immense, with losses of 90% in western Montana, Oregon and southwestern Washington. Native grassland reduction reaches its peak in California. San Diego has lost 94% of its original grasslands, the needle grass steppe community has been reduced by 99.9%, the north coastal bunchgrasses by 90%, and California native grasslands overall by 99.9% (Noss et al. 1998).

California native grass communities have been termed 'critically endangered' (Noss et. al. 1989) and all native grass associations were given the highest threat rating by the California Department of Fish and Game's Natural Diversity Data Base (Sawyer and Keeler-Wolf 1995). Fewer than 4,000 hectares of the approximately 7,000,000 hectares of grasslands currently found in the state (Huennecke 1989) contain documented native

grass stands (Barry 1972). The one statewide survey of 'large' native grass stands revealed that almost all were formed by *Nassella pulchra* (Barry 1972).

Even though the rarity of native grasses is well accepted it is difficult to find quantitative studies of native grass abundance at the local or regional level. The only published study that explicitly attempted to assess the native grass abundance of a given locale was marred by an off-season sampling regime that precluded definite species identifications (Keeley 1991). The only regional guide devoted to native grasses in the San Francisco Bay area, while admirable, does not provide quantitative data on species abundance (Edwards and Havlik 1984, Edwards 1984a). Many other estimates are undoubtedly buried in informative, mostly inaccessible, environmental assessment reports (Buck 1983). Aside from these sources, estimates of native grass abundance must be inferred (usually indirectly) from studies of vegetation types (Hektner and Foin 1977, Oberbauer 1978, Goode 1981, Fielder and Leidy 1987). Even when expressed quantitatively, native grass abundance below the dominant species that make up the major vegetation types, is generally uncharacterized (Hektner and Foin 1977, Goode 1981, Fiedler and Leidy 1987).

Almost all information regarding native grass abundance reflects *N. pulchra* abundance rather than the native grass flora as a whole. *Nassella pulchra* is by far the most abundant native grass in California grasslands and occurs in many habitat types under many conditions. At present this species shows little danger of disappearing from California grasslands (Bartoleme and Gemmill 1981, Stromberg and Griffin 1996). Aside

from a few studies in the coastal regions (Hektner and Foin 1977, Bluestone 1981), almost no information exists regarding the abundance of native grasses other than *N. pulchra*.

Habitat descriptions of native grass stands are mostly based on qualitative assessments (Sawyer and Keeler-Wolf 1995). Stand composition even in *N. pulchra* stands is rarely documented (White 1967, Hull and Muller 1977, Savelle 1977, Goode 1981). Only eight plot-based descriptions of *N. pulchra* stands are cited in the *Manual of California Vegetation* (Sawyer and Keeler-Wolf 1995). Information for stands dominated by other native grasses is even rarer (Elliott and Wehausen 1974, Foin and Hektner 1977, Bluestone 1981, Fiedler and Leidy 1987, Blumler 1992a), is often incomplete when it does occur (Fiedler and Leidy 1987), and for several native grasses does not exist.

Patterns of native species richness and dominance in California grasslands (aside from vernal pools and serpentinite areas) are virtually unknown. The identification of such patterns in the Santa Cruz Mountain region can assist in identifying conservation 'hotspots' which contain important elements of the California flora.

In addition to reductions in abundance, native grasslands around the world have suffered floristic degradation primarily as the result of non-native species originating in Eurasia. Grasslands in California, the intermountain western region of the United States (Mack 1989), South America (Gulmon 1977), and Australia (McIntyre and Lavorel 1994b, Tremont 1994, Kirkpatrick and Gilfedder 1995) have all undergone remarkable floristic transformations (Noss et. al. 1998) mostly as a result of the 'Mediterraneanization' of their flora (Parsons 1992).

No studies have yet characterized either the extent of non-native species introgression into the remaining native grass stands or identified the most serious non-native species threats. While the detrimental effects of non-native species invasions on some grassland species are well known (Cook 1965, Robinson 1968, Hull and Muller 1977, Bartoleme and Gemmill 1981, Dyer et. al 1996), little information exists regarding patterns of species invasions in the grassland habitat in California (Rejmanek et. al. 1991, Hobbs and Mooney 1998).

Little is known regarding the invasibility of specific habitat types (aside from vernal pools and serpentine grasslands) within the grassland community (Rejmanek et. al. 1991). Because native grasses exploit a wide array of habitat types, analysis of their vulnerability to non-native species invasions can also help determine patterns of susceptibility of common grassland habitats.

The factors which govern native grass stand distribution and abundance today are only now beginning to be fleshed out (Barry 1972, Bartoleme and Gemmill 1981, Keeley 1990, 1991, Stromberg and Griffin 1996). Past historical practices such as cultivation, grazing, and landscape conversion may affect native grass abundance in preserves that are largely undisturbed today (Keeley 1990, 1991, Stromberg and Griffin 1996).

Research Questions

To address these gaps in our knowledge this thesis had four main objectives:

- (1) To quantitatively assess native grass stand abundance in a specific region.**
- (2) To characterize native grass habitats and determine the effects of abiotic factors on grass stand composition.**
- (3) To determine the extent of non-native species introgression into specific native grass stand types and to identify the principal non-native species threats to native grass stands.**
- (4) To explore past disturbance patterns which may affect native grass abundance today.**

In order to fulfill these objectives nine questions were addressed with respect to native grass stands found in upland grassland environments in Santa Cruz Mountain region preserves. Only stands larger than 250 square meters and with greater than 10% native grass relative cover were included. Twenty-seven public preserves and eight state beaches were surveyed for native grass stands.

- 1. Determine the quantity and area of native grass stands in grasslands in Santa Cruz Mountain region preserves.**
- 2. Determine distribution patterns and estimates of abundance for native grasses forming stands in grasslands in Santa Cruz Mountain region preserves.**

3. **Identify the abundance and distribution of rare plant species in native grass stands in grasslands in Santa Cruz Mountain region preserves.**
4. **Identify patterns of non-native species introgression into native grass stands and identify the primary non-native species invaders in Santa Cruz Mountain region preserves.**
5. **Investigate the relationship between cultivation and landscape conversion, and native grass stand distribution and abundance in grasslands in Santa Cruz Mountain region preserves.**
6. **Investigate the effects of isolation and reduced disturbance on grassland composition by comparing the non-native flora of native grass stands in the Santa Cruz Mountain Region with that of an isolated, long undisturbed, nearby preserve.**
7. **Identify the effects of abiotic factors (slope, cose, distance to coast, distance to bay, soil texture, rock cover) on the composition and structure (native and non-native grass, forb and shrub cover, conservation value, site uniqueness value) of native grass stands in Santa Cruz Mountain region preserves.**
8. **Provide a literature review on the rarer native grass communities in grasslands in Santa Cruz Mountain region preserves.**

9. **Recommend management strategies and areas of future research needed to conserve native grass stands in the Santa Cruz Mountain region and California grasslands.**

This information will be useful to public lands managers, native grass restorationists, and researchers interested in native grasses, the effects of disturbance in California grasslands, and the native: non-native interface in California grasslands.

CHAPTER TWO

NATIVE GRASSES IN CALIFORNIA GRASSLANDS

Native Grass Stand Distribution and Rarity

When discussing native grass abundance and distribution it is important to note that virtually all the large native grass remnants identified and all discussions of native grass distribution concern *Nassella pulchra* stands and not the wide variety of native California grasses that exist.

Barry (1972) found thirty-nine 'large' native grass stands in a statewide survey of 'Central Valley Prairie' relict native grass sites, most of which were located in coastal regions. Eleven of the 13 native grass stands found in the Central Valley occurred in mesic environments such as near rivers, or close to the Delta and the San Francisco Bay. Since Barry's study Kelley (1991, 1993) identified seven more sites in Southern California with substantial native grass populations. Since his report in 1972 Barry published a map showing fifty-four native grass sites scattered all across the state (Barry 1981). No information was given regarding the size, quality or species composition of these sites but it includes many sites outside of *N. pulchra's* range and appears to be the first attempt to provide a comprehensive native grass survey.

Most assessments of native grass decline or rarity describe the native grass community in terms of broad vegetation types (i.e. north coastal bunchgrass) (Noss et.al. 1998). The plant communities program of the California Department of Fish and Game's Natural Diversity Data Base (NDDDB) breaks up the broad vegetation types in which

native grasses are found into their constituent parts (vegetation 'series'), and ranks them regarding to rarity and threat (Sawyer and Keeler-Wolf 1995). A five-tiered ranking system is used to rank the number of 'viable occurrences' found statewide and globally. A three-tiered ranking system is used to describe threats (see Table 1). These characterizations form the most detailed assessments of native grass rarity yet published.

The vegetation series identified by the NDDDB are vegetation assemblages with similar dominant and subdominant species that occur regularly over the landscape. The identification of the vegetation series that make up the California landscape is ongoing. Not all the native grasses that form stands in the Santa Cruz Mountain region may form a series in the *Manual of California Vegetation* (Sawyer and Keeler-Wolf 1995).

Nine of the 54 native grasses found in the Santa Cruz Mountain grasslands (see Appendix I) currently form a vegetation series in the Manual of California (Sawyer and Keeler-Wolf 1995). Six of the nine native grass communities score the second highest possible global and state ranking (G3; S2) (see Table 1). One species (*Leymus mollis*) scores the highest global and state ranking (G1.S1.1). The only native grass to score in the third global and state ranking is *N. pulchra*.

Vegetation Conversion and Native Grass Distribution

The conversion of grasslands to agricultural and urban uses, and the conversion of chaparral and oak woodlands to grasslands, can obscure the true extent of native grass rarity. Just as immense amounts of California grasslands have been converted to

Table 1.--Native Grass Rarity and Threat in California.

Global ranks

- G1: less than six viable occurrences and/or less than 2,000 acres worldwide.
- G2: 6-20 viable occurrences and/or 2,000-10,000 acres worldwide.
- G3: 21-100 occurrences or 10,000-50,000 acres worldwide.
- G4: Greater than 100 viable occurrences worldwide and/or greater than 50,000 acres.
- G5: Community demonstrably secure due to worldwide abundance.

State ranks

- S1: Less than six viable occurrences statewide and/or less than 2,000 acres
- S2: 6-20 viable occurrences statewide and/or 2,000-10,000 acres.
- S3: 21-100 viable occurrences statewide and/or 10,000-50,000 acres.
- S4: Greater than 100 viable occurrences statewide and/or greater than 50,000 acres.
- S5: Community demonstrably secure statewide.

Threat ranks

- 0.1: Very threatened.
- 0.2: Threatened
- 0.3: No current threats known

Rarity Ratings and Vegetation Types of the Native Grass Series Found in Santa Cruz Mountain Grasslands (Sawyer and Keeler-Wolf 1995)

- California oatgrass series (*Danthonia californica*) - coastal prairie - G2.S2.2. Bald Hills prairie - G2.S2.1.
- Creeping ryegrass series (*Leymus triticoides*) - Valley wildrye grassland - G2.S2.1.
- Foothill heedlegrass series (*Nassella lepida*) - Serpentine bunchgrass - G2.S2.2
- Idaho fescue series (*Festuca idahoensis*) - Bald hills prairie - G2.S2.1.
- Native dunegrass series (*Leymus mollis*) - Northern foredune grassland - G1.S1.1.
- Pacific reedgrass series (*Calamagrostis nutkaensis*) - Coastal terrace - G2.S2.1
- Purple needlegrass series (*Nassella pulchra*) - Valley needlegrass grassland - G3.S3.1.

Table 1.--cont.

Saltgrass series (*Distichlis spicata*) - Alkali meadow - G3.S2.1.

Tufted hairgrass series (*Deschampsia caespitosa*) - Coastal terrace prairie - G2.S2.1. state ranking (G1; S1).

agricultural and urban areas, much grassland area has been created by the conversion of other vegetation types to grasslands (Freudenberger et. al. 1987, Huennecke 1989).

Large portions of the grasslands presently found in California have been carved out of the foothill oak woodland/chaparral belt (Huennecke 1989). Early photographs of the Coast Ranges show newly created grasslands extending far up the montane slopes, sometimes even to the ridgelines (Amme 1991). Many grassland areas in Southern California have been converted from former chaparral sites either intentionally or as a result of higher fire frequency in modern times (Wells 1962, Freudenberger et. al. 1987).

The shift upwards in elevation for grasslands from valley floors to the foothills has deposited many grasslands onto atypical (and often less productive) substrates (Wells 1962, Freudenberger et. al. 1987, Huennecke 1989, Keeley 1993). Native grasses may be not be so much out-competed by non-native grasses in these environments as they are ill-suited to the soil environments found there, and/or lack the seed sources to colonize them (Keeley 1991, 1993).

The process of converting chaparral to grasslands results in high rates of nitrate loss for several years, thus turning an already nutrient poor soil even more so (Davis 1987). The effects of chaparral conversion on native grass abundance are unclear. While native grasses were reported to chiefly occur on isolated old-fields in the chaparral in San

Luis Obispo (Wells 1962), few native grasses were found in grassland sites believed to have been converted from chaparral in southern California (Keeley 1991, 1993)

Oak woodlands converted to grasslands in the North Coast Ranges had a distinct vegetative structure and composition relative to nearby natural grass stands (Heady and Pitt 1979). Tall annual (*Avena* spp., *Bromus diandrus*) and perennial grasses (*Dactylis glomerata*, *Phalaris aquatica*) and perennial exotic forbs (*Vicia* spp., *Carduus pycnocephalus*) had much higher cover rates on converted oak savanna stands than on natural grass stands. Non-native grasses of short stature (*Aira caryophylla*, *Gastridium ventricosum*), and forbs (*Daucus pusillus*, *Geranium* spp.) were abundant only initially on converted sites and declined dramatically as succession proceeded.

Native grass remnants may provide clues to the distribution of natural grassland areas (Keeley 1991). Native grasses at a Southern California site were completely absent from grasslands on thin-textured stony soils that probably used to support chaparral, but they were often present, at least in small amounts, in deeper soils that may have formerly supported grasslands (Keeley 1991, 1993).

Species Rarity in Native Grass Stands

Few studies have assessed the prevalence of rare native species in native grass stands. Only serpentine and vernal pool grasslands have been surveyed to any extent (Edwards 1984a, Kruckeberg 1984, Fiedler and Leidy 1987, McCarten 1987, 1992,

Murphy and Ehrlich 1989, Lake 1995). The rare species component of even serpentine grasslands is inadequately assessed as serpentine 'grasslands' are composed of several different vegetation types, only one of which is bunchgrass dominated (McCarten 1987).

The grassland habitat statewide is rich in rare plant species. California grasslands contain the highest number of List 1A (believed extinct) plants of any community (10), and the third highest number of List 1B species (157). California grasslands have the fourth highest number of rare species (247) of the 34 communities listed in the Inventory of Rare and Endangered Vascular Plants of California (Pavlik and Skinner 1994b).

The Santa Cruz Mountain region is home to 214 rare plant species, of which 45 or 21% are found in valley, coastal prairie, or coastal dune grasslands (Pavlik and Skinner 1994a). In the Santa Cruz Mountain region serpentine and sandy soils harbor significant numbers of rare species (Pavlik and Skinner 1994b).

Factors Influencing Native Grass Stand Distribution

Much native grass rarity is the result of their inability to capture sufficient amounts of light and moisture to survive to reproductive age (Bartolome and Gemmill 1981, Dyer et. al. 1996, Dyer and Rice 1997b). Native grass and native forb germination and growth are inhibited by the low light levels found underneath the dense annual grass canopies and litter mats found in today's grasslands (Hull and Muller 1977, Turitzen 1978). Canopy effects are particularly strong in the Coast Range grasslands where light levels at ten to fifteen centimeters are markedly reduced as early as January (Hull and

Muller 1977, Turitzen 1978). Aspect and substrate are two factors that have important effects on resource availability (light interception, soil moisture levels, temperature, soil nutrient levels) in California grasslands (Evans et. al. 1975, Heady 1977, Rice 1989).

Aspect

The effects of aspect on vegetation are frequently noted in ecology texts. Aspect effects are most pronounced in mid-latitudes (Holland and Steyn 1975) but have been poorly studied in California (Evans et. al 1975, Young et. al. 1981, Bartoleme 1989). North facing slopes were found in one study to have one-third less light intensity than south facing slopes (Evans et. al. 1975) although greater differences, particularly during the winter months, have been noted (Evans and Young 1989). Despite the greater light intensities found on south facing slopes, less light may actually reach the soil surface there because the greater litter mats and canopies produced on the grass dominated southern slopes intercept a greater percentage of the available light (north-facing: 80%, south-facing 90%) (Evans et. al. 1975). At the soil surface north slopes received about fifty percent more sunlight (13.6%) than south-facing slopes (9%).

Aspect effects on temperature levels are high year round with average temperature levels on north-facing slopes ranging from two to twenty degrees centigrade lower than on south-facing slopes. Temperature levels affect the timing of seed germination which in turn effects community composition (Young et. al. 1973, Evans et. al. 1975, Pitt and Heady 1978, Bartoleme 1979, Young et. al. 1981). Reduced temperature levels, particularly in the fall, may benefit native grasses by reducing non-

native grass germination and growth and extending the time of canopy closure (Hedrick 1939, Cook 1965). Native species generally germinate and emerge later than do exotic grasses (Hedrick 1939, Hobbs and Mooney 1985).

Soil moisture levels on north slopes exhibit small to moderate increases in the mid to deep soil layers from mid-season on relative to south facing slopes (Evans et. al. 1975). Soils on north slopes in the Central Valley and Coast Ranges, exhibit higher nitrogen and carbon levels (Jenny 1980), and have more developed soil profiles and greater depths (Hedrick 1949, Biswell et. al. 1952, Evans et. al. 1975), and thus have higher soil moisture holding capacities than those on south facing slopes. Higher soil moisture levels in deeper soil layers late in the season may be particularly advantageous for native perennial grasses because they are dependent on late season moisture levels for optimal seedling survival and reproductive output (Jackson and Roy 1986).

Most reports regarding the slope orientation of native grasses concern *Nassella pulchra*, a grass that can have a wide variety of slope preferences even within the same region (White 1967, Hull and Muller 1977, McNaughton 1968, Bartoleme and Gemmill 1981, Goode 1981, Blumler 1992a, Keeley 1991, McCarten 1992). Most other native grasses appear to have more consistent slope preferences. Several reports have linked native grasses to north-facing slopes in the San Francisco Bay area (Edwards and Havlik 1984, Edward 1984a). North facing slopes had higher native grass species richness and cover at two sites in the San Francisco Bay area (Blumler 1992) and native grass species richness was highest on the north slopes at a third (Bern 1985).

Edaphic Factors

The effect of soils on vegetation type varies dramatically from place to place. For instance, while grasslands are generally found on finer textured, deeper, more nutrient rich soils, many exceptions can be found (Wells 1962, Freudenberger et. al. 1987, Keeley 1991, 1993). Even in the geologically heterogeneous environment of the Coast Ranges, vegetation fidelity to soil type is limited (Wells 1962). On less heterogeneous substrates and in areas with changed disturbance regimes, the effects of soils on vegetation type can be hard to discern (Wells 1962, Hobbs 1983, Freudenberger et. al. 1987).

Anthropomorphically derived disturbance regimes, in particular, have widely obscured soils relationships to vegetation (Wells 1962, Oberbauer 1978, Freudenberger et. al. 1987, Keeley 1993).

Studies have linked a number of California native grasses to specific soil environments. *N. pulchra* distribution has been tied several times to clay-rich soils (Robinson 1968, Keeley 1991, 1993, Stromberg and Griffin 1996). *Leymus triticoides*, *Melica californica*, *N. pulchra*, and *Poa secunda* were found on more clay-rich, and *Bromus carinatus*, *Elymus glaucus*, *Hordeum californicum*, and *Koeleria macrantha* were found on sandier soils in the central Coast Ranges (Robinson 1968, Stromberg and Griffin 1996). *Festuca idahoensis* occurred on one soil texture type in the Great Basin and another in Oregon (Borman et. al. 1990). *Deschampsia caespitosa* distribution on a north coastal prairie was positively correlated with soil moisture levels (Peart and Foin

1985). Several authors have qualitatively linked a number of native grass species with general soil environments (Beetle 1947, Edwards 1984a, b, 1995, Keeley 1993).

Serpentine Soils and Native Grasses

Serpentinite soils are shallow, stony soils derived from metamorphosed peridotite, a plutonic ultramafic rock (Edwards 1997). Numerous nutrient imbalances including high magnesium and low calcium, nitrogen, potassium and phosphorous levels thwart plant growth, reducing non-native grass abundance in particular, and allowing a rich native flora to flourish (Kruckeberg 1984, Hobbs et. al. 1988).

Contributing more rare species than any other chemical substrate type (Pavlik and Skinner 1994b), serpentinite soils constitute the single greatest resource for plant conservation in the state. Reaching their greatest abundance in northwestern California, serpentine soils decline greatly south of the San Francisco Bay area but still contain sometimes dazzling amounts of native species, including many rare ones (Kruckeberg 1984, Edwards 1984a, Fielder and Leidy 1987, McCarten 1987, Correlli and Porter 1999). Despite its rich flora, serpentine grassland vegetation has until recently (McCarten 1986, Fiedler and Leidy 1987) been almost completely unsurveyed and remains poorly characterized (Murphy and Ehrlich 1989). They are an important refugia for native grasses in the San Francisco Bay area (Edwards 1984a, 1988, 1997, Edwards and Havlik 1984).

Several habitat types with distinctive vegetation groups have been identified on serpentinite soils, including bunchgrass dominated deeper soils (McCarten 1987), and forb dominated north slopes, rock outcrops, and shallow soils (Gulmon et. al. 1983, McCarten 1992). Many serpentinite soils support a sparse grass cover, and are so wildflower dominated as to bring the term 'grassland' into question (McCarten 1987, Edwards 1997). Only one of the four vegetation types revealed by a Twinspan analysis of a serpentinite site in the Santa Clara Valley was bunchgrass dominated (McCarten 1992). Although the species composition of several native grass associations on serpentinite soils have been anecdotally noted (Edwards and Havlik 1984, Edwards 1984b), only in a few sites has species composition been quantitatively assessed (Bern 1985, Fiedler and Leidy 1987, McCarten 1992).

Several more or less distinctive species distribution patterns (endemics, indicator species, indifferent, avoiders) occur relative to serpentinite soils. While several native grasses, including one San Francisco Bay area species (*Calamagrostis ophiditis*), are endemics, the contribution of the grass family given its size is surprisingly minor. A closer examination of native grasses found on serpentinite soils, seems likely, however, to increase this number (Kruckeberg 1984, Edwards 1989).

Most native grasses (including *Danthonia* spp., *Calamagrostis* spp., *Elymus* spp., *Festuca* spp., *Melica* spp., *Nassella* spp., *Vulpia* spp.) have been classified as bodenvag or indifferent species which occur both on and off serpentinite soils with equal frequency (Kruckeberg 1984). Several native grasses found in the Santa Cruz Mountain

region are proposed as definite (*Deschampsia*, *Koeleria*) or possible (*Danthonia*, *Nassella*) serpentinite avoiders (Kruckeberg 1984).

Native Grass Habitats in the San Francisco Bay Area

Native grasses have been linked to a variety of habitat types in the San Francisco Bay area, most of which occur on unproductive substrates. These include thin rocky soils, road cuts, trailsides, salt windblast zones on seabluffs, mesic areas, high clay soils, serpentinite soils, and steep north-facing slopes (McNaughton 1968, Edwards and Havlik 1984, Fielder and Leidy 1987, Murphy and Ehrlich 1989, Langstroth 1991). That most of the largest native grass stands in the state occur on fertile soils (Barry 1972, Goode 1981, Keeley 1991) illustrates, however, that native grasses are not necessarily relegated to marginal habitats.

CHAPTER THREE

THREATS TO NATIVE GRASSES

Non-Native Species

Non-native species present significant threats to native grasses in the Santa Cruz Mountain region. The San Francisco Bay and Central Coast sub-regions (Hickman 1993), of which the Santa Cruz Mountain region is a part, have the greatest concentrations of non-native species in the state (Randall et. al. 1998). Only 47% of the approximately 170 grass species found in the region are native (Thomas 1961), a substantially lower percentage than in the grass flora statewide (59%) (Hickman 1993). Approximately half of the non-native grasses found in the state occur in the region (Thomas 1961).

Grazing did not occur in any of the preserves covered in this thesis. Taller-statured non-native grasses (*Anthoxanthum odoratum*, *Avena* spp., *Bromus* spp., *Phalaris aquatica*) and forbs (*Brassica nigra*, *Carduus pycnocephalus*, *C. tenuiflorus*, *Centaurea solstitialis*, *Sonchus asper*) typically increase when grazing is eliminated in California grasslands (Goode 1981, Cockburn and Lidicker 1983, Peart and Foin 1985, Edwards 1992, 1994, 1995). Eliminating grazing has sparked an explosion of noxious weeds in several preserves (Goode 1981, pers. comm., Edwards 1988, 1994, Hastings and DiTomaso 1996, Hayes 1998), and has been implicated in native grass stand loss (Bartoleme and Gemmill 1981, Goode 1981, pers. com, Peart and Foin 1985). Several non-native species have been specifically linked to recent native grass stand loss including *Ammophila arenaria* (Pavlik 1983a,b), *Anthoxanthum odoratum* (Peart and Foin 1985),

Carduus pycnocephalus (Bartoleme and Gemmill 1981), and *Phalaris aquatica* (Goode 1981). The most egregious example of native grass loss resulting from the elimination of grazing and the unleashing of a highly aggressive invader in a preserve, occurred in Southern California, where *Phalaris aquatica* has overcome significant portions of one of the finest *N. pulchra* stands found in the state (Barry 1972, Goode 1981, pers. com).

The extent of non-native species introgression into native grass stands has been assessed only a few times for only a few species. Non-native species common to native grass stands found in the Santa Cruz Mountain region are listed below (see Table 2).

While only a small fraction of the native grass stands in the state have been sampled, the invasive species found in California grasslands have become fairly well delineated in the past few years by the California Exotic Pest Council (CalEPPC), a group of academics, government biologists, consultants, and citizens. CalEPPC ranks invasiveness in the California flora (California Exotic Pest Plant Council 2001) in five categories. Species found in List A-1 and A-2 species are the "most invasive wildland pest plants" which have widespread and regional distributions respectively in California. List B identifies "wildland pest plants of lesser invasiveness". Two more lists include annual grasses "of the greatest ecological concern" and species for which more information is needed. The 39 invasive species found in the Santa Cruz Mountain region grasslands are listed in Table 3 below.

Cultivation

Not all native grass disappearance is the result of competitive interactions.

Table 2.--Non-Native Species Occurring in Native Grass Associations Found in the Santa Cruz Mountain Region

Dominant Native Grass	Non-Native Species	Citation
<i>Calamagrostis nutkaensis</i>	<i>Anthoxanthum odoratum</i> , <i>Holcus lanatus</i>	Sawyer & Keeler-Wolf 1995
<i>Danthonia californica</i>	<i>Anthoxanthum odoratum</i>	Sugihara & Reed 1987, Viers 1987,
<i>D. californica</i>	<i>Agrostis stolonifera</i>	Viers 1987
<i>D. californica</i>	<i>Aira carophylla</i> , <i>Bromus hordaceus</i> , <i>B. diandrus</i>	Kotanen 1994
<i>D. californica</i>	<i>Anthoxanthum odoratum</i> , <i>Arrhenatherum elatius</i> , <i>Holcus lanatus</i>	Sawyer & Keeler-Wolf 1995
<i>Deschampsia caespitosa</i>	<i>Plantago lanceolata</i> , <i>Rumex acetosella</i>	Elliot and Wehausen 1974
<i>D. caespitosa</i>	<i>Anthoxanthum odoratum</i> , <i>Holcus lanatus</i> , <i>Rytidosperma pilosum</i>	Peart & Foin 1985, Foin & Hektner 1986
<i>D. caespitosa</i>	<i>Anthoxanthum odoratum</i> , <i>Holcus lanatus</i>	Sawyer & Keeler-Wolf 1995
<i>Festuca idahoensis</i>	<i>Anthoxanthum odoratum</i> , <i>Arrhenatherum elatius</i> , <i>Holcus lanatus</i>	Sawyer & Keeler-Wolf 1995
<i>Leymus mollis</i>	<i>Ammophila arenaria</i> , <i>Carpobrotus edulis</i>	Sawyer & Keeler-Wolf 1995
<i>Leymus triticoides</i>	<i>Avena spp.</i> , <i>Bromus spp.</i> ,	Sawyer and Keeler-Wolf 1995
<i>Nassella lepida</i>	<i>Bromus hordaceus</i>	Sawyer and Keeler-Wolf 1995
<i>Nassella pulchra</i>	<i>Avena barbata</i> , <i>A. fatua</i> , <i>Bromus diandrus</i> , <i>B. diandrus</i> , <i>B. madritensis</i> , <i>Lolium multiflorum</i>	Sawyer and Keeler-Wolf 1995
<i>N. pulchra</i>	<i>Lolium perenne ssp. multiflorum</i> , <i>Phalaris aquatica</i>	Goode 1981
<i>N. pulchra</i>	<i>Carduus pycnocephalus</i> , <i>Taeniatherum cap-medusae</i>	Bartolome & Gemmill 1981
<i>N. pulchra</i>	<i>B. hordaceus</i>	Robinson 1968
<i>N. pulchra</i>	<i>B. hordaceus</i> , <i>Vulpia bromoides</i>	Hull & Muller 1977
<i>N. pulchra</i> (serpentine soils)	<i>Lolium multiflorum</i>	Fiedler & Leidy 1987

Table 3.--Invasive Species Found in Santa Cruz Mountain Region Grasslands

Species	Ranking	Habitats of Concern
<i>Aegilops triuncalis</i>	annual grass	serpentine soils, grasslands
<i>Agrostis avenacea</i>	info needed	vernal pools
<i>Ammophila arenaria</i>	A-1	coastal dunes
<i>Avena barbata</i>	annual grass	lower elev. SoCal; coastal scrub, disturbed sites
<i>Avena fatua</i>	annual grass	lower elev. SoCal; coastal scrub, disturbed sites
<i>Bellardia trixago</i>	B	grasslands, serpentine
<i>Brachypodium distachyon</i>	annual grass	expanding in SoCal, common in Orange County
<i>Brassica nigra</i>	B	coastal communities, esp. fog-belt grasslands
<i>Bromus diandrus</i>	annual grass	coastal dunes, coastal sage scrub, grasslands
<i>B. madritensis</i> ssp. <i>rubens</i>	A-1	widespread
<i>Carduus acanthoides</i>	info needed	wildlands
<i>C. pycnocephalus</i>	B	grasslands, shrublands, oak woodlands
<i>Centurea calcitrapa</i>	B	grasslands
<i>C. melitensis</i>	B	widespread (sometimes misidentified)
<i>C. solstitialis</i>	A-1	grasslands
<i>Cirsium arvense</i>	B	especially troublesome in riparian areas
<i>Cirsium vulgare</i>	B	riparian areas, marshes,
<i>Conium maculatum</i>	B	disturbed areas
<i>Cytisus scoparius</i>	A-1	coastal scrub. oak woodlands, Sierra foothills
<i>Echium candicans</i>	info needed	riparian, grassland, coastal scrub
<i>Ehrharta erecta</i>	B	wetlands, moist wildlands, grassland habitats
<i>Euphorbia lathyris</i>	info needed	coastal scrub, marshes, dunes
<i>Hypochaeris radicata</i>	info needed	coastal grasslands, wetlands
<i>Festuca arundinacea</i>	B	coastal scrub, grasslands in NCo, CCo
<i>Foeniculum vulgare</i>	A-1	grasslands
<i>Holcus lanatus</i>	B	coastal grasslands, wetlands - No. Calif.
<i>Leucanthemum vulgare</i>	B	invades grasslands, coastal scrub
<i>Lolium multiflorum</i>	annual grass	wetland areas, esp. vernal pools in San Diego Co., common in disturbed sites
<i>Mesembryanthemum crystallinum</i>	B	coastal bluffs, dunes, scrub
<i>Oxalis pes-caprae</i>	info needed	disturbed sites
<i>Parentucellia viscosa</i>	info needed	dune swales
<i>Pennisetum clandestinum</i>	info needed	disturbed sites
<i>Phalaris aquatica</i>	B	coastal sites, esp. moist soils
<i>Spartium junceum</i>	B	coastal scrub, grasslands, woodlands, NW forests
<i>Taeniatherum caput-medusae</i>	A-1	grasslands, particularly poorly drained

Cultivation has had profoundly negative effects on native grass distribution in valley grasslands and is responsible for a significant part of the native grass disappearance in California (Stromberg and Griffin 1996). Railroad right of ways, for instance, often boast rich assemblages of native grasses (and other native species) because they were generally established before cultivation wiped out the native flora in the land around them (Thomsen et. al. 1996).

The effects of cultivation on soil properties in arid areas can be long lasting (Burke et. al. 1995). Cultivation results in undifferentiated soil horizons and increased soil aeration and oxidation, which in the short term causes a pulse of increased nutrient availability, but over the long term causes nutrient levels to decline as the soil structure decays and nutrients are removed through harvesting (Bettany et. al. 1980).

Restoration of old-fields in the arid portions of the western United States occurs slowly. Although mineralizable nitrogen and carbon levels recovered in Colorado old-fields, organic matter and silt were still significantly lower in former old-fields than in nearby native grasslands more than fifty years after abandonment. Recovery of soil nutrient pools in formerly cultivated Colorado grasslands was closely tied to the re-establishment of the native perennial grass cover (Burke et. al. 1995).

Native grass re-invasion of old-fields in California grasslands has been documented only a few times (Heady 1956, White 1966, Kotanen 1995, 1996). In the drier inland portions of the central Coast Ranges *N. pulchra* invaded few old-fields after many decades even when located around their edges (Stromberg and Griffin 1996 but see Wells 1962). In contrast to the relatively stable stands elsewhere, the species composition in *N. pulchra*

stands in old fields tended to show high variability over time (Stromberg and Griffin 1996).

PART TWO

METHODS AND RESULTS

CHAPTER FOUR

THE STUDY AREA

The Santa Cruz Mountain Region

Running for approximately 75 miles from Salinas to San Francisco and ranging in width from five to 30 miles, the Santa Cruz Mountain region covers approximately 1400 square miles (Thomas 1961). This moderately low section of the Central Coast Ranges achieves its highest elevation at 3806 ft at Loma Prieta.

The climactic diversity in the Santa Cruz Mountain region is extraordinary, even for California (see Table 4). Westerly winds picking up moisture from the cold California Current off the coast often blanket the entire west side of the mountains with fog creating a 'cool summer' Mediterranean climate in the coastal region (Thomas 1961). The east side of the Santa Cruz Mountains remains hot and dry while the west side is cool and humid. Summer temperature levels in the San Francisco Peninsula and coastal regions are often 20 degrees lower than in the interior region (see Table3). Precipitation levels are just as variable; precipitation in the montane region is double that of the interior (see Table 4).

The San Francisco Bay, the largest estuary in California, moderates the climate over several hundred square miles and creates a unique environment in the state. Except for the thin coastal strip, the entire Santa Cruz Mountains chain is contained within the San Francisco Bay climactic region (Hickman 1993).

The ocean, the San Francisco Bay, and a mountainous topography, create a range

Table 4.--Climactic Data for the Santa Cruz Mountain Region.

Site (region)	Average Maximum August Temperature	Average Minimum January Temperature	Average Total Precipitation
San Francisco (bay)	64.4	43.9	19.9
Half Moon Bay (coastal)	65.1	58.2	26.8
Santa Gregorio (coastal)	70.0	39.9	29.30
Woodside (interior)	87.8	36.6	30.3
Black Mountain (montane)	-	-	34.8
Palo Alto (interior)	78.4	38.5	15.41
San Jose (interior)	81.8	41.3	14.40

of unique habitats in the Santa Cruz Mountain region. The Sunset Gardens horticultural map (upon which the climactic zones in the Jepson Manual are largely based) reports that five climactic zones occur in the Santa Cruz Mountain region, making it one of the most varied climactic regions in California for its size (Sunset 1995).

A wide range of topographic landforms and geologic structures further accentuate the environmental heterogeneity. In the coastal region sandy dunes merge into broad, low sloping grassy marine terraces, which disappear into redwood and Douglas fir forests. In the more arid interior foothill region, hilly annual and serpentine grasslands merge into oak woodlands and chaparral. Redwood/Douglas fir forests in the montane region surround wet ridge top grasslands. The hilly grasslands of the San Francisco peninsula, which is bisected by passes that enhance the maritime nature of the area, are surrounded on three sides by water.

The Coast Ranges, of which the Santa Cruz Mountains are a part, comprise one of the most geologically complex and chaotic landscapes in North America (McPhee 1993). The geologic foundations of the Santa Cruz Mountains are the Franciscan *mélange*; a mess of rock types containing sandstones, shales, chert, limestone, greenstone, etc (Brabb 1961). Significant granite outcrops and lava flows occur as well as the all important serpentinite soils. The Coast Ranges contain approximately 25% of the grasslands found in California (Huennecke 1989).

In 1961, the vascular flora of the Santa Cruz Mountains consisted of 1799 species, subspecies, varieties, etc. (Thomas 1961). While this number has undoubtedly gone down as taxonomic revisions have eliminated many subspecies, varieties, etc., it is indicative of how floristically rich the area is. This relatively small region is home to approximately 20-25% of all plant species found in California (Thomas 1961). Fifty-four native grasses occur in Santa Cruz Mountain grasslands, meadows, coastal bluffs or dunes (Hickman 1993) (see Appendix 1).

CHAPTER FIVE

METHODOLOGY

Locating Stands

Twenty-seven public preserves in the Santa Cruz Mountain region with greater than twenty-five acres of grasslands and 11 beaches were surveyed for native grass stands (see Table 5). Preserves with significant grasslands were identified from maps, interviews, and a series of trail guides that covered all the preserves of the Santa Cruz Mountain region (Taber 1994, Spangle and Rusmore 1995a, b). Almost all the trails that encountered grassland areas in the preserves identified (see Table 5) were walked, and the grasslands surveyed for native grass stands. Surveys were done by walking the grassland areas and identifying native grass stands by their color and/or bunchgrass structure. The bunchgrass form, which is almost unique to native grasses in the California grassland environment, was readily identified.

The surveying took place in 1996 through 1998 during the summer, fall and winter periods when the bunchgrass form stood out most readily. After a visual sighting was made, the presence of the bunch structure was felt for by stepping on the suspected plant. This method was accurate with all but the most weakly bunch-forming species such as *Hordeum brachyantherum* and *Melica californica*. If the presence of a bunch was questionable the site was revisited during flowering for further inspection.

Table 5.--Survey Area.

<u>Region/Preserve</u>	<u>Survey Complete/ Incomplete</u>	<u>Area Surveyed (hectares)</u>
Coastal Region: grasslands mostly on marine terraces from Santa Cruz to Ano Nuevo		
Ano Nuevo/Cascade Ranch State Reserve.	I	80
University of California at Santa Cruz.	C	200
Wilder Ranch State Park.. . . .	C	<u>450</u>
		730
Bay Region: hilly grasslands in the San Francisco peninsula from San Pedro Point north.		
Milagra Ridge County Park.	C	20
San Bruno County Parks.	I	80
San Pedro Point.	C	0.5
Sweeney Ridge County Park	C	<u>20</u>
		120
Interior Region: foothill grasslands below approximately 300 meters on the east side of the Santa Cruz Mountains from Calero County Park to Stanford Preserve		
Almaden Quicksilver County Park	I	60
Arastradero Preserve	C	160
Calero Reservoir County Park.	C	160
Fremont Older Open Space Preserve.	C	40
Edgewood County Park.	C	40
Rancho San Antonio County Park/Rancho San Antonio Open Space Preserve	C	80
Santa Teresa County Park	C	360
Sierra Azul Open Space Preserve (St. Francis Hill).	C	20
Stanford Academic Reserve	C	<u>200</u>
		1120
Interior Region (serpentinite soils): serpentine grasslands on east side of the Santa Cruz Mountains		
Edgewood County Park.	C	70
Santa Teresa County Park.	C	20

Table 5. (cont.)

Sierra Azul Open Space Preserve		
(Mt Umunhum)	C	20
WaterDepartment lands (across from Edgewood). .	C	<u>20</u>
		130
Montane Region: mostly ridge top grasslands above 500 meters		
Long Ridge Open Space Preserve.	I	40
Los Trancos Open Space Preserve	I	20
Monte Bello Open Space Preserve.	C	360
Russian Ridge Open Space Preserve	C	320
Saratoga Gap Open Space Preserve	C	20
Skyline Ridge Open Space Preserve.	C	40
Windy Hill Open Space Preserve	C	160
Wunderlich County Park.	C	<u>10</u>
		970
		total 3250

Beaches

Rockaway

San Pedro

Montara State Beach

Half Moon Bay State Beach

San Gregorio State Beach

Pescadero State Beach

Pomponio State Beach

Bear Hollow State Beach

Gazos Creek State Beach

Sunset Beach

Pajaro River and Dunes

Determining Native Grass Stand Area

The total grassland area surveyed was determined by outlining the preserve boundaries on USGS topographic maps, cross hatching the preserves with squares, and using the vegetation characterizations on the maps to determine the grassland percentages in each preserve.

The stands included in this study had to fulfill the parameters of the California Department of Fish and Games vegetation sampling program. Stands needed to measure at least 50 meters x 5 meters long and contain at least 10% native grass cover. Stands of this size and native grass cover are considered to be 'significant' conservation resources by the Natural Diversity Data Base of the California Department of Fish and Game (Keeley 1991). In practice, the great majority of native grass stands found which were readily visible and which were large enough for inclusion into the study, easily surpassed this density. The only exceptions to this were some native grass stands found on serpentinite soils. Surveying in these areas was restricted to denser native grass stands. Area figures for serpentine grasslands included, however, all serpentine grassland area. Given the time constraints of the study it was not possible to differentiate serpentine grass stands with >10% relative native grass cover from those with <10% relative native grass cover.

Native grass stand size was estimated visually during the vegetation sampling using the 50 meter transect line as a guide. The time constraints of the vegetation sampling given the large number of stands sampled, the length of the growing season, and the amorphous shapes of the stands obviated taking more precise measurements. Stands that were significantly larger than 50 meters on end, were estimated for size by walking the width and length of the stand and converting steps taken to meters. All stand sizes were estimated by the author except for the very large stands on serpentinite soils at Edgewood County Park. Assistance with stand size at Edgewood County Park was provided by Toni Corelli, a botanist well acquainted with the park. Area figures for the three native grasses

(*Danthonia californica*, *Elymus multisetus*, *Nassella pulchra*) found in the three large native grass stands were estimated to the fifth hectare (i.e. 25, 30, 35 hectares).

Each time a native grass attained >10% relative cover over 250 square meters, the area of the stand it was found in, was included in that native grasses area totals. If two native grasses in a stand both attained >10% relative cover over 250 square meters then each received 'credit' for area of the stand in the individual species area accounts (see Table 9). In the area figures for the total native grass community, the area of each stand was only counted once.

The Habitat and Vegetation Structure of Native Grass Stands

The Canonical Correlations

Two canonical correlations (Zar 1974) were used to characterize native grass habitats and vegetation structure. The first included all native grass stands sampled before 1998 (n=140), the second included all *N. pulchra* stands sampled before 1988 (n=75).

Canonical correlations are multivariate analyses designed to uncover the patterns underlying separate data sets, one of which contains independent variables (abiotic factors), and one which contains dependent variables (vegetation structure). The data must be linear and the variables within each data set must be only moderately correlated.

All variables were subjected to a Pearson Product Moment correlation test to ensure that confounding variables were not included in the analysis. One member of any

product pair with a score of greater than .700 was removed. Multiple iterations of the canonical correlations were run using a variety of the variables seen below to determine which combination of variables explained the most variance. Paired and standard t-tests were used to examine the vegetation differences within and between native grass stands and regions.

Sampling occurred between 4/12/96 and 7/20/96, 4/4/97 and 7/4/97, and 3/28/98 and 7/4/98. The sampling dates on which stand area and physical and vegetation data were gathered can be found below (Table 6). Some sites were visited more than once in order to identify species that were not in flower or seed at the first sampling date. Sampling occurred from the lower elevations of the interior regions upward and coastward, and sampling stopped when too many species had senesced for a satisfactory community characterization to be made.

The Data

Stand data were gathered using the techniques developed by the California Native Plant Society (CNPS) for its plant community program (Sawyer and Keeler-Wolf 1995). At every 0.5 meters along a fifty meter measuring tape, a piece of rebar (3/8 " diameter) was dropped and the different plant species hit were recorded. Ideally a smaller point diameter would have been better, but because this was the point size that was initially used, it was used throughout in order to ensure consistency. In larger stands the middle of the transect was situated in the middle of the stand and the direction of the transect was

Table 6.--Sampling Dates for Area Estimates and Physical and Vegetation Data

Preserve	Sampling Dates
Ano Nuevo/Cascade State Park	6/28-29/97
Calero County Park	5/7/96 - 5/13/96
Duveneck Windmill Open Space Preserve	5/23/96
Edgewood County Park/Water Dept.	5/16/96, 6/24/96
Long Ridge Open Space Preserve	6/14-15/98, 6/20-1/ 98, 6/28/98, 7/4/98
Milagra Ridge National Recreation Area	4/26/96
Monte Bello Open Space Preserve	5/28-31/96, 6/20-21/96
Rancho San Antonio Open Space Preserve	5/22/96
Russian Ridge Open Space Preserve	7/8/95, 5/27/96, 6/2-5/96
San Bruno County Park	4/12/96, 5/3/96, 6/23/96, 6/25-26/96, 7/10/96, 4/5/97, 4/13/97, 5/17/97
San Pedro Point	7/4/98
Santa Teresa County Park	6/1/96, 6/26/96, 7/10/96, 4/4/97, 4/19/97, 4/20/97, 4/27/97, 5/4/97, 7/4/97, 3/28/98, 4/26/98, 5/3/98
Sierra Azul Open Space Preserve	5/3-4/96
Skyline Ridge Open Space Preserve	7/8/95, 7/1/96
Stanford Academic Reserve	4/27/96-5/1/96, 5/9/96, 5/2/97
Sweeney Ridge County Park	5/17-18/96, 7/20/96
University of California at Santa Cruz	6/9-11/96, 7/13/96
Wilder Ranch State Park	6/12/96, 7/14/96

chosen randomly. In practice, most stands were so small as to obviate any possibility of random placement, and the transect line was simply stretched along the longest axis of the stand.

If no plant species were hit then the condition of the substrate (litter, soil, rock)

was noted. A 250 square meter plot surrounding the transect line was then extensively searched for additional species to get the total species found in each plot. Relative cover values were obtained by dividing the number of hits each species received into the total number of hits.

The approximate elevation, slope, and aspect were determined. Slope was measured using a wood square. A protractor with a plumb line centered in the middle of the protractor was attached in the middle of the square. The square was placed along the slope and the slope reading was taken by the angle the plumb line formed. Aspect was measured with a compass.

When stands were found which were intermediate between weather stations, precipitation figures were estimated by establishing a precipitation/elevation gradient between weather stations in lowland and montane areas, and using that gradient to arrive at precipitation totals for each preserve. The gradient was formed by determining the difference in the precipitation/elevation ratio between two stations and converting it to number of inches/meter. That figure was multiplied by the difference in elevation between the intermediate station and the lower station and then added to the rainfall total from the lower station. For instance, if two stands at 100 meters and 1000 meters had 10 and 40 inches of rainfall respectively and the precipitation of a native grass stand at 500 meters was unknown, the ratio between the two stations ($40-10/1000-100 = .03$) equals a gradient of .03 inches per meter. Multiplying this figure by the distance between the lower and unknown site ($400 \text{ meters} \times .03$) equals 12 inches of precipitation gained over the increase of elevation from the lowland to the unknown site. This figure is added to lower

stations precipitation figure (10+12) to get an estimate of rainfall for the native grass stands (22 inches).

Distance from the bay or coast was the closest distance between the bay or coast and the native grass site measured on a map. Soil samples were taken from the upper ten centimeters of the soil, four times along the transect. Approximately four cups of soil were taken from each site. A texture analysis was performed using the hydrometer method (approximate analysis procedure) (Cox 1976).

Different variables were used in the two canonical correlations. They are given below.

Canonical Correlation I: Native Grass Stands In Santa Cruz Mountain Region Preserves

Physical variables

Ten physical variables were measured, and eight were used. Elevation was not used because of its high correlation with precipitation and bare soil was not used because of its limited value. The physical variables used included:

Slope	Aspect
Precipitation	Distance from coast
Distance from bay	% clay
% sand	% gravel
Rock cover	

Vegetation variables

Most of the native grasses which formed large enough stands (10% relative cover over @ 250 square meters), and which occurred frequently enough (at least four times), to fit the parameters of the canonical correlation, were included. The relative cover values of 11 native grass species were included in the final canonical correlation. These species were:

<i>Bromus carinatus</i>	<i>Calamagrostis nutkaensis</i>
<i>Danthonia californica</i>	<i>Deschampsia caespitosa</i>
<i>Elymus glaucus</i>	<i>Elymus multisetus</i>
<i>Festuca idahoensis</i>	<i>Hordeum brachyantherum</i>
<i>Leymus triticoides</i>	<i>Melica torreyana</i>
<i>Nassella pulchra</i>	

Nineteen vegetation measures were obtained and seven were used* in the canonical correlation. Others were used in various t-tests. They included:

Native grass relative cover*
 Non-native grass relative cover*
 Native forb relative cover*
 Non-native forb relative cover*
 Shrub relative cover*
 Total native species relative cover
 Total non-native relative cover
 Shannon-weaver diversity

Simpson diversity
 Conservation value*
 Average rarity*
 Site uniqueness value (SUV)*
 Native grass richness
 Non-native grass richness
 Native forb richness
 Total native richness
 Non-native forb richness
 Total non-native richness
 Total species richness

A vegetation measure termed “conservation value” was introduced in an attempt to identify conservation ‘hot spots’, i.e., native grass stands with a native species-rich flora including many species of limited ranges. Each native species was given a score corresponding to the inverse of the number of sub-regions in California in which it was found (Hickman 1993). Species that had smaller ranges and thus are of more value from a conservation standpoint received higher scores and vice-versa. For example, if a species was found in one of the twenty-four sub-regions occurring in California, it was given a value of twenty-four points, if found in twenty regions, then five points, etc. A total stand value was derived by adding up the scores of all native species in each stand. For example, a stand containing *Monardella undulata* whose range in California is two sub-regions (=23 points), *Grindelia hirstula* var *hirsutula* (4 sub-regions=21 points), and *Erigeron glaucus* (4 sub-regions=21 points), would receive 65 points (23+21+21=65). A stand with more widely distributed species such as *N. pulchra* (17 sub-regions=8 points),

Ranunculus californica (17 sub-regions=8 points), and *Sisyrinchium bellum* (24 sub-regions=1 point) would receive 17 ($8+8+1=17$) points. The conservation values for the different native grass stands ranged from under 20 to over 200. This variable was included because the canonical correlations in which it occurred explained more variance than those with more commonly used diversity measures (Shannon-Weaver diversity index, Simpson diversity, total species richness).

A “rarity” variable was introduced to determine if native grass stands that had a rarer native flora could be differentiated from those with a more common flora. The variable was derived by giving each native species a value based on the number of geographic sub-regions in California that it occurred (Hickman 1993), and then adding the values of all the native species in a stand, and then dividing the total by the number of native species in the stand to get an average.

“Site uniqueness” values were used to identify native grass stands with distinctive floras (Dony and Denholm 1985). Each native species found in a stand was given a value according to the number of native grass stands it occurred in regionwide; the values for all the native species in each stand were added together and then divided by the number of native species in the stand to get an average. This number was used to identify the average site uniqueness value of each stand.

Canonical Correlation II: *Nassella pulchra* Stands in Santa Cruz Mountain Region Preserves

A second canonical correlation was run in order how physical factors influence vegetation composition in *N. pulchra* stands (>10% *N. pulchra* relative cover). The physical and vegetation variables used are found below.

Physical variables:

Slope	Cose
Precipitation	Distance to coast
Distance to bay	% sand
% Gravel	

Vegetation variables:

Patch size	Conservation value
Native grass cover	Non-native grass cover
Native forb cover	Non-native forb cover
Forb rarity	Non-native grass richness

Non-Native Species Threats to Native Grass Stands

The most abundant non-native species found in the native grass community were identified by determining the frequency and relative cover of the non-native species found

in the stands sampled (n=160). All non-native species found in >10% of native grass stands are identified.

Non-native species threats to the individual native grasses that formed stands were determined by identifying the non-native species that occurred regularly (>25%) and abundantly (>10% relative cover non-native grasses, >5% relative cover non-native forbs) in the stands that each native grass formed.

The species identified by the California Exotic Pest Plant Council as invasive which occur in Santa Cruz Mountain region grasslands were identified and their relative cover and frequency in the regions native grass stands was determined.

Thomas's remarks on species abundance in his Flora of the Santa Cruz Mountains of California are noted to determine if any non-native species now abundant in native grass stands were rare or not present at the time his flora was written (Thomas 1961).

The Relationship Between Cultivation, Landscape Conversion and Native Grass Stand Distribution and Abundance

Historical data on land use practices was gathered to determine if any sites which currently contain native grass stands, had been cultivated before. Aerial photographs dating from 1928 to 1981 were viewed at the United States Geological Survey in Menlo Park, and at the map rooms in the libraries at the University of California at Santa Cruz and Berkeley (see Table 7).

Original surveyors notebooks at the surveyors office in Santa Clara County were

Table 7.--Aerial Photographs Used to Determine Prior Cultivation in Native**Grass Stands**

<u>Preserve</u>	<u>Aerial Photographs</u>
Ano Nuevo/Cascade Ranch State Parks	1928 , 8/1/39, 10/11/43, 6/7/74
Calero County Park	1953, 6/18/68, 7/12/74
Edgewood County Park	1930, 9/26/48, 8/5/60, 7/8/63, 5/15/68, 6/7/73
Milagra Ridge County Park	5/27/56, 4/22/73
Monte Bello Open Space Preserve	8/1/39, 1968, 6/7/73, 1981
Russian Ridge Open Space Preserve	8/1/39, 10/11/43, 6/19/63
San Bruno County and State Parks	5/27/56
Santa Teresa County Park	9/28/63, 5/24/65, 7/12/74
Skyline Ridge Open Space Preserve	8/1/39, 1968, 6/7/73, 1981
Stanford Academic Reserve	8/1/39, 8/15/60
Sweeney Ridge County Park	1928, 10/11/43
University of California at Santa Cruz	6/17/40, 10/11/43
Wilder Ranch State Park	1928, 8/1/39, 10/11/43,
Wunderlich County Park	1930, 8/1/39

examined to help determine the original vegetation types and the presence of cultivation.

Because the surveyors were not undertaking a vegetation survey, notations on vegetation types were sketchy and incomplete or non-existent. Occasionally more complete descriptions are given such as this "land (is) so densely covered with chaparral and is so utterly worthless that it was deemed impractical to survey" (Rancho San Antonio, John Reed 1870). Only surveyor's notes with more complete vegetation descriptions were used.

Various historical documents and personal conversations with Charles Graham, an expert on wine growing in the Santa Clara and San Mateo County, were used to determine previous disturbance patterns occurring on some of the preserves.

Field observations used to identify converted grasslands included noting the size, shape, location, and general soil environment of each grassland surveyed in relation to the surrounding environment. Grasslands deemed to have been either partially or completely converted included; large grassland patches surrounded by dense oak woodland, chaparral or forest, whose boundaries were discrete and displayed no evidence of a gradual ecotonal boundary; large grasslands existing where only small grassland meadows generally occur such as in heavily forested areas; and grassland patches with vegetation boundaries which ran up and down rather than parallel to a slope without any obvious edaphic discontinuities, and/or which ran along a fence line without conforming to natural habitat boundaries.

Isolation, Disturbance and Non-Native Species Invasions

This section was not originally part of the thesis. The presence of complete floristic data on the grasslands of a nearby preserve with a dramatically different disturbance history and degree of isolation provided the impetus for an intriguing, if preliminary investigation of the effects of these factors on non-native species invasions.

Determining the effect the current management scheme has on native grass abundance is important. It is impossible, given the lack of baseline information on species composition at the time of preserve acquisition in the Santa Cruz Mountains, to other than anecdotally assess how native grasses have fared in the last several decades. One preserve, however, exists in the central California Coast Ranges, which has not only been

ungrazed and uncultivated for a fairly long period of time (approximately 60 years), but which has also kept detailed floristic records throughout that period.

Located approximately eighty miles south of the of the interior preserves of the Santa Cruz Mountains, Hastings reservation in the Santa Lucia Mountains has remained undisturbed during a period of time when many aggressive exotic species either entered the state or expanded their ranges significantly (Robbins 1940, Rejmanek et. al. 1991, Rejmanek and Randall 1994). It constitutes a living laboratory against which more human impacted preserves can be compared. A study of Hastings reservation and nearby off-reservation grasslands found that different suites of species were found on sites with different disturbance histories (grazing, cultivation) (Stromberg and Griffin 1996).

A comparison of the non-native species found in Hastings grasslands and in native grass stands in preserves in the interior region of the Santa Cruz Mountains was conducted in order to investigate the impact Hastings isolation and policy of non-interference may have on non-native species composition and abundance. In particular, are there noxious species present in Santa Cruz Mountain native grass stands that have been unable to penetrate Hastings more isolated and less disturbed grasslands?

The two categories of introduced species in Hastings reserve created (Knops et al. 1995); introduced established, and introduced but not established were compared with the non-native species found in Santa Cruz Mountain interior region (off serpentinite soils) native grass stands. Two categories of species were formed; non-native species present in the Santa Cruz Mountain native grass stands but either not found at Hastings, or present but not established at Hastings.

The approximate ranges of the non-native species at the time of Hastings prior to the establishment of the preserve were noted to determine if they were likely to occur at Hastings prior to the establishment of the preserve, and its policy of no grazing or cultivation (Robbins 1940). Given the incomplete and sometimes inaccurate state of reporting about non-native species ranges which exists today (Rejmanek 1991), Robbins observations of sixty years ago, centered apparently in the San Francisco Bay area, must be viewed with some caution.

CHAPTER SIX

RESULTS

Native Grass Stand Abundance and Distribution

Five tables illustrate different components of native grass stand abundance and distribution in grasslands in Santa Cruz Mountain region preserves.

The total stand area formed by the native grass community in the Santa Cruz Mountain region preserves can be seen below (Table 8). Native grasses formed 'stands' when they maintained >10% relative cover over 250 square meters. Native grass stand abundance in individual preserves can found in Appendix 2.

Table 8.--Native Grass Stand Abundance in Santa Cruz Mountain Region Preserves-

Region	Grassland Area Surveyed (hectares)	Native Grass Area (hectares)	Percent Native Grass	Number of Native Grass Stands
<i>Interior region (non-serpentinite soils)</i>	1070	7	0.7	53
<i>Montane</i>	990	7	0.7	43
<i>Coastal</i>	730	29	4.0	23
<i>Bay</i>	230	3	1.3	23
Total - non-serpentinite soils	2990	46	1.5	142
<i>Interior region serpentinite</i>	80	47	>50.0	18
Total surveyed	@ 3070	@ 93	@ 3.0	160

of grassland area occupied by the dominant native grasses (>10% relative cover) in native grass stands are found in Table 9.

Table 9.--Percent of Grassland Area Occupied by the Dominant Native Grasses in Native Grass Stands

Species	Number of Stands* (n=160)	Stand Area (hectares)	Percent of Grassland
<i>Nassella pulchra</i>	75	45 (50)**	1.7
<i>Danthonia californica</i>	20	40	1.3
<i>Elymus multisetus</i>	9	30	1.0
<i>E. glaucus</i>	13	1.6 (2)	0.07
<i>Bromus carinatus</i>	12	1.9 (2)	0.09
<i>Melica torreyana</i>	4	1.9 (2)	0.09
<i>Leymus triticoides</i>	7	0.9 (1.0)	0.02
<i>Festuca idahoensis</i>	8	0.8	0.03
<i>Calamagrostis nutkaensis</i>	5	0.7	0.03
<i>Leymus triticoides</i>	7	0.9	0.02
<i>Vulpia microstachys</i>	2	0.9	0.02
<i>Festuca rubra</i>	2	0.4	0.01
<i>F. californica</i>	1	0.4	0.01
<i>Melica californica</i>	3	0.3	0.01
<i>Leymus mollis</i>	4	0.2	<0.01
<i>Deschampsia caespitosa</i>	4	0.2	<0.01
<i>Hordeum brachyantherum</i>	4	0.2	<0.01
<i>Nassella lepida</i>	5	0.2	<0.01
<i>Distichlis spicata</i>	2	0.06	<0.01

*number of stands in which the species occurred. A stand had >10% relative cover

*() includes stands noted during the survey but not sampled.

Frequency (% of stands in which a species is found) and average relative cover are provided in Table 10. In contrast to Table 8 which includes only instances when each native grass attains greater than 10% relative cover, all occurrences by native grasses are included in Table 9. All the native grass found in this survey are included in this table.

Table 10.--Frequency and Average Relative Cover Values of Native Grasses Occurring in Native Grass Stands

<i>Species</i>	Total Occurrences (n=160)	Frequency (% of Total Stands)	Mean Relative Cover
<i>Nassella pulchra</i>	102	64	21.4
<i>Elymus glaucus</i>	59	37	10.9
<i>Bromus carinatus</i>	50	31	7.2
<i>Elymus multisetus</i>	38	24	7.2
<i>Danthonia californica</i>	34	21	22.8
<i>Melica californica</i>	29	18	3.7
<i>Festuca idahoensis</i>	13	8	13.6
<i>Leymus triticoides</i>	13	8	42.2
<i>Koeleria macrantha</i>	11	7	1.0
<i>Hordeum brachyantherum</i>	10	6	14.7
<i>Vulpia microstachys</i>	10	6	7.4
<i>Nassella lepida</i>	10	6	10.6
<i>Calamagrostis nutkaensis</i>	5	3	36.4
<i>Deschampsia caespitosa</i>	5	3	46.0
<i>Melica torreyana</i>	5	3	19.1
<i>Poa secunda</i>	5	3	0.7
<i>Agrostis pallens</i>	5	3	3.3
<i>Leymus mollis</i>	4	2	36.8
<i>Panicum acuminatum</i> var. <i>acuminatum</i>	3	2	1.7
<i>Distichlis spicata</i>	2	1	39.5
<i>Festuca rubra</i>	2	1	20.4
<i>Leymus multiflorus</i>	2	1	22.0
<i>Poa tenerrima</i>	2	1	1.0
<i>Vulpia octoflora</i>	2	1	1.5
<i>Agrostis microphylla</i>	1	<1	7.0
<i>Festuca californica</i>	1	<1	95.0

Mean stand size is often a critical component of stand viability (see Table 11).

Stand size for each native grass includes only those stands in which each native grass had >10% relative cover.

In order to determine the regions of greatest abundance for each native grass, the

Table 11.--Mean Stand Size of Native Grasses Forming Stands.

Species	Number of Stands* (n=160)	Mean Stand Size (hectares)
<i>Elymus multisetus</i>	9	2.9
<i>Danthonia californica</i>	20	1.3
<i>Melica torreyana</i>	4	1.1
<i>Nassella pulchra</i>	75	0.7
<i>Festuca californica</i>	1	0.4
<i>Festuca rubra</i>	2	0.2
<i>Bromus carinatus</i>	12	0.1
<i>Calamagrostis nutkaensis</i>	5	0.1
<i>Elymus glaucus</i>	13	0.1
<i>Festuca idahoensis</i>	8	0.1
<i>Melica californica</i>	3	0.09
<i>Leymus triticoides</i>	7	0.08
<i>Deschampsia caespitosa</i>	4	0.06
<i>Leymus mollis</i>	4	0.06
<i>Hordeum brachyantherum</i>	4	0.05
<i>Distichlis spicata</i>	2	0.03
<i>Nassella lepida</i>	5	0.03

*greater than 10% relative cover

percentage of stands (>10% relative cover, >250 meters square) in every region that each native grass forms is listed below (see Table 12). Stands in which a native grass is present but achieves >10% relative cover are noted as well in order to determine how widespread the grass is. For instance, the first row indicates that *N. pulchra* occurred with >10% relative cover in 75% of all the native grass stands found in the interior region, and occurred with <10% relative cover in only 7% of all the native grass stands found in the interior. These figures indicate that not only is dominant *N. pulchra* in this region, but that it almost always abundant when found; it only rarely is found with less than 10%

cover. Comparing these figures with those for *N. pulchra* in the montane region illustrates that *N. pulchra* generally occurs sparsely (<10% relative cover) in the native grass stands in that region.

Rare Species in Santa Cruz Mountain Native Grass Stands

Each plot (250 square meters) was extensively searched to identify all the species found within it. Only a sampling of each native grass stand occurred. Therefore rare species occurring outside the 250 square meter plot but still in the native grass stand may have been missed.

Five of the forty-three rare species found in the regions grasslands occurred in the native grass stands surveyed (see Table 13). Another rare species not listed as being found in a grassland habitat (*Arctostaphylos imbricata*) occurred, bringing the total to six. One species listed in the *Jepson Manual* as endangered in California (Webster 1993) but not by the California Native Plant Society also occurred.

Non-Native Species Threats to Native Grass Stands

Particularly invasive and threatening non-native species that occur in the regions grasslands are identified in this section and their presence and frequency and abundance in the region's native grass stands are quantified. The frequency and abundance of other common non-natives is quantified as well. Native grass stands with particularly high abundances of non-native species are identified.

Table 12.--Regional Abundance in the Native Grass Community

	% of Interior Region Stands > 10% Cover	% of Interior Region Stands < 10% Cover	% of Serpent inite Region Stands > 10% Cover	% of Serpent inite Region Stands < 10% Cover	% of Montane Region Stands > 10% Cover	% of Montane Region Stands < 10% Cover	% of Coastal Region Stands > 10% Cover	% of Coastal Region Stands < 10% Cover	% of Bay Region Stands > 10% Cover	% of Bay Region Stands < 10% Cover
<i>N. pulchra</i>	75	7	72	22	10	22	25	15	48	12
<i>D. californica</i>	-	-	11	-	10	8	55	10	-	24
<i>E. multisetus</i>	-	2	17	44	15	40	-	-	-	-
<i>E. glaucus</i>	3	7	-	28	20	50	5	-	4	20
<i>B. carinatus</i>	2	8	6	17	20	38	-	10	12	40
<i>M. torreyana</i>	-	-	28	11	-	-	-	-	-	-
<i>F. idahoensis</i>	-	-	-	-	13	5	-	-	16	4
<i>C. nutkaensis</i>	-	-	-	-	-	-	-	-	20	4
<i>L. triticoides</i>	12	-	-	-	1	-	-	-	-	2
<i>M. californica</i>	-	6	-	28	13	18	-	-	-	12
<i>L. mollis</i>	-	-	-	-	-	-	20	-	-	-
<i>D. caespitosa</i>	-	-	-	-	-	-	20	-	-	-
<i>H. brachyantherum</i>	5	-	6	11	-	1	-	-	-	-
<i>N. lepida</i>	2	3	-	-	-	-	-	-	12	4
<i>Festuca rubra</i>	-	-	-	-	-	-	-	-	8	-
<i>F. californica</i>	-	-	-	-	-	-	-	-	4	-
<i>D. spicata</i>	2	-	-	-	-	-	5	-	-	-
<i>V. microstachys</i>	-	-	28	22	-	-	-	-	-	-
<i>Lxmulti florus</i>	-	-	-	-	-	-	-	-	4	-
<i>Poa secunda</i>	-	-	-	11	-	3	-	-	-	-
<i>A. pallens</i>	-	-	-	-	-	3	-	-	-	16
<i>P. acuminatum</i> var. <i>acuminatum</i>	-	-	-	-	-	-	-	15	-	-
<i>K. macranthra</i>	-	2	-	33	-	10	-	-	-	12
<i>V. octoflora</i>	-	-	-	6	-	-	-	-	-	-
<i>A. densiflora</i>	-	-	-	-	-	-	-	-	-	4
<i>A. microphylla</i>	-	-	-	6	-	-	-	-	-	-

*each native grass which attains >10% relative cover value is included. Because co-dominant species sometimes form stands the column will add to >100%

(-) indicates not present

Table 13.--Rare Species in Native Grass Stands

Rare Species	Rarity	Native Grass Stand Occurring In
<i>Arctostaphylos imbricata</i>	IB	<i>Calamagrostis nutkaensis</i>
<i>Castilleja latifolia</i>	4	<i>Leymus mollis</i>
<i>Horkelia marinensis</i>	IB	<i>Calamagrostis nutkaensis/ Festuca rubra</i>
<i>Lessingia hololeuca</i>	3	<i>Melica torreyana</i>
<i>Linanthus ambiguus.</i>	3	<i>Nassella pulchra</i>
<i>Monardella undulata</i>	4	<i>Calamagrostis nutkaensis/ Festuca rubra</i>
<i>Streptanthus albidus</i> <i>ssp. peramoenus</i>	IB	<i>Melica torreyana, Vulpia microstachys</i>
<i>Pentachaeta bellidiflora</i>	IB	<i>Nassella pulchra/Elymus multisetus</i>
<i>Panicum acuminatum</i> var. <i>acuminatum</i>	Jepson	<i>Deschampsia caespitosa/ Danthonia californica</i>

Invasive Species Found in Native Grass Stands

The frequency and abundance of the twenty-two invasive grassland species as identified by CALEPPC are listed below (see Table 14).

Commonly Occurring Non-Native Species in Native Grass Stands in Santa Cruz Mountain Region Preserves

The list of CALEPPC invasive species is contrasted with those found in the following two tables which identify the most frequently occurring (>10% of stands) non-native invaders (invasive or otherwise) found in native grass stands in the Santa Cruz Mountain region preserves (see Tables 15 and 16).

Table 14.--Frequency and Abundance of Invasive Species in Native Grass Stands

Species	Frequency (n=160)	Mean Relative Cover
<i>Lolium multiflorum</i>	.57	12.3
<i>Bromus diandrus</i>	.46	4.9
<i>Avena barbata</i>	.44	6.5
<i>Brachypodium distachyon</i>	.41	22.7
<i>A. fatua</i>	.31	10.8
<i>Carduus pycnocephalus</i>	.27	2.5
<i>C. solstitialis</i>	.24	2.4
<i>Hypochaeris radicata</i>	.15	.73
<i>B. madritensis ssp. rubens</i>	.14	2.4
<i>Cirsium vulgare</i>	.09	.6
<i>Brassica nigra</i>	.08	2.6
<i>Holcus lanatus</i>	.08	2.5
<i>Phalaris aquatica</i>	.04	.83
<i>Foeniculum vulgare</i>	.03	0
<i>Cytisus scoparius</i>	.02	1.3
<i>Bellardia trixago</i>	.01	1.0
<i>Oxalis pes-caprae</i>	.01	0
<i>Conium maculatum</i>	.01	0
<i>Parentucellia viscosa</i>	.006	1.0
<i>Centaurea melitensis</i>	.006	0
<i>Ammophila arenaria</i>	.006	0
<i>Taeniatherum caput-medusae</i>	.006	0

Table 15.--Frequency and Relative Cover of Non-Native Grasses in Native Grass Stands

Species	Frequency (n=160)	Mean Relative Cover
<i>Bromus hordaceus</i>	.79	7.0
<i>Lolium multiflorum</i>	.57	12.3
<i>Bromus diandrus</i>	.46	4.9
<i>Avena barbata</i>	.44	6.5
<i>Vulpia bromoides</i>	.42	6.3
<i>Brachypodium distachyon</i>	.41	22.1
<i>Avena fatua</i>	.33	10.6
<i>Aira caryophylla</i>	.19	6.0
<i>Bromus madritensis</i>	.14	2.4
<i>Briza minor</i>	.13	1.0
<i>Briza major</i>	.11	9.8

Table 16.--Frequency and Relative Cover of Non-Native Forbs in Native Grass Stands

Species	Frequency (n=160)	Mean Relative Cover
<i>Rumex acetosella</i>	.34	2.8
<i>Geranium dissectum</i>	.33	3.6
<i>Carduus pycnocephalus</i>	.27	2.5
<i>Sonchus asper</i>	.27	1.9
<i>Centaurea solstitialis</i>	.19	2.5
<i>Erodium botrys</i>	.19	3.1
<i>Anagalis arvensis</i>	.18	1.1
<i>Crepis vesicaria ssp. taraxacifolia</i>	.16	3.1
<i>Hypochaeris radicata</i>	.15	.73
<i>Torilos nodosa</i>	.13	3.2

Abundant Non-Native Species in Specific Native Grass Stands

In order to determine specific non-native species threats to specific native grass stand types, non-native species that occur both frequently (>25% of stands) and abundantly (>10% relative cover-grasses, >5% relative cover-forbs) in specific native grass stand types, are quantified (see Table 17). Thus, the first row indicates that *Lolium multiflorum* occurred in 50% of *Bromus carinatus* stands and had a mean relative cover of 24%.

Cultivation and Vegetation Conversion And Native Grass Distribution and Abundance

Cultivation

The following aerial photographs showed evidence of cultivation at the following preserves.

Ano Nuevo/Cascade Ranch	1928, 8/1/39, 10/11/43, 6/7/74
Milagra Ridge County Park	5/27/56
Monte Bello Open Space Preserve	8/1/39, 1968
Skyline Ridge Open Space Preserve	8/1/39, 1968, 6/7/73, 1981
Sweeney Ridge Open Space Preserve	1928, 10/11/43

A history of cultivation was confirmed at Fremont Older County Park and at Sierra Azul (St. Joseph's Hill) using historical records. Both preserves were vineyards that had been carved out of the dense chaparral vegetation behind Los Gatos, Cupertino and Saratoga in the late 1800's (1876 New Historical Atlas of Santa Clara County, Sullivan 1982, Charles Graham pers. com.). Sierra Azul was the home of the Novitiate Winery. A 1919 panoramic photo taken by E. R. Freeman shows cultivation at the

Table 17.--Abundant Non-Native Grasses (>10% Relative Cover) and Forbs (>5% Relative Cover) in Native Grass Stand Types

Native Grass Stand Type	Non-Native Species	Freq- uency	Rel. Cover
<i>Bromus carinatus</i>	<i>Lolium multiflorum</i>	0.5	24.0
<i>Calamagrostis nutkaensis</i>	<i>Rubus ursinus</i>	1.0	11.5
<i>Danthonia californica</i>	<i>Geranium dissectum</i>	0.33	7.5
<i>Elymus glaucus</i>	<i>Geranium dissectum</i>	0.3	9.0
	<i>Rumex acetosella</i>	0.3	9.0
<i>Elymus multisetus</i>	<i>Avena barbata</i>	0.7	15.0
<i>Festuca idahoensis</i>	<i>Aira caryophylla</i>	0.5	13.3
<i>Leymus triticoides</i>	<i>Lolium multiflorum</i>	1.0	20.7
	<i>Carduus pycnocephalus</i>	0.6	19.3
	<i>Erodium botrys</i>	0.4	11.0
<i>Hordeum brachyantherum</i>	<i>Lolium multiflorum</i>	1.0	52.5
<i>Melica californica</i>	<i>Avena barbata</i>	0.5	21.6
	<i>Bromus hordaceus</i>	0.75	17.3
	<i>Bromus diandrus</i>	0.5	17.0
<i>Nassella lepida</i>	<i>Brachypodium distachyon</i>	0.8	39.8
<i>N. pulchra</i>	<i>Brachypodium distachyon</i>	0.27	36.8

Table 18.--Non-Native Species in Hasting Reservation and in Native Grass Stands in the Interior Region of the Santa Cruz Mountains

Non-Native Species Abundant in Native Grass Stands in the Interior Region Preserves of the Santa Cruz Mountains But Not Reported to Occur at Hastings.

<u>Species</u>	<u>Frequency (% sites)</u>
<i>Brachypodium distachyon</i>	46%
<i>Carduus pycnocephalus</i>	34%
<i>Centaurea solstitialis</i>	30%

Non-Native Species Abundant in Native Grass Stands in the Interior Region Preserves of the Santa Cruz Mountains and Introduced But Not Established at Hastings Reservation

<u>Species</u>	<u>Frequency (% sites)</u>
<i>Lolium multiflorum</i>	76%

winery. Orchard trees are still present at Fremont Older as are the ridges from an old vineyard at St. Joesphs Hill (Sierra Azul).

The 'cultivation' at Santa Teresa County Park consists of a firebreak that goes around the park in which a small *Leymus triticoides* stand is able to persist year after year. This stand is part of a larger, uncultivated stand and undoubtedly receives recruits from that stand. Observations during the course of this study of small patches of *L. triticoides* in regularly cultivated urban lots in San Jose further suggest that *L. triticoides* can persist even under a regime of regular cultivation.

Marshall Fields, the site of several native grass stands (*Danthonia californica*, *Deschampsia caespitosa*, *Elymus glaucus*) at University of California at Santa Cruz, was

also cultivated. Because the extent of cultivation could not be determined, the native grass stands found there were not included in this analysis.

Vegetation Conversion

For only a few preserves could historical data be found which indicated land conversion from another vegetation type. Rancho San Antonio County Park was originally covered with live and white oaks (surveyors field notes 1866, 1873) and dense growths of chamisal (chaparral) (surveyors field notes 1866, 1870, 1873). No mention of grasslands on any of the field notes is made.

The grassland areas found at Windy Hill and Arastradero are so irregular given the vegetative zone they are found in, that large-scale vegetation conversion is certain. Found on steep north-facing slopes, Windy Hill is bordered by dense Douglas Fir/Redwood Forest. A very large grassland, it occurs in a setting where grass stands usually consist of small meadows found on moist flatlands. The vegetation boundaries between the grassland and the surrounding forest are discrete and show no signs of ecotonal intergrading. Windy Hill grasslands support the densest non-native thistle stands found during the survey.

Arastradero County Park is a large grassland area occurring at the lower end of the foothill range, surrounded on almost four sides by oak woodlands and exhibiting the same characteristics as Windy Hill. No other large grassland areas with the exception of Windy Hill were found extending so high into the oak woodland/Douglas Fir forests.

Slope is moderate to high. Vegetation boundaries are discrete with little ecotonal intergrading present. Soils appeared productive and were neither mesic enough for meadows nor xeric enough to possibly support natural grasslands.

Habitat and Vegetation Structure

Canonical Correlation I: Native Grass Stands in Santa Cruz Mountain Region Preserves

Four roots containing seven distinct abiotic and community characteristics were developed in the first canonical correlation. The canonical roots, characteristic sites, the degree of correlation achieved, and the plots are found below. The canonical loadings for each root can be found in Appendix Four.

Figure 1: Canonical Correlation I: Root I:

Root I: *Melica torreyana* stands found on steeper slopes with higher rock cover have higher native forb cover and higher conservation values

Characteristic stands: Santa Teresa 1-4, 9; Edgewood 1-4, 6; Water3; Sierra Azul 1-3.

Canonical correlation: 0.851

Figure 2: Canonical Correlation I: Root II

+ *B. carinatus* cover
 + *E. glaucus* cover
 + *E. multisetus* cover
 + *F. idahoensis* cover
 + conservation value

+ *N. pulchra* cover
 + native grass
 cover

Further from the bay

+ % gravel
 + slope
 + cose
 + precipitation

Root IIa: *Bromus carinatus*, *Elymus glaucus*, *E. multisetus* and *Festuca idahoensis* stands with lower native grass cover and higher conservation values are found closer to the bay on more gravel-rich soils on steeper, more north facing slopes with higher precipitation levels.

Characteristic stands: Russian Ridge 1, 2, 4, 5-11; Monte Bello 1-5, 7; San Bruno 1, 3, 5.

Root IIb: *Nassella pulchra* stands with higher native grass cover and lower conservation values are found further from the bay on less gravel-rich soils on flatter, less north facing slopes with lower precipitation levels.

Characteristic stands: Calero, Stanford

Canonical correlation: 0.823

Figure 3: Canonical Correlation I: Root III

+ *D. californica* cover
 + *D. caespitosa* cover
 + *L. mollis* cover
 + native forb cover
 + non-native forb
 cover

+ *L. triticoides* cover
 + *N. pulchra* cover
 + non-native grass
 cover

+ slope
 further from the bay
 further from the coast

+ precipitation
 - % gravel

Root IIIa: *Danthonia californica*, *Deschampsia caespitosa*, and *Leymus mollis* patches with lower non-native grass cover and higher native and non-native forb cover are found in areas of higher precipitation closer to the coast on lower gravel soils on less steep slopes.

Characteristic sites: Ano Nuevo/Cascade Ranch 1-8; UCSC 1-5, 7, Monte Bello 8, 10, 11, 13

Root IIIb: *Nassella pulchra* and *Leymus triticoides* stands with higher non-native grass cover and lower native and non-native forb cover are found in areas of lower precipitation further from the coast in higher gravel soils on steeper slopes

Characteristic sites: Stanford 1,2; Santa Teresa 10, Rancho San Antonio 1

Canonical correlation: 0.761

Figure 4: Canonical Correlation I: Root IV

+ *H. brachyantherum*
+ non-native grass
cover

+ *C. nutkaensis*
+ conservation value
+ rarity
+ shrub cover

+ % sand
closer to the coast

+ % clay
closer to the
bay

Root IVa: *Calamagrostis nutkaensis* stands closer to the coast and bay on sandier soils have lower non-native grass cover, higher shrub cover and a more localized native flora.

Characteristic stands: San Bruno 7-9, San Pedro Point 1-3.

Root IVb: *Hordeum brachyantherum* stands further from the coast and bay on less sandy soils have higher non-native grass cover, lower shrub cover and a more widespread native flora.

Characteristic sites: Santa Teresa County Park 5-8.

Canonical correlation: 0.655

Figure 5: Canonical Correlation II: Root I

Root Ia: *N. pulchra* stands found on more gravelly soils on steeper slopes in more arid environments further from the coast are smaller and have lower native grass and non-native forb cover and non-native grass richness, and higher *N. pulchra* and non-native grass cover and lower conservation values.

Characteristic sites: Stanford 2, 6, 7; Calero 6, 8, 18; Sierra Azul 3, Rancho San Antonio 4, 5; Duveneck Windmill 1, 3.

Root Ib: *N. pulchra* stands on less gravelly soils on flatter slopes in wetter environments nearer to the coast are larger, have higher native grass and non-native forb cover and non-native grass richness, and lower *N. pulchra* and non-native grass cover and higher conservation values.

Characteristic sites: UCSC 4, 5, 6; San Bruno 2, 6, 10; Monte Bello 5, 9; Sweeney Ranch 5, 6; Russian Ridge 10.

Canonical correlation: .782

Figure 6: Canonical Correlation II: Root II

Root IIa: *N. pulchra* stands found further from the bay on less gravel rich soils on more south-facing slopes have higher *N. pulchra* and non-native grass cover and non-native grass richness, and lower native forb cover, conservation values and a more common flora.

Characteristic sites: Calero 3, 6, 12, 13, 15, 16; Rancho San Antonio 5; Stanford 7, Wilder Ranch 2, Siera Azul 1

Root IIb: *N. pulchra* stands found closer to the bay on more gravel rich soils on more north-facing slopes have lower *N. pulchra* and non-native grass cover and non-native grass richness, and higher native forb cover, conservation values and a rarer flora.

Characteristic sites, Edgewood 2, 4, 6; Water 2, 3, Santa Teresa 6; San Bruno 2, Stanford2, 3.

Figure 7: Canonical Correlation II: Root III

Root IIIa: *N. pulchra* stands found further from the bay on lower clay and higher sand and gravel soils have lower *N. pulchra* and native grass and higher non-native grass relative cover values.

Characteristic sites: Santa Teresa 4, 5, 6, 8; Almaden Quicksilver 2, 4; and Calero 4, 5, 6, 7, 8, 9, 13, 15, 16.

Root IIIb: *N. pulchra* stands found closer to the bar on higher clay and lower sand and gravel soils, have higher *N. pulchra* and native grass and lower non-native grass relative cover.

Characteristic sites: Stanford 4, 6, 8, 9, 11; Water 1, 2, 3; Duveneck 3; Wilder Ranch 1; San Bruno 9, 11; Calero 2, 3.

Canonical correlation: 0.556

PART THREE

DISCUSSION

CHAPTER 7

NATIVE GRASS RARITY AND THREAT

Native Grass Abundance in Santa Cruz Mountain Preserves

This research showed that native grasses are rarely encountered in Santa Cruz Mountain preserves and, when encountered, they usually occur in very small stands. Native grass stands made up roughly 3% of the total grassland area surveyed (see Table 8). If native grass stand area on serpentinite soils is removed then native grass stands (>10% relative cover, >250 square meters) occupy only about 1.5% of the grasslands found on the more productive soils which underlie the vast majority of grasslands surveyed.

This was a surprisingly small percentage, given the areas mild climate and the relative abundance of 'large' native grass stands reported by Barry (1972) in the San Francisco Bay area. Native grasses covered a lower percentage of the grassland community than in San Diego (approximately 6%), which is an area with much lower native grass richness (Beetle 1947, Noss et al. 1998). Documented reports of several large, native grass stands in the southern California region (Barry 1972, Keeley 1991, 1993) and Oberbauer's estimates (Noss et al. 1998) indicate that valley grasslands in this area may have especially high native grass (i.e. *N. pulchra*) abundance.

Coalescing native grasses into their vegetation types indicated that native grasses that were associated primarily with the valley grasslands (*Nassella pulchra*, *Elymus glaucus*, *Leymus triticoides*, *Melica californica*, etc.) formed stands totaling 18 hectares; those associated with coastal prairie (*Calamagrostis nutkaensis*, *Danthonia californica*, *Deschampsia caespitosa*, *Festuca idahoensis*, *F. rubra*) formed stands totaling 30 hectares, those found on serpentinite soils (*N. pulchra*, *E. multisetus*, *Melica torreyana*,

Vulpia microstachys) formed stands totaling 47 hectares.

Fewer assessments of native grass abundance in coastal prairie exist than for valley grasslands (Hektner and Foin 1977). The area of coastal prairie stands in the entire Santa Cruz Mountain preserves appears to be substantially less than for a single reserve, Sea Ranch, in Sonoma County about 100 miles north of San Francisco (Hektner and Foin 1977). It is impossible to derive accurate area figures for *Deschampsia caespitosa*, one of the dominant native grasses at Sea Ranch, but both it and *Calamagrostis nutkaensis* appear to be on the order of several magnitudes more abundant than in the Santa Cruz Mountain region preserves. The Santa Cruz Mountain region occurs at the very southern end of the coastal prairie, and the more mesic elements of the coastal prairie (*C. nutkaensis*, *D. caespitosa*, *Festuca idahoensis*, *F. rubra*) are exceeding rare in the Santa Cruz Mountain region preserves.

Most of the native grass stand area (approximately 70%) in the Santa Cruz Mountain region preserves occurs in three large stands. Although the average native grass stand size in Santa Cruz Mountain preserves is small ($n=160$, $mn=0.5$ hectares) (see Table 11), it is swelled by the presence of these three 'large' stands. If they are removed then the mean stand size drops dramatically to 0.1 hectares.

That much of native grass stand area is found in a few large native grass stands suggests that Barry's survey (1972) of 'large' native grass stands in California may, so far as it is complete, in fact, be an fairly accurate measure of native grass abundance. If most native grass area is bound up in a few larger stands then their value as conservation resource rises greatly. The many smaller stands require increased monitoring because of their small size and susceptibility. They provide the genetic stocks for restoration efforts for most of California grasslands.

The importance of the few large native grass stands remaining highlights the

the need to uncover the factors governing native grass stand persistence in California grasslands. Edaphic, climactic, and historical events (prior grazing, cultivation, and landscape conversion) all probably play important roles. Further studies are needed to assess the importance of large native grass stands as reservoirs of native grass stand area.

Asymmetrical species abundance patterns also have important conservation implications for native grass conservation. *Nassella pulchra*, abundant (>10% relative cover) in over 60% of native grass stands found, is by far the most common native grass in the region (see Table 9). *Nassella pulchra*, *Danthonia californica* and *Elymus multisetus* were each abundant (>10% relative cover) in 40% or more of the total native grass stand area found. (Because *Nassella pulchra* and *Elymus multisetus* are co-dominant in several very large native grass stands on serpentinite soils, three native grasses can be abundant in over 40% of total stand area). The 15 other native grasses which achieved greater than 10% relative cover rates in a stand, accounted for about 10% of the total native grass stand area found.

The same pattern persists regarding native grass frequency. Only five native grasses are found (in any amount) in thirty or more stands, and the great majority of native grasses are extremely rare (see Table 10). If the top five most frequently occurring native grasses are excluded, then the average number of stands the twenty-one other native grasses found in the survey occur in is seven ($n=21$, $mn=7$, $sd=6.5$).

A review of relative cover values and abundance indicate that within stand native grass cover is, oddly enough, not correlated with native grass stand area. The native grasses which show the greatest dominance in their stands, and which appear to be the most resistant to non-native species invasion, are not the most abundant native grasses. That many of these native grasses with high cover values (*Calamagrostis nutkaensis*, *Danthonia californica*, *Deschampsia caespitosa*, *Distichlis spicata*, *Elymus glaucus*,

Leymus triticoides) are bottomland species suggests that this niche in California grasslands was fairly well filled by the native grasses prior to European colonization. Some evidence suggests that they may be, despite their rarity, more resilient in the face of disturbance than other native grasses. A small stand of *Leymus triticoides* is able to persist in a regularly cultivated firebreak at Santa Teresa County Park. *Danthonia californica* and *Elymus glaucus* have been able to re-invade formerly cultivated sites. Their rarity in the Santa Cruz Mountain preserves now may be partially due to lack of habitat. Few bottomland sites were found during the survey.

Proportionally, native grass abundance is greatest on serpentinite soils (>50%). Occupying less than 5% of the areas grasslands, serpentinite soils contain over half the native grass area found. Off serpentinite soils native grasses occupy approximately from 2-4% of grassland area in the bay and coastal regions, and around 1% in the montane and interior regions.

Not only did native grass stands occur more abundantly on serpentinite soils than on non-serpentine soils, serpentinite soils also had much higher native grass richness. More native grass species occurred in the 18 native grass stands (14 spp.) that were found on serpentinite soils than on the 53 other native grass stands in the interior region occurring off serpentinite soils (10 spp.). Mean native grass species richness per stand on serpentinite soils was high ($n=16$, $mn=4.3$, $sd=1.6$).

Eight of the 10 native grasses found in the interior region appear to be significantly more likely to be encountered in a serpentine native grass stands than in non-serpentine stands (see Table 19). Three native grasses show especially high fidelity to serpentinite soils; two (*Danthonia californica*, *Vulpia microstachys* spp.) form stands in the interior region only on serpentinite soils, and one, *Melica torreyana*, was found only on serpentinite soils. These taxa join several other native grasses in the South Coast

Table 19.--Native Grass Frequency in Serpentine and Non-Serpentine Native Grass Stands in the Interior Region

<u>Species</u>	<u>Proportion of Non-Serpentine Stands Occupied (53 sites)</u>	<u>Proportion of Serpentine Stands Occupied (18 sites)</u>
<i>Bromus carinatus</i>	11%	22%
<i>Danthonia californica</i>	0%	22%
<i>Elymus glaucus</i>	15%	22%
<i>E. multisetus</i>	8%	50%
<i>Hordeum brachyantherum</i>	9%	11%
<i>Leymus triticoides</i>	13%	0%
<i>Melica californica</i>	8%	17%
<i>M. torreyana</i>	0%	28%
<i>Nassella lepida</i>	10%	0%
<i>N. pulchra</i>	89%	83%
<i>Vulpia microstachys</i> spp.	0%	33%

region which are also restricted locally to serpentinite soils (Kruckeberg 1984).

Three native grasses appear to be serpentine avoiders (*Nassella lepida*, *Leymus triticoides*, and *Distichlis spicata*). They did not form stands on serpentinite soils, but did so on off-serpentinite soils in the interior region. Native grass fidelity to serpentinite soils appears to increase dramatically the further south in the state one goes. Most of the native grasses Kruckeberg (1984) identified as bodenvag (*Danthonia*, *Elymus*, *Melica*, *Nassella*, *Vulpia*) appear to qualify as indicator species in the more arid and stressful serpentinite soils of central California. Aside from nutrient stresses, environmental stress in California serpentines is correlated with soil moisture levels (Moral 1982, Gulmon et. al. 1983).

The California Native Plant Society (CNPS) assessment of community rarity focuses on the presence of 'viable occurrences'. What constitutes a viable occurrence is a critical aspect of the CNPS system and of conservation biology in general (Shaffer 1987,

Menges 1990, 1992). Viable occurrences are populations which are able to withstand perturbations such as climactic fluctuations, species introductions, changed disturbance regimes, demographic fluctuations etc., over many years. Population viability analysis, however, has been applied to only a few species (Menges 1990,1992).

If native grass stands have survived thus far can one assume they are fit enough to survive through the twenty-first century? The minimum viable population size needed to maintain a population over time rises as environmental stochasticity increases (Menges 1992) and it is difficult to imagine a more stochastic terrestrial environment than California grasslands (Talbot et al. 1939, Duncan and Woodmansee 1975, Pitt and Heady 1978, Hobbs and Mooney 1991, Hobbs and Mooney 1995). As non-native species continue to enter or expand their ranges in California grasslands (Heady 1988, Rejmanek and Randall 1994), natives will face ever more difficult challenges (Heady 1988, Thomsen et. al. 1996). If global warming occurs it will effect the grassland environment most rapidly, which being composed mostly of annual species, tracks climactic fluctuations more quickly than other vegetation types (Pitt and Heady 1978).

The California Native Plant Society uses two factors, rarity and threat, to assess community viability. That more explicit parameters of viability are not given (patch size, patch density, location) is understandable given the site-specific factors that can influence viability (evolutionary history, reproductive type, genetic makeup, matrix type, disturbance regime, etc). Stand viability needs to be addressed on a case by case basis (Menges 1992). Some small native grass stands in the Central Coast region have remained stable over many decades (White 1967, Stromberg and Griffin 1996) while much larger ones

elsewhere are being rapidly invaded (Goode 1981, pers. com. 1998). Patch size can have an important effect on stand viability. Larger populations sample a larger portion of the environment than smaller populations and so are buffered against perturbations that can swamp smaller populations. Qualitative assessments indicate that *N. pulchra* stand quality is correlated with stand size. Eleven of the twelve stands of over 100 acres of *N. pulchra* grassland had from 'good' to 'excellent' quality ratings, while only one of the six sites with 50 acres or less had as high as a 'good' rating (Barry 1972).

Given the grassland's uncertain future it is difficult, however, to imagine a minimum population size that will ensure community viability over the long run. Recent events suggest that even high quality stands and 'large' population sizes provide little guarantee for future security. The 'finest stand' of *N. pulchra* in the state that either Barry or Heady had ever seen (Barry 1972) found in La Jolla Valley, has been extensively overrun by *Phalaris aquatica* in the last 25 years (Goode 1981, pers. com. 1998).

The average native grass stand size off of serpentinite soils in the Santa Cruz Mountain region preserves is so small (0.1 hectares) as to make any assertions of viability based on stand size untenable. Stand size was small, however, in the long-lived *N. pulchra* stands found at Hastings Reservation in Santa Lucia Mountain which is also part of the central Coast Ranges.

Small native grass stand size can result in decreased demographic and genetic stability. Small populations are likely to experience greater genetic drift, retain more genetic mutations (Cwynar and MacDonald), exhibit more inbreeding depression (Karron a.b, Waller 1988, Lacy 1992) and ultimately display reduced reproductive output and/or

viability (Lacy 1992, Menges 1992, Holsinger 1993, Wolf and Harrison 2001). A greater proportion of stand area in small stands is composed of edges making them more accessible to non-native invaders (Harris and Silva Lopez 1992). Small stands are less likely to be monitored, as well, and their degradation or disappearance, if it occurs, is less likely to be noted (Rabinowitz 1981).

Many smaller populations can, however, go a long way towards establishing some sort of assurance regarding regional viability. Many small populations may in fact be preferable to a few large ones, if they are demographically and genetically stable, because they are less susceptible to catastrophic events that can decimate local populations (Goode 1981, Noy-Meir 1988). Many populations also sample a greater portion of the available environmental heterogeneity and therefore contain more genetic diversity overall. Only a few species, however, form even 20 or more stands across this large region (see Table 9).

Grasses that form dense stands with high biomass should be more resistant to species invasion than those with lower biomass (Peart and Foin 1985). As mentioned earlier relative cover values are, however, not well correlated with frequency of occurrence in the Santa Cruz Mountain region (see Table 10). Several very rare native grasses (*Calamagrostis nutkaensis*, *Deschampsia caespitosa*, *Distichlis spicata*, *Festuca rubra*, *F. californica*, *Leymus mollis*, *L. triticoides*) dominate their given stands more completely than more frequently but also more sparsely occurring grasses (*Bromus carinatus*, *Elymus multisetus*, *Melica californica*).

The rarity and small stand sizes of the native grass community and the stochastic grassland environment they are found in (see Chapter 16), place this community at

substantial risk. Its long-term persistence in the Santa Cruz Mountain region preserves is uncertain.

Rarity in the Native Grass Community

Because little information on native grasses in California exists in a single format other than Crampton's book (Crampton 1974), a literature review of the rarer grasses is included in this section. As much information is already readily available on *Nassella pulchra* it is not included in this review. Following the literature review of each grass, information on its distribution and abundance in Santa Cruz Mountain region preserves is presented.

Bromus carinatus (California brome)

The *Bromus* genera, a very large one (@ 150 spp.), is distributed worldwide and contains many important forage and weedy species. *Bromus carinatus* is the only native brome species found throughout most of California. Despite its moniker, it has a wide distribution, being found from Alaska to Mexico. In California it is reported to occur in a variety of habitats including open shrublands, woodlands, coniferous forest, and dunes and meadows near the coast (Wilken and Painter 1993).

A facultatively cleistogamous grass (Harlan 1945a) which displays high morphological and genetic variability (Stebbins and Tobagy 1944, Harlan 1945b), *B. carinatus* has evolved many different races, including a 'weedy' type adapted to disturbed areas (Harlan 1945b). The native species of the genera in California are in need of 'critical study' (Wilken and Painter 1993). *Bromus carinatus* does not form a vegetation series in A Manual of California Vegetation (Sawyer and Keeler-Wolf 1995).

As is the case with many native grasses *B. carinatus*'s grazing tolerance is murky. Both anecdotal (Blumler 1992a, Edwards 1992) and quantitative (Elliot and Wehausen 1977) reports from the San Francisco Bay area and northern California suggest that it tolerates the high litter levels of ungrazed grasslands well and increases rapidly after grazing elimination (Edwards 1992). In the Santa Lucia Mountains, however, *B. carinatus* was more abundant on grazed lands (Stromberg and Griffin 1996).

Bromus carinatus in Santa Cruz Mountain Region Preserves.

Bromus carinatus was the third most commonly encountered native grass (n=59, 37% of total) in the Santa Cruz Mountain region. Frequently found in the montane (26/43 sites; 60%) and bay regions (12/23; 53%), it was rarely found in the coastal (2/23; 9%) or on non-serpentine soils in the interior region (8/53; 15%). Low abundance in the coastal regions was surprising given its mesic orientation and its frequency in coastal prairies elsewhere (Sugihara et. al. 1987), but probably reflects a paucity of low-gravel sites.

Despite its ubiquity, outside of the montane region *B. carinatus* generally occurred in sparse amounts, and as a subordinate in other native grass dominated stands. Average relative cover was low (n=59, mn=7%) and it formed a stand (>10% relative cover) in only ten of its occurrences. Total stand area in the few stands *B. carinatus* formed was 1.6 hectares.

Calamagrostis nutkanesis (Pacific Reedgrass)

A large genus (100+ spp.) found in cooler, mostly montane regions, *Calamagrostis* has been taxonomically problematic (Stebbins 1930, Nygren 1954). Four name changes have occurred in the relatively small number of species found in California

(10) in the last thirty years (Munz 1968, Greene 1993). Extensive hybridization, polyploidy, and self-fertilization have resulted in widely variable populations (Greene 1993).

All *Calamagrostis* species in California are perennials found in cool, moist conditions. South of the San Francisco Bay region, 80% of *Calamagrostis* species are restricted to the coastal regions or the Sierra Nevada Mountains (Greene 1993).

Calamagrostis' distribution pattern in California and the United States - many species found in mostly small populations in widely separated areas - closely resembles other 'relictual' species which were more abundant at one time but now survive in isolated pockets (Nygren 1954). Three species in California are 'uncommon', and six have species ranges that cover three or less geographic sub-regions (Greene 1993).

Calamagrostis nutkaensis is one of three *Calamagrostis* species to have a primarily coastal distribution. Found at least as far south as San Luis Obispo and as far north as Alaska, *C. nutkaensis* reaches inland in California only in the San Francisco Bay area (Greene 1993). A facultative wetland species, it grows in habitats seasonally or permanently saturated with shallow water tables and forms the Pacific reedgrass vegetation series in the *Manual of California Vegetation* (Sawyer and Keeler-Wolf 1995).

Calamagrostis nutkaensis in Santa Cruz Mountain Region Preserves

Found only in coastal sites with particularly intense maritime influences in the Santa Cruz Mountain preserves, *C. nutkanesis* formed only six small stands ($n=6$, $mn=0.14$ hectares) in two preserves (San Bruno County and State Park, San Pedro Point). Total stand area (> 10% *C. nutkanesis* relative cover) was very low (0.8 hectares).

Both sites were so small they could hardly be termed 'coastal prairie'. Enveloped on generally steep slopes in a coastal scrub matrix, *C. nutkaensis* did not occur in any of the habitats thus far reported (beaches, dunes, coastal woodlands (Greene 1993), areas with shallow water tables (Sawyer and Keeler-Wolf 1995). It is found near the southern end of its range in the Santa Cruz Mountain region.

Calamagrostis nutkaensis stands had the highest 'conservation values' of all native grass stands despite the author inability to identify almost one quarter of the species because they were not in flower. Most of the rarer species in *C. nutkaensis* stands were limited to the central and north coast sub-regions of the state (Hickman 1993).

Danthonia californica (California oatgrass)

Danthonia is a widespread genus found in both hemispheres from the tropics to the temperate regions. Despite its name, California oatgrass is not endemic to California but is found throughout the western United States and western Canada. While taxonomic revision in the last 30 years has markedly reduced the number of species in the *Danthonia* genus worldwide from 100 (Munz 1959) to 20 (Hitchcock 1993), a re-examination of *D. californica* has resulted in the recognition of two new varieties. Even with this revision, *D. californica* is still in 'critical' need of further taxonomic study (Allred 1993). The other native *Danthonia* species found in California occur in the coastal and montane regions north of the Santa Cruz Mountains (Allred 1993).

None of the species in the United States are considered abundant (Hitchcock 1971), although *D. californica* was believed to be a dominant in north coastal prairie (Burtt-Davy 1902). It is a nutritious oatgrass (1963 Hitchcock 1951, Heady et. al. 1963) that can contribute significant forage in the right environment (Sampson et. al. 1951, Crampton 1974). It was one of the few

native grasses able to re-invade fields in northern California when the grazing regime was altered (Cooper 1960), or non-native species were reduced (Huffaker 1951). Believed to be tolerant of grazing (Elliot and Wehausen 1977), *D. californica* forms cleistogamous spikelets in its lower sheaths, and readily adopts short forms when grazed (Edwards 1992, 1995).

Danthonia californica in Santa Cruz Mountain Region Preserves

One of the dominant species of the original coastal prairie, *D. californica* was most frequently found in the coastal region (56% of sites) but was common in the montane (30% of sites) and bay regions (26% of sites) as well. It was rarely found in the interior region, where it occurred only on serpentinite soils (3% of sites). *Danthonia californica*'s abundance on serpentinite soils in the interior region was surprising given its rarity in off-serpentinite interior native grass stands. Kruckeberg (1984) questioned whether *D. californica* was an avoider of serpentinite soils, but they are apparently an important refugia for *D. californica* in the interior sections of the central Coast Ranges.

Total stand area (*D. californica* relative cover >10%), was 26 hectares. Having higher than average relative cover values ($n=34$, $mn=23\%$, $sd=19$), *D. californica* tended to be abundant where found. It formed the largest native grass stand off of serpentinite soils found in the Santa Cruz Mountain region preserves on a site that had been cultivated as recently as 1975.

Deschampsia caespitosa (Tufted hairgrass)

Deschampsia is a small genus (30-40 spp.) found in temperate regions worldwide. All four of the species found in California are natives that are confined to mesic sites (Wilken 1993b).

Deschampsia caespitosa is divided into two subspecies; one occurs from the central coastal northwards, and the other is found as far south as the Peninsular ranges in California and as far east as the eastern United States.

Deschampsia caespitosa is a very widely distributed, morphologically variable native grass species. A common garden experiment showed that coastal and montane populations had distinctive growing seasons, flowering times, frost tolerances, and disease resistances. Distinct ecotypes were found within a thousand feet of elevation of each other (Lawrence 1945, Ward 1969). *Deschampsia caespitosa*'s variability, particularly in the Coast Ranges, makes it another native grass in need of further taxonomic examination (Edwards 1984b).

Deschampsia caespitosa occurs most commonly in montane meadows in the Sierra Nevada (Halpern 1986, Allen-Diaz 1991) where it is an important source of forage (Crampton 1974, Sampson et. al. 1951). It is less common in the Coast Ranges where it is reported to occur in marshy areas or on wet serpentinite soils (Thomas 1961, Crampton 1974, Edwards 1984b). Local distribution in both montane and coastal sites is a function of drainage characteristics and soil moisture levels (Peart and Foin 1985, Halpern 1986, Allen-Diaz 1991).

Deschampsia caespitosa's ability to withstand grazing is unclear. One subspecies, *D. caespitosa caespitosa* tolerates grazing well; the other, *D. caespitosa holiciformis* does not (Mark Stromberg, pers. com.). Elliot and Wehausen (1973) found that it expanded rapidly in a coastal prairie after grazing was eliminated. Ten years of grazing elimination in another coastal prairie, however, *D. caespitosa* populations were in decline (Peart and Foin 1985).

Deschampsia caespitosa in Santa Cruz Mountain Region Preserves

A member of 57 different plant associations across the western United States (USDA 2001), *D. caespitosa* is extremely rare in the Santa Cruz Mountain region preserves, forming just

four stands covering 1/5th hectare. Confined to a rare habitat type in Santa Cruz Mountain preserves - mesic meadows surrounded by redwood/douglas fir forests - it appeared just one preserve (UCSC). Despite its rarity, stand vigor appeared good as mean relative cover rates ($n=4$, $mn=46\%$, $sd=9.5$) were amongst the highest found. *Deschampsia caespitosa* appears to be more abundant on coastal terraces to the north (Peart and Foin 1985), and to the south (Mark Stromberg, pers. com.) of the Santa Cruz Mountain region. Many *D. caespitosa* stands in southern California, however, appear to be on private lands (Mark Stromberg, pers. com.).

Distichlis spicata (Saltgrass)

A perennial, rhizomatous grass, *D. spicata* is widely distributed across the western United States and Canada. It forms dominant stands in finely textured, often bottomland, saline soils with high water tables (United States Department of Agriculture 2001). Seed production is uncommon; reproduction is mainly vegetative. Its palatability is low and livestock and ungulates avoid it when other forage is available (United States Department of Agriculture 2001).

Distichlis spicata in Santa Cruz Mountain Region Preserves

Alkaline meadows are a rare habitat type in the grasslands of the Santa Cruz Mountain region preserves. Only two were found (Santa Teresa County Park, Ano Nuevo State Park), and *D. spicata* occurred in both of them. Despite their small size, stand vigor appeared good as *D. spicata* displayed high mean relative cover values.

***Elymus glaucus* (Blue wild-rye)**

Elymus glaucus is a non-rhizomatous, self-fertilizing native grass found in small patches usually in mesic micro-environments in meadows, along forest margins, and occasionally in open grasslands. (Hektner and Foin 1977, Halpern 1986, Sugihara and Reed 1987, Franklin and Dryness 1988, Grenier 1989, Edwards 1990, Hickman 1993). A statewide survey of valley grasslands indicated that it was most common in areas of higher rainfall (Janes 1969).

A precocious grass, *E. glaucus* forms hybrids with at least four other congeners, including *E. multisetus* (Barkworth 1993b). The great morphological variability of the species has sparked several studies over the years (Snyder 1950, Knapp and Rice 1996). A recent isozyme analysis of *E. glaucus* populations in Oregon and California indicated that interpopulational differentiation can be high even between nearby stands. Genetic similarity bore, in fact, little correlation with population proximity. Stands hundreds of miles apart were sometimes more similar genetically than stands in the same region (Knapp and Rice 1996).

Elymus glaucus does not form a vegetation series in A Manual of California Vegetation (Sawyer and Keeler-Wolf 1995).

***Elymus glaucus* in Santa Cruz Mountain Region Preserves**

Found in many plant communities across the western United States, including prairie, steppe, chaparral, woodlands and forests (USDA 2001), *E glaucus* was widely distributed within the Santa Cruz region preserves as well, occurring in all five regions.

The second most commonly occurring native grass, *E. glaucus* was ubiquitous in the montane region occurring in 77% of all native grass stands.

While *E. glaucus* was very commonly found within the native grass community it rarely formed stands of its own. It was abundant (>10% relative cover) in only twelve native grass stands and total stand area (>10% relative cover) was low (1.5 hectares). *E. glaucus*, however, displayed vigorous growth in these stands having high relative cover rates. Typically occurring in flat areas and meadows in the montane region - two very rare habitat types in the Santa Cruz Mountain preserves - these stands were much larger and *E. glaucus* cover was much higher (25-79%) than in stands encountered in the rest of the study area. They constitute an important resource in the Santa Cruz Mountains.

Elymus multisetus (Big Squirreltail)

Elymus multisetus is found in sparse amounts in open rocky or sandy soils among many plant associations in the western United States (Munz 1968, Barkworth 1993b). Formerly known as *Sitanion jubatum*, it hybridizes with three other species, including *Elymus glaucus*. *E. multisetus*'s long bristly awns irritate the mucous membranes of livestock making it one of the few native grasses actively discouraged by ranchers (Sampson et al. 1951). Mostly associated with the more arid western states, it was the only native grass to increase during five years of drought on serpentinite soils (Armstrong and Huennecke 1992), and is a favored grass for restorations on serpentinite soils (Mark Stromberg pers. com.).

Elymus multisetus does not form a series in a Manual of California Vegetation (Sawyer and Keeler-Wolf 1995).

***Elymus multisetus* in Santa Cruz Mountain Preserves**

Elymus multisetus occurs commonly (n=38 or 24% of total) in Santa Cruz Mountain region native grass stands. Found in conjunction with *N. pulchra* on serpentine soils, it forms large stands with low relative cover values (n=3, mn=17, sd=3.7). Off of serpentinite soils, it occurs sparsely, forming very small stands on infertile red Franciscan soils in the montane region.

***Festuca californica* (California fescue)**

Primarily associated with woodlands and scrub but also occurring in the fescue-oatgrass plant associations (Kuchler), *F. californica* occurs in the Coast Ranges from central California to southwestern Oregon (USDA 2001).

***Festuca californica* in Santa Cruz Mountain Region Preserves**

The one *F. californica* stand was found within a scrub matrix on an extremely steep north-facing slope at San Bruno County Park. Basically a monoculture of the species, relative cover values were extremely high (95%). It was not found in any other grass stands.

***Festuca idahoensis* (Idaho fescue, Blue bunchgrass, Bluebunch fescue)**

Festuca is a large genus of perennial grasses of over 100 species found in cool and temperate regions worldwide (Munz 1968). Several fescues are important forage species in the United States (Hitchcock 1971). The twelve native species found in California are

distributed primarily in the northern half of the state. Four of the six fescues found in the Santa Cruz Mountains are associated with forest areas. *Festuca idahoensis* forms the Idaho fescue series in A Manual of California Vegetation (Sawyer and Keeler-Wolf 1995).

Festuca idahoensis ranges from central California northward into Canada and eastward into Colorado (Aiken 1993). It is an important component of at least three different vegetation types; the Palouse prairie in eastern Washington and Oregon, the arid steppe vegetation of northeastern California (Young et. al. 1977, Franklin and Dryness 1988), and the coastal prairie stretching from California northward (Heady et. al. 1977). *F. idahoensis'* range in California terminates somewhere south of the San Francisco Bay area (Crampton 1974), making it another grass whose southern terminus occurs near the Santa Cruz Mountains. An important forage grass in the mountains it is sparsely found in the Coast Ranges, especially at lower elevations. Very variable in color and form, Edwards (1989) suggests that a close examination of different populations should be done.

Festuca idahoensis in Santa Cruz Mountain Region Preserves

Festuca idahoensis's rarity in the Santa Cruz Mountains is distinctive given its description as 'one of the most common and widely distributed grasses in the western United States' (United States Department of Agriculture 2001) and its abundance elsewhere in California (Crampton 1974). One of the major native components of the coastal prairie, its stands are restricted in the Santa Cruz Mountain region to a series of isolated ridge tops at Long Ridge and Russian Ridge Open Space Preserves, and to a few north facing slopes at San Bruno County and State Park. (Two populations reported from Twin Peaks and Hunters Points in San Francisco were not surveyed).

Festuca idahoensis formed eight stands (relative cover >10%) in three preserves, with a total area of .8 hectares. Stand vigor appeared low with *F. idahoensis* having low relative cover rates ($n=8$, $mn=20\%$, $sd=6.8$) in the stands it formed.

Festuca rubra (Red Fescue)

Another very widespread native grass, *F. rubra* is found in cool temperate regions throughout the world (Aiken 1993). Charting its distribution accurately in California is complicated by the presence of commercial cultivars that have become naturalized (Aiken 1993). *Festuca rubra* ranges throughout most of the montane regions (>2500 meters) of California (Aiken 1993). Long believed to terminate along the coast at Monterrey, its range was extended to San Luis Obispo in the late 1960's. Distinct forms occur on the North Coast in sand dunes, ocean bluffs, and in salt marshes (Aiken 1993).

Festuca rubra in the Santa Cruz Mountain Region Preserves

Found in many cool, wet, coastal and cold montane habitats across the western United States (USDA 2001), *F. rubra* is restricted to the westernmost slopes on San Pedro Point in the Santa Cruz Mountain preserves. The second rarest of all native grasses to form stands, the two populations found formed stands of approximately .4 hectares.

Despite visiting the site several times in what was purportedly the middle of its flowering season (May, June -Munz 1968), and engaging in an intensive search for some suggestion of flowering, the only florets found apparently came from the year before. The apparent lack of sexual reproduction aside, the population appeared vigorous and was characterized by high native grass cover (49%).

Festuca rubra (and *C. nutkaneensis*) stands had the highest native species relative cover rates (95%) of all native grass stands found, and very high conservation values as well. As with *C. nutkaensis*, many native species in its stands are found only in the Central Coast and North Coast sub-regions of California (Hickman 1993).

Hordeum brachyantherum (Meadow barley)

Hordeum is a small genus (32 spp.) found in temperate regions worldwide. An atypical native grass genus in several ways, four of the five native species are annuals (Barkworth 1993d). Three are associated with moist sites primarily in arid regions and two species are southern tending. Two of the species found in California are exotic; both are more commonly found in the Santa Cruz Mountains than the natives.

Hordeum brachyantherum is a widespread perennial native grass found in meadows, pastures and stream banks across the western United States and into Eurasia (Barkworth 1993d). A rapidly growing and non-aggressive species, it is a common choice for the initial stages of grass restorations when a native groundcover is desired.

Hordeum brachyantherum in Santa Cruz Mountain Region Preserves

Found in mesic grassland habitats in the San Francisco Bay area (Edwards and Havlik 1984), *H. brachyantherum* occurred almost entirely on weakly serpentinized and or alkaline soils in the most arid preserve in the Santa Cruz Mountain region. Forming only five small stands (four sampled) ($n=4$, $mn=.05$ hectares, $sd=.02$) which total .17 hectare, *H. brachyantherum* stands are immersed in dense stands of non-native grasses with high relative cover values ($n=4$, $mn=55\%$, $sd=8.6$).

Leymus mollis (American dunegrass)

Ranging from the central coast region of California north to Alaska and into Asia, *L. mollis* is widely distributed but is restricted to a rare habitat type - sandy beaches and dunes (Barkworth 1993). *Leymus mollis* populations have been severely reduced by *Ammophila arenaria* and *Carpobrotus edulis* (Boyd 1992). A survey of nineteen California beaches in 1976 found *L. mollis* stands at seven (Barbour 1976). Increased urbanization and development in beach areas and continued habitat introgression by non-native species in the twenty-five years since Barbour's report have, however, continued to reduce *L. mollis* populations.

Leymus mollis in Santa Cruz Mountain Region Preserves

Found in only four stands in one preserve (Ano Nuevo State Park), *L. mollis* is probably the most endangered native grass in the Santa Cruz Mountain preserves. While most other native grasses undoubtedly occur in private lands, most of *L. mollis*' habitat is either already in public hands or has been converted to urban areas. Total area when *L. mollis* was abundant (>10% relative cover) was less than one half hectare (.3 hectares). All stands occurred within an *Ammophila arenaria* matrix and were found in the foredune area.

Leymus x multiflorus

One small stand of *Leymus x multiflorus*, a hybrid restricted to the San Joaquin Valley and Central west regions of California (Hickman 1993), occurred in a midst of *Leymus* species at San Bruno County park. Neither of the other two were in flower but their general descriptions imply

that they may be the parents of the hybrid; one a shorter dark green one not yet in flower, may be *L. triticoides*; the other, a taller light green type that had not yet flowered may be *L. condensatus*.

Leymus triticoides

(Creeping ryegrass, Beardless or Creeping wildrye, Alkali ryegrass)

The *Leymus* genera in California, (an anagram of *Elymus*), is a recent formulation composed entirely of former *Elymus* species (Barkworth 1993e). Another widely interbreeding genus, six of the eight species found in California hybridize with other *Leymus* species, and two are products of hybridization. Forming hybrids with no less than five other *Leymus* species, *L. triticoides* is the most precocious species of the genus.

Two markedly different distribution groups in the *Leymus* genus occur in California; one (four species) is southern tending; the other (three species), is restricted to sandy beaches and bluffs mostly in northern California (Barkworth 1993e). *Leymus triticoides* is the only *Leymus* species with found statewide or associated with a grassland type ('meadows') habitat (Barkworth 1993e). It is a recognized association (creeping ryegrass) in Manual of California Vegetation (Sawyer and Keeler-Wolf 1994).

Leymus triticoides is typically found in moist meadows throughout much of the western United States (Barkworth 1993e). When found in swales and other areas of low drainage it often forms dense stands (Sampson 1951, Crampton 1974). Many stands have been restricted by cultivation to small patches along fencerows (Crampton 1974). Highly tolerant of grazing, *L. triticoides* is an important source of forage in higher locations but its coarser, thicker leaves in lower elevations reduce its forage value markedly except in fall and winter (Crampton 1974, Mark Stromberg, pers. com.).

Reports of seed production in *L. triticoides* stands are, as with other aspects of native grass 'lore', mixed and contradictory. Crampton (1974) reports 'extremely poor' seed production while Sampson (1951) reports 'heavy' seed production. Seed production displays high heterogeneity among populations, with most displaying low seed production rates, and some displaying high seed production rates (Mark Stromberg, pers. com.).

Leymus triticoides in Santa Cruz Mountain Region Native Grass Stands

Aside from *Nassella pulchra*, *L. triticoides* is the only native grass to occur with any regularity in the non-native grass dominated arid, interior regions. Occurring in just 10 patches, *L. triticoides* was rarely found in Santa Cruz Mountain preserves. (Numerous stands too small to be surveyed (<50x5 meters) occurred in Calero and Santa Teresa County Parks. Several other fairly large and unsurveyed stands occur in Arastradero.) Total stand area (*L. triticoides* >10% relative cover) was 1 hectare.

Leymus triticoides generally occurred in small patches (n=8, mn=.07 hectares, sd=.08 acres) in flat areas (n=8, mn=4% slope, sd=3), swales, or at the bottoms of hills where drainage kept soil conditions moist.

Despite its relative rarity stand vigor appeared high, as relative cover rates were high, and it tended to dominate the stands it was found in. Showing an astonishing ability to tolerate cultivation, it was able to persist, albeit in diminished density, in a regularly cultivated firebreak in Santa Teresa County Park and an urban lot in San Jose (pers obs.).

Melica californica and *torreyana* (California Melic, Torrey's Melic)

The *Melica* genus (@ 80 spp.) is found in temperate regions worldwide. Sixteen

species are found in California, six in the Santa Cruz Mountains. All the species found in California are native and all, except for *M. californica*, are primarily woodland or chaparral species (Beetle 1947). Generally a more northerly distributed genus, some species reach into the Coast Ranges of southern California (Hickman 1993). Though widely distributed throughout the state, Melic grasses are 'rarely if ever, found in dense stands' (Crampton 1974) or pure stands (Sampson et. al. 1951), and are not an important forage species (Sampson et. al. 1951).

The melics are one of the few native grasses which never underwent polyploidy; a genetic transformation which is believed to assist in adapting to more extreme environments (Stebbins and Love 1941). While many factors contribute to native grass rarity, it is possible that the melics inability to achieve polyploidy contributed to their rarity in advance of the non-native grass invasion. Most diploid grasses in the Great Plains, for instance, occur in genera of only minor importance (Stebbins and Love 1941).

Melica californica in the Santa Cruz Mountain Region Preserves

While *M. californica* occurred fairly commonly within the native grass community, it rarely formed stands of its own, only twice achieving relative cover values above 10%. Stand area (.3 hectares) was very low. High non-native grass relative cover rates (mn=49%) indicated that these stands were dominated by non-natives. *Melica californica's* tendency to appear in habitats (south facing slopes) favored by non-native grasses has, no doubt, reduced its abundance in the region.

Melica torreyana in the Santa Cruz Mountain Region Preserves

The six *M. torreyana* stands found were restricted to steep, rocky, mostly north facing slopes at Santa Teresa County Park. *Melica torreyana*'s relative cover rates were low but the stands were mostly pristine and the population appeared stable. Total stand area was 2.2 hectares. The extreme rarity of this species in the Santa Cruz Mountain region preserves belies both Thomas 's (1961) description of *M. torreyana* as being 'fairly common' in rocky serpentine soils, grasslands, brush covered slopes and redwood forests, and its presence in at least five preserves in the San Francisco Bay area (Edwards and Havlik 1984). *Melica torreyana*'s rarity and the possible decline it may have recently suffered make it a species of special concern.

***Nassella lepida* (Foothill needlegrass)**

Occurring in three widely separated sites *N. lepida* displayed a very disjunct distribution in Santa Cruz Mountain region preserves. It formed five stands totaling .2 hectares. Generally found in conjunction with *N. pulchra*, *N. lepida* relative cover values were low ($n=5$, $mn=13.6\%$, $s.d.=9.5$), indicating low vigor. Non-native grass relative cover was very high ($n=5$, $mn=50.4\%$, $s.d.=17.0$).

***Nassella pulchra* (Purple needlegrass)**

Nassella pulchra in Santa Cruz Mountain Region Preserves

Occurring in 102 patches or 64% of all native grass stands surveyed, *N. pulchra* is far and away the most frequently occurring and abundant native grass in the Santa Cruz

Mountain preserves (see Tables 9,10,12). The stands it forms (*N. pulchra* > 10% relative cover) occupy a greater percentage of native grass area (62%) than any other native grass.

A very widely distributed grass in the Santa Cruz Mountains, it is the only native grass to dominate at least one stand in each region. It is the most commonly occurring native grass in the interior region off of serpentinite soils (46/53; 87%; of sites), in the interior serpentinite sites (13/18; 81%), and in the bay region (11/23; 65%), and occurs in about one third of all coastal (8/23; 35%), and montane (13/43; 30%) native grass stands.

Nassella pulchra's abundance relative to other native grasses in the interior foothill regions is extraordinary and no doubt partially accounts for its dominance in the literature. It is the most abundant native grass in almost eighty-five percent of interior region native grass stands, and is often the only native grass and one of the few native species found. Native grass richness in interior off-serpentine stands is the lowest of any region ($n=40$, $mn=1.4$, $sd=.8$).

Nassella pulchra stands cover more area in the interior region (approximately 50 hectares) than in any other. Most of this stand area occurs, however, on serpentinite grasslands in one preserve (Edgewood County Park). If only off-serpentine stands are included then stand area in the region is quite low (@ five hectares) relative to the coastal/bay regions (approximately 25 hectares). Coastal valley grasslands in central and northern California have attracted little attention and are often not displayed on maps, yet *N. pulchra* is almost as abundant as *Danthonia californica* in the coastal region. As noted before, almost all the large native grass stands in California are found either in the Coast Ranges or in mesic habitats in the Central Valley. *Nassella pulchra*'s historical abundance in the very arid interior regions has been repeatedly called into question in the last few decades (Wester 1981, Blumler 1992b, Hamilton 1997).

***Vulpia microstachys* (Small fescue)**

One of the few native annual grasses found, *V. microstachys* occurs throughout much of the western United States on open and/or disturbed sites, often on sandy soils. It begins growth and matures early than native perennial grasses. Forming stands with low cover, it has little forage value, and generally increases in abundance when grazing is initiated (United States Department of Agriculture 2001).

***Vulpia microstachys* in Santa Cruz Mountain Region Preserves**

Vulpia microstachys formed stands only on south facing serpentinite soils at Santa Teresa County Park. Stand area (.9 hectares) was low. Occurring most abundantly in the most arid serpentinite soils found, *V. microstachys* mean relative cover values were moderate ($n=3$, $mn=23\%$, $sd=6.5$), and the stands appeared vigorous given the little non-native grass introgression that was exhibited.

Native Grass Stand Distribution and Conservation

An important aspect of native grass stand conservation is the highly heterogeneous nature of their distribution. Aside from the few fairly abundant native grasses (*Danthonia californica*, *Nassella pulchra*) which form stands (>10% relative cover) in multiple regions, many native grasses displayed distinct centers of abundance (see Table 20). Nine of the eleven native grasses used in the canonical correlation had 50% or more their stands occur in two or fewer preserves. Forty percent of the preserves surveyed (9/23) which contained native grasses harbored high percentages of a native grasses total area.

Preserves in the native grass rich regions (bay, coastal, montane, serpentine), in particular, tended to harbor distinct native grass populations.

The heterogeneous nature of native grass distribution has important implications for native grass conservation. Native grasses occupy a number of widely varying habitats; no single or small group of preserves contains the environmental diversity in a region as heterogeneous as the Santa Cruz Mountains to preserve a representative sampling of native grasses. Conserving native grass populations region wide requires having multiple preserves which contain the numerous grassland habitats into which native grasses segregate themselves. In the Santa Cruz Mountain region these habitats include coastal meadows (*Deschampsia caespitosa*), coastal flatlands (*Danthonia californica*), maritime rocky foothills (*C. nutkaensis*, *Festuca rubra*), montane meadows (*E. glaucus*), montane rocky ridge-tops (*Festuca idahoensis*), infertile montane flatlands (*Elymus multisetus*), north facing montane slopes (*B. carinatus*), interior bottomlands (*Leymus triticoides*), alkaline meadows (*Distichlis spicata*), north facing serpentine soils (*Melica torreyana*), south facing serpentine soils (*Vulpia microstachys*), and coastal and interior foothills (*N. pulchra*).

Native grass distribution was at least as heterogeneous on serpentine soils as off them. The two most native grass rich preserves with serpentine soils maintained distinctly different native grass stands. Edgewood County Park contained *E. multisetus*, *D. californica*, and *N. pulchra* stands. Santa Teresa County Park contained *H. brachyantherum*, *M. torreyana*, *N. pulchra* and *V. microstachys* stands (as well as *D. spicata* and *L. triticoides* stands off of serpentine soils).

Only the preserves found in the interior and coastal regions tended to have similar
Only the foothill preserves found in the coastal and interior regions tended to have similar

native grass populations. The foothill belt - which featured native grass populations in fairly productive soils - was largely dominated by *N. pulchra*.

Vegetation Conversion and Native Grass Rarity

Six of the twenty-eight preserves surveyed in the Santa Cruz Mountain region

Table 20.--Native Grass Centers of Abundance.

Species	Preserve(s)	Percent of Stands*
<i>Bromus carinatus</i>	Russian Ridge	50
<i>Calamagrostis nutkaensis</i>	San Bruno/San Pedro Pt.	100
<i>Deschampsia caespitosa</i>	UCSC	100
<i>Elymus glaucus</i>	Monte Bello/Long Ridge	67
<i>Elymus multisetus</i> (montane) (serpentinities soils)	Monte Bello Edgewood/Water Dept.	80 100
<i>Festuca idahoensis</i>	San Bruno/ Russian Ridge	100
<i>Hordeum brachyantherum</i>	Santa Teresa	80
<i>Leymus mollis</i>	Ano Nuevo	100
<i>Melica californica</i>	Long Ridge	100
<i>Melica torreyana</i>	Santa Teresa	100
<i>Vulpia microstachys</i>	Santa Teresa	100

*refers to the percent of stands (relative cover >10%) formed by each species

(Fremont Older, Pogonip, Rancho San Antonio County Park, Saratoga Gap, Sierra Azul (St. Josephs Hill), Windy Hill) supported no native grass stands large enough to include in this survey. That the grasslands of at least five of them (Arastradero, Fremont Older, Rancho San Antonio County Park, Sierra Azul and Windy Hill) have almost certainly been type-converted indicates how poorly native grasses fare in these grassland types.

Type conversion was determined by historical means (Fremont Older, Sierra Azul), and by deduction (Arastradero, Rancho San Antonio, Windy Hill). All the historically determined sites occurred in the oak woodland/chaparral dominated foothills behind Los Gatos, Saratoga and Cupertino whose vegetation was largely reconfigured during the peak orchard and wine-growing years in the late 1800's. Orchard trees are still present at Fremont Older as are the ridges from an old vineyard at St. Josephs Hill.

The large grassland areas found at Windy Hill and Arastradero are so irregular given the vegetative zone they are found in that large scale vegetation conversion seems certain. Windy Hill extends from the ridgeline downward, and was apparently carved out of redwood/ Doug fir forest and oak woodland. It contains the same habitat type (northern facing montane slopes) which supports large native grass rich populations at nearby Russian Ridge. This large preserve, however, aside from a few small stands of *Festuca idahoensis* in the rocky ridge top area, and a small stand of *Nassella pulchra* in the lowest section of the preserve, is almost completely devoid of native grasses. Instead the grassland is dominated, as was suggested by Pitt and Heady's study (1978), by the most extensive thistle stands (*Carduus pycnocephalus*, *Cirsium vulgare*, *Silybum marianum*) the author found in any Santa Cruz Mountain preserve.

Arastradero County Park is found at the lower end of the foothill range. Surrounded almost on four sides by dense oak woodlands, it too is one of the most native grass-poor preserves in the Santa Cruz Mountains. It is found within a half mile of Stanford University, which contains more *N. pulchra* stand area (off serpentinite soils) than any other preserve in the interior region. Arastradero does harbor several small

Elymus glaucus stands in the grassland/oak woodland ecotone, plus several *Leymus triticoides* stands in the lower section of the park. This lower section reaches into a zone where savannas may have begun to occur.

The grassland areas carved out of oak woodland and/or chaparral for orchards or vineyards are similarly depauperate in native grasses. Even though *Nassella lepida* is present in the chaparral vegetation surrounding Stevens Creek it has made no inroads into the grasslands found there. Neither has *N. pulchra* invaded the former vineyards at St. Joesphs Hill to any degree, even though a small but vigorous *N. pulchra* stand occurs on serpentinite soils bordering the grassland. Both these sites contrast strongly with the small native grass dotted meadows found in similar habitats and elevations in the Rancho San Antonio and Duveneck Windmill Open Space Preserves a short distance away.

Type conversion may help explain one of the most notable distribution patterns encountered during the study; the virtual exclusion of native grasses from large grassland areas in the interior region (off of serpentinite soils). Almost all native grass stands in this region occur in smaller grassland areas found within or around the oak woodland matrix. During the survey native grasses were usually noted to sparsely occur in the grassland environment where native grass stands were found. Native grasses are able even in the midst of extensive disturbances to persist in sparse amounts in small plots of undisturbed lands such as railroad right of ways (Thomsen et al. 1996). The large grasslands were anomalous in that not only were almost no native grass stands found but native grasses were almost never encountered. They are essentially devoid of native grasses.

The predominant vegetation type on the valley floor in the Santa Clara Valley,

seems to have been oak savanna with some scattered grasslands, chaparral and marshy areas (Broek 1932). It is likely that all the large open grasslands (aside from serpentine grasslands) found in the foothill preserves (Rancho San Antonio County Park and Open Space Preserve, Calero County Park, Santa Teresa County Park, Stanford Academic Reserve) were converted either from savannas, oak woodlands or chaparral.

Most of the grasslands found on south-facing slopes in the montane region in Saratoga Gap, Russian Ridge, and Long Ridge were probably also converted from oak woodlands and forest. These sites exhibit little ecotonal intergradation and do not appear to exhibit unusual edaphic conditions. Grasslands in montane regions are usually restricted to ridge tops (balds), sites with shallow soils, and meadows with high water tables. None of these conditions apply to the aforementioned grasslands. These grasslands, too, are virtually devoid of native grasses.

The virtual disappearance of native grasses from all these areas is probably due both to type conversion, which eliminated all the ecotonal 'hiding spots', and the cultivation or intensive grazing which may have followed. That these were the only preserves (aside from coastal beaches) in the Santa Cruz Mountain region which were essentially native-grass free supports Keeley's proposition (1991, 1993) that native grasses do not readily invade grassland stands type converted from other vegetation types and that current native grass distribution may provide clues to former 'natural' grassland sites.

Vegetation conversion does not directly impact native grass rarity. If all or many of these areas have been 'type-converted' from other vegetation types, however, then the extent of native grass rarity may be obscured by the presence of large grassland areas

which are either ill-suited to support native grasses or lack the seed sources necessary for native grass invasion. If significant portions of the California grasslands in the Coast Ranges or in the Peninsular Ranges (Keeley 1990, 1991, 1993) are in sites which are unsuitable for native grasses, then the importance of identifying natural grasslands and retaining the native grass stands found in them remaining rises considerably (Keeley 1990, 1991, 1993). Further research is needed to uncover the factors governing native grass stand persistence.

Rare Species in Native Grass Stands

Fourteen of the 160 native grass stands surveyed or about 9% of native grass stands sampled contained a rare species. All of the rare species either occurred in the coastal or bay regions (5 spp.) or in the interior region on serpentinite soils (4 spp.).

Native grass stands are a significant reservoir for rare native species but only in certain environments. Native grass stands in the more mesic sections of the coastal and bay regions and on serpentinite soils in the interior region harbored rare species. No rare species were found on foothill habitats in the coastal region, or in the interior region off of serpentinite soils, or in the montane native grass stands.

CHAPTER EIGHT

NATIVE GRASS STAND DISTRIBUTION

Centers of Native Grass Rarity

Three sections of the Santa Cruz Mountain region host high concentrations of locally rare native grasses (coastal/bay, montane, interior serpentinite). Containing the most mesic environments found in the Santa Cruz Mountains, these areas function as refuges for elements of the Arcto-tertiary geoflora, which is primarily composed of more northerly tending species (Beetle 1947, Thomas 1961, Stebbins and Major 1965, Raven and Axelrod 1978, Axelrod 1981). This flora, which most native grasses in the Santa Cruz Mountain region belong to, flourished during the Miocene (@2-20 million years ago) when summer rainfall was common and temperatures were milder (Axelrod 1977). Native grasses became largely confined to the coastal and montane regions as seasonality increased and summer rainfall disappeared (Beetle 1947, Raven and Axelrod 1978, Adam et al. 1981). More endemic native grasses are found in the Central Coast Ranges and Northern Coast Ranges than in any other region of California (Beetle 1947). The San Francisco peninsula, surrounded on three sides by water and exposed to high winds and continual flows of off-shore air, contains an especially rich northern tending flora (McClintock et. al. 1990).

The coastal and bay regions serve as refuges for the rarest of the native grasses still able to survive in the more arid grassland environments (Thomas 1961, Axelrod 1981). Confined to the thin coastal strip, native grasses of this group, (*C. nutkaensis*, *Deschampsia caespitosa*, *Festuca rubra*, *L. mollis*) not only have the most restricted

ranges of any found in the Santa Cruz Mountain region but are largely restricted to the most maritime habitats (points, peninsulas, bays) of the coastal region (Beetle 1947).

A second center of abundance for species derived from the Arcto-tertiary geoflora occurs in the montane region. Here cool, wet winters give way to warm but not hot summers. Most of the native grasses found in the montane region (*Bromus carinatus*, *Festuca idahoensis*, *Elymus glaucus*, *Elymus multisetus* (non- serpentine soils), *Melica californica*) are widely distributed in sparse amounts in the Santa Cruz Mountain, but display distinct centers of abundance here.

Located in the more xeric interior region, serpentine soils provide a refuge for a broad mixture of both the more xeric tending elements of the Arcto-tertiary geoflora – which tended to form stands - (*E. multisetus*, *Melica torreyana*, *Vulpia microstachys*) and more mesic tending ones – which occurred sparsely within stands (*Agrostis microphylla*, *Bromus carinatus*, *Danthonia californica*, *Elymus glaucus*, *Hordeum brachyantherum*, *Koeleria macrantha*, *Melica californica*, *Poa secunda*, *P. tenerrima*).

Edwards (1990, 1992) speculates that serpentine grasslands may have provided refugias for native grasses not only from the non-native species invaders of the last two hundred years but during the large climatic shifts which characterized the last period of the Pleistocene and the introduction of the Holocene period. As the temperatures and seasonality increased during the Holocene, grasslands, particularly in the hotter, interior regions, may have undergone large upheavals, possibly changing from a perennial grass dominated vegetation type to an annual wildflower dominated one (Edwards 1988).

Serpentine areas, which are often located near springs or seeps along fault lines, may have

provided refugias for the more mesically oriented native grasses (Edwards 1984). That most of the more mesically oriented native grasses in the Santa Cruz Mountains are more frequently found on serpentinite soils appears to support speculation that serpentinite soils formed a climactic refuge before they formed a primarily biotic one.

Distribution Patterns in Santa Cruz Mountain Preserves

Habitat factors from the canonical correlation, results from the distribution table (Table 12), and personal observations indicate that three distribution patterns occur in the native grasses that form stands in the Santa Cruz Mountain region preserves. Each distribution pattern provides clues to the historical context in which these native grasses have persisted, and helps illustrate the threats they face, and the conservation values they have.

Most of the native grasses in the first two categories appear to be relicts of the Arcto-tertiary period. They fit the mold of most relictual species or paleo-endemic species quite well; they either do not have many close relatives (*Deschampsia caespitosa*), or their close relatives are disjunct geographically (*Calamagrostis nutkaensis*, *Festuca idahoensis*, *F. rubra*, *Leymus mollis*).

The rarity, small population sizes, isolated distributions, relictual status and the high variability of the native grasses in the first two categories gives their populations especially high conservation values (Lesica and Allendorf 1992, 1995). The remnants of a grassland type that probably flourished during the Pleistocene, several species in the first two categories (*Calamagrostis nutkaensis*, *Deschampsia caespitosa*, *F. idahoensis*, *Leymus mollis*) occur in the Santa Cruz Mountains near the edges of their ranges.

(1) Native grass stands embedded completely within a native species matrix occur only in coastal or near bay areas. All have small population sizes and are very rare overall. They include *Calamagrostis nutkaensis* and *Festuca rubra* stands.

Only these native grasses form stands that are completely embedded in a native species matrix (coastal scrub). No longer found in grassland habitats in the region, they are restricted to the most intensely maritime sections (peninsulas, passes) of the coastal region where they survive in extremely small populations. The rarest of all native grasses in the Santa Cruz Mountain region, it appears that, any overt habitat destruction or transformation notwithstanding, much of their rarity is a result of climactic changes over time. They fit the long/wide (long persistence/wide distribution) category developed by Fiedler and Ahouse (1992) which describes species which are rare because of historical events, evolutionary history and taxon age. They undoubtedly experienced large shifts in abundance during the glacial and interglacial periods of the Quaternary. If population extinction occurs it will most likely come from the invasion of native not non-native species.

Containing a native species rich, northerly tending flora, they also harbor the most distinct and localized native floras found.

(2) Native grass stands found on distinct edaphic substrates within a non-native grass matrix, which occur in small populations in only one or two regions and are very rare region wide. These include *Deschampsia caespitosa*, *Festuca idahoensis*, *Leymus mollis*, *Melica torreyana* and *Vulpia microstachys*.

Mostly but not entirely restricted to coastal/bay regions, these relictual native

grasses are largely confined to a variety of distinct edaphic environments that shield them to some degree from non-native grass invasions. Their population sizes (generally small) mirror the extent of the edaphic environment they are found on.

Unlike the first category species these stands usually experience low to moderate rates of non-native species invasion. While the larger native grass stands on serpentinite soils are probably the most stable and secure in the Santa Cruz Mountains, most of these stands, even some embedded within serpentinite soils, are so small (montane *F. idahoensis*, *D. caespitosa*, *V. microstachys*) as to preclude any assumption of long term security.

Often found near their range limits and isolated in very small populations, the native grasses in the first two categories form peripheral populations in the Santa Cruz Mountain region. Peripheral populations often have high conservation value because they tend to have distinct genetic characteristics (Lesica and Allendorf 1993, 1995). Selection pressures are amplified in peripheral populations because of their small sizes, and because they tend to occur in atypical habitats which present them with unusual environmental stresses (Stebbins and Love 1941).

The combination of small population size and unusual environmental stresses can lead to developmental instabilities resulting in rapid genetic changes (Levin 1970), and the formation of new hybrids and allopolyploids (Stebbins and Major 1965, Levin 1970, Lesica and Allendorf 1995). Increased ploidy levels in grasses appears to be associated with increased heat and cold tolerance, two conditions often found on the range margins of a species (Stebbins and Love 1941). Peripheral grass populations have been noted for their genetic (Knapp and Rice 1996), morphological (Harlan 1945 a, b, Lawrence 1945, Stebbins and Tobagy 1944, Ward 1969), phenological (Ward 1969), and even sexual (monecious vs. dioecious) (Huff and Wu 1992) variability.

While these populations are usually small, many are 'old', and have experienced many 'boom and bust' cycles, which may have enabled them to purge their deleterious alleles. They may, therefore, have high viability even though their genetic variability may be reduced (Menges 1992).

(3) Native grasses found on a wider variety of edaphic environments within a non-native grass matrix have larger population sizes, occur in multiple regions, and are common relative to other native grasses. These include *Bromus carinatus*, *Danthonia californica*, *Elymus glaucus* and *Nassella pulchra*.

All these grasses are widespread, occurring in at least four of the five regions, and all form in at least two regions, stands in which they are the most abundant native grass. These were probably the grassland dominants before the non-natives invaded the California grasslands. The relictual (ie. disjunct) nature of their current local distributions is largely the result of recent historical events (i.e., cultivation, type conversions, native grass invasions, etc.) which have fragmented what were once much more extensive populations. Based on their current distributions it seems likely that *Danthonia californica* covered much of the coastal plain; *N. pulchra* largely clothed the coastal and interior foothills and the interior valley savannas; *Bromus carinatus* and *Elymus glaucus* flourished in the wetter ridgetop and north facing slopes of the montane region; and *D. californica* and *E. glaucus* dominated the wet meadows in both the coastal and montane regions.

The native grass stands formed by these species serve as important seed banks for widespread restoration efforts. Their probable former abundance puts them in the category of 'critically endangered' ecosystem types (Noss et. al. 1998). The high genetic

variability expressed thus far in the native grasses studied (Huntsinger et. al. 1996, Knapp and Rice 1996, Dyer and Rice 1997a) suggests that a tight adaptive fit to local conditions exists in native grasses, necessitating that a wide variety of stands be maintained if restoration is to occur. Within this context any native grass stand, no matter how small or degraded, can be considered to have a high conservation value.

Despite their more widespread nature and greater abundance the stability and resilience of these grass stands is in question. Their location in the most productive and competitive grassland environments leaves them more susceptible to new non-native species invasions than native grasses in less productive sites (Noss et. al. 1998). Many interior and coastal *N. pulchra* stands are enveloped in a sea of *Brachypodium distachyon*, a recent annual grass invader, which now dominates large grassland areas. Similarly, *Carduus pycnocephalus*, *Centaurea solstitialis*, and *Phalaris aquatica* - all noxious species - appear to have rapidly expanded their ranges into the grassland habitats in the interior foothill and montane regions in the last few decades.

CHAPTER NINE

THREATS TO NATIVE GRASS STANDS

Non-Native Species

Identifying invasive species threats to native grass stands is critical given their small size and rarity.

The Frequency and Abundance of Invasive Non-Native Species Listed by the California Exotic Pest Plant Council (CalEPPC)

Plants currently identified as invasive species frequently occur in native grass stands in California (see Table 2). At least one CalEPPC listed invasive species was reported to commonly occur in *Calamagrostis nutkaensis*, *Danthonia californica*, *Deschampsia caespitosa*, *Festuca idahoensis*, *Leymus mollis*, and *N. pulchra* stands. Most of these are annual or perennial grasses.

Twenty-two of the invasive or possibly invasive (more info needed) non-native species identified by CalEPPC which occur in the Santa Cruz Mountain region grasslands (Hickman 1993) are found in native grass stands in the regions preserves (Table 13). Forty percent occur frequently (>10% of native grass stands). Most of these are on the annual grass list (5), two are List A species, one is List B, and one is on the Info Needed list (see Table 14).

Most (17/29) of the non-native species which are frequently found in native grass stands are not at this time considered 'invasive' at this time in California grasslands (see Tables 14,15).

The non-native species found in the regions native grass stands can be divided up into several categories:

CalEPPC Identified Invasive Species Found Both Frequently and Abundantly in Native Grass Stands in the Regions Preserves.

CalEPPC species found in Table 16 make up this list. Their invasive nature and abundance in native grass stands suggests that they pose significant threats to native grass stands in the Santa Cruz Mountain region preserves. They include most of the annual grasses (*Avena barbata*, *Brachypodium distachyon*, *Bromus diandrus*, *Lolium multiflorum*) and *Carduus pycnocephalus*.

Two especially aggressive non-native species are of special note. Because of their high relative cover values and frequent appearance, *Lolium multiflorum* and *Brachypodium distachyon* are more potentially disruptive of native grass stands than other annual grasses found in the regions grasslands.

Lolium multiflorum does not occur as frequently as other non-native annual grasses in California grasslands (Janes 1969, Gulmon 1977) but when it does occur it tends to be abundant and can, under the right conditions, form very dense stands (Hedrick 1939, Facelli et al. 1987). Abundant in half of the native grass types listed in Table 16, *L. multiflorum* effects more different native grass types in the Santa Cruz Mountain region preserves than any other non-native species and achieves relative cover rates of >30% in almost 10% of all native grass stands. All *Avena* and *Bromus* species achieve this amount of cover only six times. High *L. multiflorum* cover is associated with low species richness in grassland environments (Facelli et al. 1987).

The only non-native grass to occur with abundance (>10% relative cover) in over 25% of *Nassella lepida* and *N. pulchra* stands, *Brachypodium distachyon* is the most dominant non-native species in the regions native grass stands. Its mean relative cover rates in *N. lepida* (39.6%) and *N. pulchra* (36.8%) stands are from 50 to over 100%

higher than other non-native grasses on this list. This species not infrequently achieves average relative cover values of >50% in the regions native grass stands (see Four Non-Natives).

Avena barbata was abundant in two types of native grass stands (*Elymus multisetus*, *Melica californica*). *Avena barbata* has been abundant in California grasslands for over 150 years (Wester 1981) and can, like other of the older non-native inhabitants of the California grasslands (*Avena fatua*, *Brassica nigra*, *B. hordaceus*, *B. diandrus*, *Erodium botrys*, *E. cicutarium*, *Hordeum* spp., *Lolium multiflorum*), be considered stable at the present time. While these annual grasses pose substantial problems for native grass restoration efforts, they probably do not under the current conditions pose significant future threats to the still extant native grass stands.

The stability of the grassland environment, however, in the Santa Cruz Mountain region preserves, is unclear. At question is whether the grasslands have reached an 'equilibrium state' after grazing was eliminated at the time of grassland acquisition, or whether some species are continuing to increase in abundance. Moderate to heavy grazing regimes result in a proliferation of mostly shorter noxious weedy species (rosettes, therophytes, thistles) which give way to taller annual and perennial grasses and forbs (*Avena*, *Bromus*, *Phalaris*, spp., *Carduus* spp.) when grazing is eliminated (Sampson et al. 1951, Heady 1977, Willems 1983, Noy-Meir et al. 1989, Tremont 1994, McIntyre et al. 1995). These species may impact native grasses more directly than species found in grazed sites, because their taller stature, larger mass and often perennial life form indicates they are closer ecological equivalents to native grasses. Some of the 'newer' invaders (*Phalaris aquatica*, *Carduus pycnocephalus*, *Centaurea solstitialis*) are clearly increasing. If the 'older' non-native residents of California grasslands are still increasing or conditions

occur under which they do increase, then they would pose significant threats to native grasses.

CalEPPC Identified Invasive Species Found Frequently (>10% of stands) but not Abundantly in Native Grass Stands

These species are not abundant at the present but may pose future threats because of their invasive nature. They include *Avena fatua*, *Centaurea solstitialis*, and *Hypochaeris radicata*.

Avena fatua (annual grass list) occurs very frequently in native grass stands in the interior region (66% of stands) at moderate mean relative cover rates ($n=44$, $mn=11.4\%$, $sd.=14.6$) (see Appendix 3). Like *A. barbata*, it is a longtime resident of California and is not presently considered to pose significant future threats to native grass abundance in the region.

Centaurea solstitialis (List A-1) cover values may be under estimated as much of the sampling occurred before the plants had reached maturity. A serious threat to native species and native grass abundance, it's presence and role in native grass stands in the Santa Cruz Mountain preserves is treated more in depth in a later section (Four Non-Natives section).

Hypochaeris radicata (more info needed) arrived in California grasslands in the last hundred years (Huffaker 1951). It occurred very frequently in the coastal region (70% of stands) where it was the second most common non-native species found (see Appendix Three). Mean relative cover rates were, however, very low ($n=14$, $mn=<1\%$, $sd=.6$).

Other infrequently found invasive species form a diverse group containing some

species that are already significant local threats, some which appear to be potential threats, and some species which do not appear well-adapted to the region and do not appear to be significant threats. Significant threats include *Ammophila arenaria*, *Bellardia trixago*, *Cytisus scoparius*, *P. aquatica* and *Taeniatherum caput-medusae*. Species that do not appear to be significant threats at this time include *Brassica nigra*, *Bromus madritensis* sssp. *rubens*, *Centaurea melitensis*, *Conium maculatum*, *Cirsium vulgare*, *Foeniculum vulgare*, *Holcus lanatus*, *Oxalis pes-caprae*, and *Parentucellia viscosa*.

Ammophila arenaria (and *Carpobrotus edulis*) are largely responsible for the extreme rarity of *Leymus mollis* in central and northern California coastal dunes. A large bunchgrass from the British Isles purposefully introduced to stabilize dunes, this species forms dense mono-specific stands. Found infrequently in the small *L. mollis* stands found in the Santa Cruz Mountain region preserves, it dominates the dunes surrounding them.

Found in Santa Cruz Mountain grasslands for over 100 years, *Bellardia trixago* (List B) began to spread rapidly in the region about 50 years ago (Thomas 1961). It was found infrequently in the regions native grass stands but its ability to penetrate serpentine soils - the richest repositories of native grasses in the regions preserves - make it a species of special concern.

One of the few invasive non-native shrubs in California grasslands, *Cytisus scoparius* (List A-1), appears to be rapidly invading a group of *D. californica* stands in Wunderlich County Park. These stands - the only *D. californica* stands on the eastern side of the Santa Cruz Mountains occurring off of serpentinite soils - are found in woodland meadows, a rare habitat type in the regions preserves.

A notoriously aggressive grass in the western United States, *Taeniatherum caput-medusae* (List A-1), occurred only once in native grass stands in the regions preserves. The one large stand found during the survey bordered serpentinite soils in Edgewood

County Park. *Taeniatherum caput-medusae* does not appear to have significantly encroached onto serpentinite soils, but its population appears to be fairly new (Toni Corelli pers. comm.). Perhaps more troubling, it exhibits an atypical number of nerves on the lemma ((five vs. three (Munz 1959)), a feature which may indicate hybridization between it and *Elymus multisetus*, a relative which is abundant on serpentinite soils at the park (and has a five-nerved lemma). *Taeniatherum caput medusae* does not hybridize readily with other genera but if hybridization does occur, it might, in a worse case scenario, confer adaptive value to *T. caput-medusae* on serpentinite soils (Anttila et. al. 1998, Weber and D'Antonio 1999, Harrison et. al. 2001).

Holcus lanatus is reported to commonly occur in *Calamagrostis nutkaensis*, *Danthonia californica*, *Deschampsia caespitosa*, and *Festuca iahoensis* stands in California (Sawyer and Keeler-Wolf 1995). It occurred in 50% of the coastal native grass stands in the Santa Cruz Mountain region but at low rates (2.9% relative cover) (see Appendix Three). Invasive in *D. caespitosa* stands in a North Coast preserve, it is currently present in small amounts in *D. caespitosa* stands in the Santa Cruz Mountain preserves.

Non-Native Species Not on CalEPPC's lists Which Occur Frequently and Abundantly in the Native Grass Stands in the Regions Preserves.

Four species not found on CalEPPC's lists are found abundantly enough in the regions native grass stands that they may be a cause for concern. The degree of threat these species pose is unknown. Most of these species appear to be abundant elements of the regions grasslands. All are long-term residents of California grasslands, and each has been common in Santa Cruz Mountain grasslands for at least forty years (Thomas 1961).

These species include *Aira caryophylla*, *Erodium botrys*, *Geranium dissectum*, and *Rumex acetosella*.

A. caryophylla's restriction to unproductive substrates in California and its low abundance relative to other non-native grasses has probably kept it from being considered a significant threat to native species in the states grasslands. Because it shares similar habitat preferences with many of the rarer native grass and forb species in the Santa Cruz Mountain region, it has the potential however, if abundant, to substantially impact native species diversity.

Classified as a noxious weed in 23 states (United States Department of Agriculture 2001) but not in California, *Rumex acetosella* is the most commonly found forb in the Santa Cruz Mountain regions native grass stands (see table 15). It is ubiquitous in native grass stands found in the montane (72% of stands), coastal (60% of stands), and bay (40% of stands) regions (see Appendix 3). It commonly attains high relative cover values in *E. glaucus* stands (see Table 16).

Several other species not listed by CalEPPC occur frequently but not abundantly. These species include *Anagalis arvensis*, *Crepis vesicaria* ssp. *taraxacifolia* and *Sonchus asper*. *Anagalis arvensis*, and *Sonchus asper* have been present in California grasslands for at least 140 years. *Anagalis arvensis* has been common in Santa Cruz Mountain regions grasslands at least since the 1960's (Thomas 1961) and its populations appear stable. Both *Sonchus asper* and *Crepis vesicaria* ssp. *taraxacifolia* appear to have increased markedly recently in the region. *Sonchus asper* was restricted to 'disturbed' areas in 1961 (Thomas 1961) but is now the most frequently found forb in coastal native grass stands (see Appendix 3). *Crepis vesicaria* ssp. *taraxacifolia* was 'becoming very common' by 1961; it is now found in 16% of all native grass stands (see table 15). Despite

not being classified as noxious weeds these species deserve attention because of their apparent recent population increases.

Four Non-Natives

Four non-native species with the potential to severely impact native grass populations were selected for more in depth study. All appear to have experienced large increases during the past several decades in the San Francisco Bay area.

Brachypodium distachyon

Almost forty years after Thomas's Santa Cruz Mountain flora (Thomas 1961) made no mention of it, *B. distachyon* is now the dominant non-native grass in *N. pulchra* stands found off of serpentinite soils (see Table 16, Appendix Three). *Brachypodium distachyon* is ubiquitous in interior (off-serpentinite) and coastal/bay *N. pulchra* stands, occurring in 85% and 80% of them respectively. *Brachypodium distachyon*'s average relative cover is over twice that of the next most abundant non-native grasses in *N. pulchra* stands in the interior, bay and coastal region (see Table 21).

Brachypodium distachyon's ability to withstand drought (Armstrong and Huennecke 1992), its variability (Aronson et. al. 1990, Aronson et. al. 1992sd, Aronson et al. 1993), and its rapid spread and dominance over large parts of the coastal and interior foothill grassland regions, indicate that the competitive 'bar' has been lifted significantly for native grasses in these areas. Several times the author noted dense mats of *B. distachyon* clumped around dead *N. pulchra* plants. A short statured annual grass, *B. distachyon*'s rapid growth in the ungrazed grasslands of the Santa Cruz Mountain region

preserves is unusual. Eliminating grazing usually results in a proliferation of taller non-native species that are able to overtop shorter species (Huennecke et. al. 1990).

The abundance of *B. distachyon* and *Lolium multiflorum*, another abundant short statured annual grass which forms dense canopies (Facelli et. al. 1987) in the Coast Ranges (Goode 1981), probably reflects the near optimal growing conditions for non-native grasses in the interior region. During the warm, wet spring period, rapidly growing shorter grasses can exclude more slowly growing taller grasses by monopolizing light and soil moisture resources early in the season. *Lolium multiflorum* is able to do this on wetter, more clay rich soils, and *B. distachyon* can do this on drier soils. The ability to grow rapidly and form dense stands near ground level may characterize the next 'wave' of invading grasses.

Table 21.--Non-Native Grass Frequency and Relative Cover in *Nassella pulchra* Stands

<u>Non-Native Grass</u>	<u>Number of Occurrences**</u>	<u>Mean Relative Cover</u>
<i>Brachypodium distachyon</i>	46	31.0
<i>Avena barbata</i>	16	15.7
<i>Lolium multiflorum</i>	44	13.6
<i>Avena fatua</i>	42	12.5
<i>Bromus hordaceus</i>	60	9.0
<i>Vulpia bromoides</i>	22	8.7
<i>Bromus diandrus</i>	44	4.7

*>10% *N. pulchra* relative cover

**includes only occurrences with cover values

Brachypodium distachyon appears to have markedly negative effects on species richness. Stands where *B. distachyon* is abundant (>10% relative cover) had the lowest species richness values (n=22, mn=11.2 spp., s.d.=3.7) of all Santa Cruz Mountain native

grass stands. Reduced species richness in stands dominated by one species has been noted before in California grasslands (McNaughton 1968) and elsewhere (Facelli et. al. 1987). Native species richness, in particular seemed to be negatively effected. The ratio between native and non-native species richness was twenty percent lower in native grass stands where *B. distachyon* dominated the non-native grass guild (.42), than in stands where *L. multiflorum* (.53) or *Avena fatua* (.51) did so, and thirty percent lower than in stands where *Bromus hordeaeus* (.66) did so.

Carduus pycnocephalus (Italian thistle)

Reported to be 'occasional' in disturbed areas in 1961 (Thomas 1961), *C. pycnocephalus* is now the most commonly encountered non-native forb in the interior region off of serpentinite soils (see Appendix 3). Occurring slightly less frequently but with fifty percent greater average cover than *Centaurea solstitialis*, *C. pycnocephalus* had the highest average relative cover values (n=14, mn=7.0%) of any forb in the interior region (see Appendix Three). A large, spiny thistle, *C. pycnocephalus* reaches its greatest abundance on the mesic soils found in *Leymus triticoides* stands (see Table 16). A List B species (California Exotic Pest Plant Council 1998), *C. pycnocephalus* is one the few exotics whose invasion and replacement of a native grass stand has been documented (Bartoleme and Gemmill 1981).

Centaurea solstitialis (yellow star thistle)

A CalEPPC List A-1 species, *C. solstitialis* may be the most noxious weed in California rangelands (Thomsen et. al. 1991). It appears to have increased markedly in the

last three decades, and had, as of 1985, formed 'heavy infestations' in almost seventy percent of California's counties (Maddox et. al. 1985, Gerlach et. al. 1998). It is now found in nearly eight million acres statewide (Thomsen et. al. 1991). While it has been present in the San Francisco Bay Area at least since 1869, it did not show up in large quantities in one bay area preserve for approximately one hundred years (Hastings and DiTomaso 1996). The genetic structure of its populations suggests, in fact, a relatively recent population expansion (Sun 1997).

Centaurea solstitialis's long growing season brings it into direct competition for moisture with many native grasses (Bormann et. al. 1992). Large *C. solstitialis* declines in a Sonoma County preserve following a prescribed burning regime resulted in a three hundred percent increase in perennial grass cover and a fifty percent increase in native forb cover (Hastings and DiTomaso 1996).

Centaurea solstitialis's abundance is probably under-represented in this survey because many transects were run before it reached maturity. *Centaurea solstitialis* was the second most commonly occurring (26% of sites) and abundant non-native forb, and the second most abundant ($n=15$, $mn=4.6\%$ rel. cover, $sd=5.5$) non-native forb, in the interior region (see Appendix Three). In Rancho San Antonio County Park it appears to be rapidly decimating one of the largest *Nassella pulchra* stands found in the Santa Cruz Mountain region (pers. obs.). It was the only non-native forb able to regularly penetrate, albeit in small amounts, interior serpentinite soils. It was not found in any coastal/bay native grass stands.

Some circumstantial evidence indicates that *C. solstitialis*'s impact on native grasses may depend on how closely its growth patterns approximate those of a particular native grass. While dense *C. solstitialis* stands surround *D. californica* stands but penetrate them hardly at all, *C. solstitialis* infests nearby *Elymus glaucus* stands. *Elymus*

glaucus blooms and senescences much earlier than *D. californica*. It is possible that *Danthonia californica*, a late blooming native grass with a long growing season and a short dense root system, is able to exclude *C. solstitialis* by denying it adequate soil moisture at the end of the growing season (Dyer and Rice 1999). *Elymus glaucus* and other native grasses which have a much shorter growing season may, because of their earlier senescence, leave behind sufficient soil moisture reserves for *C. solstitialis* to flourish (Dyer and Rice 1999).

Phalaris aquatica (Harding grass)

A CalEPPC List B species, *P. aquatica* had become 'sparingly naturalized' in Marin County by 1951. Reported to occur in disturbed environments and as an escape from grain fields in the coastal region of the Santa Cruz Mountains by 1961 (Thomas 1961), *P. aquatica* is now found in most Santa Cruz Mountain preserves. It reaches its highest concentrations in the montane regions where it is found in 14% of montane native grass stands, and forms very large virtually mono-specific stands on south facing slopes in the Monte Bello preserve. Only traces of what may have been one of the largest *Danthonia californica* stands in the region, now occupy the fringes of this very large stand. In a Southern California preserve *P. aquatica* has overcome from 1-200 acres of one of the "finest (*Nassella pulchra*) stands in the state" after grazing was discontinued at a preserve in Southern California (Barry 1972, Goode pers. com.),

Phalaris aquatica does not yet occur in high cover amounts in any native grass stands but many small stands occur through the regions preserves, each of which may become the focal points of larger infestations (Moody and Mack 1988). Several native

grass stands in the montane region, including some with particularly high conservation values (*Festuca idahoensis*) occur on the borders of encroaching *P. aquatica* fronts.

Once establishment occurs, *P. aquatica* forms massive bunches and produces prolific amount of seeds even in less productive environments because of its ability to tap deep soil water levels (Bentley 1967, Junak 1995). *Phalaris aquatica*'s bunch size in the Santa Cruz Mountain grasslands, is rivaled only by *Ammophila arenaria*, a non-native dune grass. Biomass is a critical factor determining in determining non-native grass invasion success in California grasslands (Peart and Foin 1985). Early to green up and remaining green well into the summer, *P. aquatica* may have the longest growing season of any grass in the Santa Cruz Mountain region. Of the non-native grasses in the Santa Cruz Mountain preserves, only *Ammophila arenaria* has the ability to so radically transform the grassland environment.

Cultivation

Given the emphasis on native grass decline which has consumed much of the literature on native grass abundance, it is noteworthy when instances are uncovered in which native grasses have not only re-colonized grasslands but have re-colonized old fields, some of the most altered and seemingly impenetrable sites of all.

It was impossible to determine precisely where cultivation had or had not occurred given the depth of the historical survey that was attempted. Some formerly cultivated areas, especially those devoted to grain crops, were surely missed. Cultivation for cereal grains - which was widespread - reached its apogee during the 1870's, long before aerial photographs are available

(Broek 1932). Cultivation for cereal crops in some places reached far up into the mountains and cultivated fields can still be found on quite steep slopes in a few areas.

Eight formerly cultivated sites were found which supported native grass stands. Seven were located in the coastal or montane regions (four surveyed), one was in the interior region. Stands (>10% relative cover) of *Danthonia californica* occurred three times, *Elymus glaucus* and *Nassella pulchra* twice, and *Bromus carinatus* and *Leymus triticoides* once.

All of these sites occurred in locations with fairly high soil moisture levels. They included, a flat marine terrace formerly farmed to vegetables which require high water conditions (Ano Nuevo), a flat tableland near the ocean (Milagra Ridge), a hillside next to the ocean (unsurveyed, and several sites which occurred at the bottoms of hills (Monte Bello, Santa Teresa County Park). The montane and interior region sites occurred in mesic flat or low sloping lands that usually occurred at the bottoms of hills.

It is not surprising that the native grass re-invasion of disturbed sites that does occur, takes place in more mesic habitats. Coastal prairies in California are believed to be less well invaded by exotics, more resilient in the face of disturbance, and more likely to exhibit native grass re-invasion than valley grasslands (Huffacker 1951, Cooper 1960, Heady 1977, Bartoleme et. al. 1980, Blumler 1992a). Productive habitats are believed to be the most resilient to non-native species invasion (Burke and Grime 1996). Native grasses in the more arid valley grasslands found in the interior portions of the central Coast Ranges are rarely able to re-invade old-fields (Stromberg and Griffin 1996).

Some evidence indicates that mesic micro-environments in the coastal prairies and valley grasslands such as meadows or benches, appear to be more resilient in the face of

disturbance than other habitats. *Danthonia californica* abundance and native species diversity, especially of native annual graminoids, was high in north coast meadows regularly disturbed by feral pigs (Kotanen 1996). Native grass richness and cover was high in a formerly cultivated bench at a coastal prairie/valley grassland ecotone in the San Francisco Bay area (Blumler 1992a). *Danthonia californica* readily invaded fill in the San Francisco Bay (Batzli and Pitelka 1970).

It is remarkable that, aside from the serpentinite stands at Edgewood (and Jasper Ridge), *D. californica* forms, in a field which was under cultivation less than 25 years ago, the largest native grass stand in the Santa Cruz Mountain preserves. Vegetation changes in the coastal prairie, however, can proceed rapidly when the disturbance regimes are changed. *Danthonia californica* rapidly regained dominance five years after an invasive weed species was decimated by released insects in northern California (Huffacker 1951). Three years of rotational grazing increased *D. californica* abundance ten-fold (to 10 percent) in a coastal prairie in Humboldt County (Cooper 1960). Perennial grass cover tripled four years after grazing was eliminated in a coastal prairie in northern California (Foin and Hektner 1986). Although recovery appeared rapid, species compositions still appeared to be in flux ten and six years after grazing was eliminated at two coastal prairie sites (Peart and Foin 1985, Grenier 1989).

Several features may predispose *D. californica* to greater success in disturbed habitats. *D. californica* readily adapts short forms when grazed (Edwards 1992, 1995), and is one of the few species in north coastal meadows able to withstand shallow burials (Kotanen 1995, 1996). It forms one of the densest bunches of all the native grasses; a feature which may enhance its ability to re-colonize a site and repel invaders once established.

While *D. californica* has attained moderately high relative cover rates on the formerly cultivated site, few native forbs have accompanied it; native forb richness and cover is very low.

CHAPTER TEN

LESSONS FROM HASTINGS

The comparison reveals a large discontinuity between the non-native floras of the two areas (see Table 18). The most abundant non-native grass in the interior region preserves of the Santa Cruz Mountains (*Brachypodium distachyon*), was not reported to occur in Hastings at all, and the second most frequently occurring non-native grass in the interior region (*Lolium multiflorum*) was not established there. Nor were the most abundant nor the second most frequently occurring non-native forbs in interior region native grass stands (*Carduus pycnocephalus*, *Centaurea solstitialis*) reported to occur all in Hastings (Knops et. al. 1995). All these species are common components not only of Santa Cruz Mountain region native grass stands but of the grasslands as well (pers. obs.).

B. distachyon had not been introduced to California around the time of Hastings creation (Robbins et. al. 1951). Hastings (500-1000 m) lies at what are reportedly the upper limits of *B. distachyon*'s elevational range (<600 m) in California (Wilken 1993). *B. distachyon* occurs, however, in the Santa Cruz Mountains in approximately 25% of the montane native grass stands which are found about 800 meters high. It is now found up and down the Coast Ranges (Wilken 1993a).

One of the earliest introductions to California grasslands (circa 1775), *Lolium multiflorum* has had ample time to spread to Hastings. Charting its abundance in the state is marred, however, by conflicting reports. In the early 1900's it was reported to be

common on the Pacific coast and was being commonly used at a meadow and pasture grass. Robbins in 1940, however, reported it had only occasionally escaped from cultivation. Approximately ten years later Robbins described it as being very common in the Coast Ranges (Robbins et. al. 1951).

Found throughout grassland areas below 1000 meters in the California Floristic Province (Wilken 1993b), *L. multiflorum*, because it is quick to establish a dense groundcover and produces excellent forage, has been seeded frequently in California to improve rangeland productivity (Robbins et. al. 1951, McKell et. al. 1969). It was abundant in grazed lands outside of Hastings (Stromberg and Griffin 1996). Either Hastings reservation was established before widespread seeding efforts in the area began or *L. multiflorum* was seeded but was overcome by taller grasses when grazing was eliminated. It seems likely that the former is true as *L. multiflorum* is abundant in some native grass stands that have been not been grazed for at least thirty years in the Santa Cruz Mountains.

Centaurea solstitialis has been in California since the mid 1800's but has increased markedly in San Francisco Bay preserves in the last thirty years (Hastings and DiTomaso 1996). It is probably the most noxious weed in the Santa Cruz Mountain grasslands, where it dominates large areas. This ubiquitous grassland species is eradicated by Hastings staff whenever it occurs, but it appears to have never occurred in other than isolated occurrences, or to have possessed any real threat to the grasslands found there.

Carduus pycnocephalus is another longtime California resident which appears also to have been rapidly expanding its range in the San Francisco Bay area at the time of

Hasting's establishment (Robbins 1940). It was reportedly confined to the San Francisco Bay area in 1951 (Robbins et. al. 1951). Now found in grasslands throughout the southern two-thirds of the state, *C. pycnocephalus* is one of the most common forbs found in the Santa Cruz Mountain interior native grass stands.

It appears that Hastings has escaped the invasion of several species that have markedly altered the grassland environment in the Santa Cruz Mountains. All four non-natives have considered invasive (California Exotic Pest Plant Council 1998). Intensive grazing as well as intentional introductions, vegetation conversion, cultivation and the high density of roads and trails in the Santa Cruz Mountain region have very likely cleared the way for the greater non-native species invasions found there. Very few species (*Erodium cicutarium*) have been able to disperse naturally into Hastings in the last fifty years (Knops et. al. 1995). Hastings isolation has reduced the frequency of non-native species introductions there.

The effects of the floristic alteration are uncertain but anecdotal evidence suggests that they may be significant. No native grass surveys have been done at Hastings but if hundreds of *N. pulchra* stands do occur there as reported (Stromberg and Griffin 1996), then Hastings, at approximately one third the size of the preserves of the Santa Cruz Mountain region, may contain several times the number of *N. pulchra* stands. Several of the invaders present in the Santa Cruz Mountains possess characteristics that make them particularly inimical to native grass and forb populations. Both *Brachypodium distachyon* and *Lolium multiflorum* produce exceptionally heavy litter mats which probably reduce native grass (Bartoleme and Gemmill 1981, Dyer et. al. 1996)) and native forb

germination (Cook 1965, Evans and Young 1972) markedly. *L. multiflorum*, furthermore, features two factors that bring it into more direct competition with native grasses.

Because it occurs in the same soil moisture rich habitats many native grasses prefer (Goode 1981), and is one of the latter maturing non-native grasses (Ratliff and Heady 1962), it probably competes with native grasses for late season soil moisture. Native grass stands with high *B. distachyon* cover have the lowest species richness values of any in the Santa Cruz Mountains (see *B. distachyon* - Four Non-natives).

The replacement of at least one native grass stand by *Carduus pycnocephalus* has been documented (Bartoleme and Gemmill 1981). *Centaurea solstitialis* has been linked to native grass rarity in the San Francisco Bay area (Hastings and DiTomaso 1996) and appears to be rapidly decimating one of the largest *N. pulchra* stands in the Santa Cruz Mountains (pers. obs.).

Reduced native species richness is another possible consequence of non-native species invasions (Tyser and Key 1988, Beatty and Licari 1992, Hastings and DiTomaso 1996). Native species make up a far larger portion of the grassland flora at Hastings (78%) (Knops et. al. 1995) than they do in the native grass stands found in the interior (55%) or montane (52%) regions of the Santa Cruz Mountains.

This study has shown that native grass stands are a rare and except for a few serpentine stands, mostly unknown component of the areas grasslands. Given their rarity, the proper management and/or restoration of native grass stands is a vital aspect of native grass conservation (Ahmed 1983, Peart and Foin 1985, Murphy and Ehrlich 1989, Fossum 1990, Keeley 1990, 1993, Langstroth 1991, Edwards 1992, 1994, 1995, Dyer et. al. 1996,

Holmes and Rice 1996, Knapp and Rice 1996, Stromberg and Griffin 1996, Dyer and Rice 1997b, Hayes 1998). Active management of native grass stands, however, is rare.

Several native grass restoration projects are underway under the aegis of different agencies in the area (Mid Peninsula Regional Open Space District, Golden Gate National Recreation Area, University of California at Santa Cruz, City of Palo Alto) but most programs are small and will only directly affect a small minority of the native grass stands in the region. Most are concerned with the more common native grasses as well, leaving the rarer and probably more threatened native grasses largely untouched.

The fate of the vast majority of native grass stands in public ownership, then, has been left to 'natural' processes. With the exception of fire, the processes naturally occurring in grassland areas such as competition, herbivory, disease, weather fluctuations, etc., are the sole arbiters of species composition. How effective unmanaged grasslands are at preserving native populations in the face of the continuing onslaught of a competitively superior exotic flora, however, is not known (Edwards 1992, 1995, 1996, Hastings and DiTomaso 1996, Hayes 1998). This analysis suggests that isolated preserves which have not been disturbed for many years may be more effective at resisting non-native species invasions than preserves found near urban areas which have experienced more recent disturbances. It also suggests that 'non-interference' is a less than effective approach at deterring invasive species in less isolated or recently disturbed preserves (Edwards 1992, 1995, Painter 1995, Hastings and DiTomaso 1996, Grey 1998).

Disturbance has often been noted as a key factor in non-native invasions (Forcella and Harvey 1963, Burgess et. al. 1991, LePart and DeBusche 1991, Rejmanek et. al.

1991, Hobbs and Huennecke 1992, Tyser and Worley 1992, McIntyre and Lavorel 1994a, 1994b, McIntyre et. al. 1995). Many exotic species are confined to disturbed sites (Rejmanek 1989, Westman 1990, Burgess et. al. 1991, Knops et. al. 1995) where they remain until the appropriate constellation of factors (genetic reorganization, climactic changes, change in grazing patterns, etc.) occur which make further invasion possible (Johnstone 1986, Burgess et. al. 1991). Those species able to invade intact communities can dramatically effect their species composition, functioning, and structure (DiAntonio and Vitousek 1992).

More detailed analyses are needed to determine the factors which govern native grass stand abundance and composition in the two regions. Factors effecting native grass stand distribution and abundance, including soil texture, soil nutrients, slope, slope position, aspect, etc. should be analyzed. Native grass stands in both areas should be sampled to determine if the following factors differ between the two sets of native grass stands: native grass stand abundance, mean native grass stand size, within stand native grass cover, within stand non-native species cover, native and non-native species composition.

CHAPTER ELEVEN

NATIVE GRASS HABITATS AND VEGETATION STRUCTURE

Canonical Correlation I: Native Grass Stands in Santa Cruz Mountain Region Preserves

The canonical correlations were designed to identify native grass habitats and to characterize the vegetation structure of different native grass stand types. This section elucidates factors that govern aspects of native grass stand structure including native grass cover, non-native grass cover, native forb cover, etc. Each root identifies vegetation assemblages with distinct physical properties.

Root I: Native Grass Stands on Serpentine Soils

Root I: *Melica torreyana* stands found on steeper slopes with rockier soils have higher native forb cover and higher conservation values

Although this grouping primarily distinguishes *Melica torreyana* stands the plot indicates that serpentine stands without *M. torreyana* are allied with it. Because they have similar community structures, all will be included in the analysis. *Melica torreyana* was identified in the canonical correlation because it was the only native grass restricted to serpentine soils. Because sampling on serpentine soils was restricted to stands with denser native grass cover, the findings may overstate both native and non-native grass cover and understate native forb cover relative to more typical serpentine sites.

The rocky, infertile serpentinite soils reduce non-native grass abundance resulting in higher native forb cover and higher conservation values (Cook 1965, Edwards 1984a, 1988, Fiedler and Leidy 1987, McCarten 1992). High rock cover increases shade and enhances soil moisture levels through runoff (Bern 1985). Moisture availability can be much higher on less fertile soils that have lower moisture holding capacities than more productive soils, because of reduced vegetation density and lower evapotranspiration rates (Gurevitch 1986).

High conservation values indicate that native grass stands on serpentinite soils form hotspots of native species richness in the native grass community. The inability of non-native forbs to penetrate these sites was distinctive. Non-native species often make up 50% or more of the flora on native grass stands found on more fertile substrates, but average only 17% of the flora, or about three species per site, on serpentine native grass stands. *Centaurea solstitialis* was the only non-native forb to regularly occur on serpentinite sites but did so at very low rates (see Appendix 3).

Similar native and non-native grass relative covers (na. gr.; $n=16$, $mn=38.4\%$, $sd=9.8$, non na. gr.; $mn=28.9\%$, $sd=16$; paired t-test; $df=15$, $p>.10$) indicated neither grass type was especially favored or abundant. Non-native grass richness was very low but one non-native grass, *Lolium mutiflorum*, was able to establish itself in moderate amounts (see Appendix 3). Relative to other native grass stands, serpentinite soils support intermediate levels of non-native grass cover; while they are much lower than interior *N. pulchra* stands on non-serpentinite soils ($n=49$, $mn=56.1\%$, $sd=19.4$), they are similar to montane and

coastal native grass stands and much higher than *Deschampsia caespitosa* ($n=4$, $mn=10.8\%$, $sd=1.5$) and *Calamagrostis nutkaensis* ($n=5$, $mn=4\%$, $sd=3.1$) stands.

Five different native grass associations occurred on serpentinite soils. *Nassella pulchra* and *E. multisetus* were the most commonly found native grasses, occurring in 83 and 60% of all sites respectively. Most (6/11) native grasses were not common and had low average relative cover values ($n=62$, $mn=12.9\%$, $sd=33.5$). Serpentinite soils in the Santa Cruz Mountains are a refugia for many native grasses but are optimum habitats for none (Huntsinger et. al. 1996).

The San Francisco Bay area and the adjoining Santa Cruz Mountain region may contain some of the most important serpentine grasslands in the state. Because serpentine vegetation in northern California appears to be largely chaparral and/or woodland dominated (Kruckeberg 1984, Wolf 2001), the San Francisco Bay area may be the most northerly area in California to support large serpentine grasslands. Serpentine grasslands are, in fact, mentioned by Kruckeberg only in reference to the San Francisco Bay area and the western slopes of the Sierra Nevada, and he does not include four of the most important serpentine grassland areas found in the San Francisco Bay area (Edgewood County Park, Jasper Ridge, Ring Mountain, Skyline Serpentine Prairie) in his report. (Most of these had probably not been incorporated into preserves at the time). While the Sierra Nevada has much larger serpentine grasslands, its flora is less rich overall, and it supports many fewer endemic serpentinite species than do serpentine grasslands in the Coast Ranges (Kruckeberg 1984).

Root II: Montane and Bay Native Grass Stands

Root IIa: *Bromus carinatus*, *Elymus glaucus*, *E. multisetus* and *Festuca idahoensis* stands with lower native grass cover and higher conservation values, are found closer to the bay on more gravelly soils on steeper, more north facing slopes with higher precipitation levels.

Root IIb: *Nassella pulchra* stands with higher native grass cover and lower conservation values, are found further from the bay on less gravelly soils on less steep, less north facing slopes with lower precipitation levels.

This root identifies factors that effect conservation value and native grass cover in native grass stands found off of serpentine soils. The community characteristics of *N. pulchra* stands are more completely characterized in canonical correlation two.

Native grass cover is lower and conservation values are higher in native grass stands found in the more mesic montane and bay regions on more gravelly soils, and steeper, more north facing slopes. Higher precipitation levels and the cooler summer climate in the montane region result in reduced soil moisture stress. Precipitation levels in the montane region approach or exceed the annual grasses ability to utilize them (Bartoleme et. al. 1980). The higher soil moisture capacities of the deeper soils on north-facing slopes (Biswell et al. 1952, Evans et al. 1975) extend the growing seasons for native grasses (Jackson and Roy 1986). Reduced light levels and cooler temperatures on north facing slopes (Evans et. al. 1975) prolong the period of annual grass germination and reduce annual grass growth during the critical fall and winter periods when non-native grasses begin to overtop native grasses and forbs (Pitt and Heady 1978, Jackson and Roy 1986). The more gravel-rich soils achieve much the same benefits by reducing annual

grass productivity. Increased time to canopy closure has been associated with higher forb cover before (Cook 1965).

More stand types are associated with this root than any other. That the montane region is native grass rich should not be surprising given the native grass guilds evolutionary history and patterns of species richness (Edwards and Havlike 1984). As indicated earlier the coastal and montane regions of California are especially native grass rich. Beetles 'northern floral unit' (1947) of native California grasses consisted of native grasses occurring in the Coast Ranges north of Monterrey Bay, the Sierras above Tulare County and montane portions of the south Coast Ranges, is the richest in California.

Higher conservation values reflect native grass stands with higher native species richness and an abundance of species with limited distributions. Forb richness in valley grasslands is positively correlated with precipitation (Janes 1969, Duncan and Woodmansee 1975, Bartoleme et. al. 1980) and north facing slopes (Evans et. al. 1975, Bern 1985, Blumler 1992a). While no rare species were found in montane regions, species with limited ranges (<5 geographic regions) make up a much larger proportion of the native flora (28%), surprisingly enough, than in interior serpentinite stands (15%), a phenomenon which can possibly be traced to the evolutionary histories of the two regions.

The Coast Ranges provide a fairly large refuge both in space and time for many older species (paleo-endemics) which became restricted to them as summer temperatures increased (Stebbins and Major 1965, Raven and Axelrod 1978, Axelrod 1982). The appearance of serpentinite soils in central California on the other hand, is a fairly recent event (Raven and Axelrod 1978). Many of the herbaceous species restricted to them are

relatively young (e.g. neo-endemics) which (a) have not had great deal of time to expand their ranges and so are rarer and (b) were probably restricted to the more mesic serpentine soils (Raven and Axelrod 1978, Edwards 1988) during the recent Xerothermic period (4,000-8,000 year bp) (Fielder and Ahouse 1992). Aside from some very rare species, serpentinite soils, particularly those in arid interior regions, draw from a more widespread habitat type- the interior valley grasslands - which is more recently formed than the Coast Range mountains, and contains many widespread species (Huennecke 1989). Thus serpentinite soils host a number of very rare but also quite common species, while montane native grass stands contain a more localized flora overall.

Despite a host of factors which would seem to enhance native grass cover in these regions, within stand native grass cover is lower than in the more xeric *N. pulchra* and *L. triticoides* associations these grasses are contrasted with in this root. This leads to an odd dichotomy; within stand native grass cover is greater in the more non-native dominated interior grasslands than in more native species and grass rich montane grasslands.

Montane grasses occur in an environment, however, which, while it has high native grass richness, is not particularly conducive to grass growth. Grasses form grasslands in areas with productive soils and relatively short but warm growing seasons. Grassy areas in montane regions usually occur on edaphic substrates that are either too wet (meadows) (Halpern 1986l, Allen Diaz 1991), or too rocky (and often windy - ridgetops) to support trees (Sugihara and Reed 1987). The north facing slopes of the montane region are probably too cool and the soils too gravelly to support a grass growth dense enough to choke out many forbs.

The Coast Ranges have warmed enough, though, that native grass stands are found in montane regions with any regularity only on north-facing slopes, ridgetops or valley bottoms. The mild temperatures and abundant precipitation of south facing montane slopes support dense stands of *Avena barbata*, a species often found in more productive sites, which gives way to small patches of native grasses only on shallow soils or on the very bottoms of slopes.

Root III: Coastal Prairie I

Root IIIa: *Danthonia californica*, *Deschampsia caespitosa*, and *Leymus mollis* stands with lower non-native grass cover and higher native and non-native forb cover, are found on lower gravel soils on flatter slopes closer to the coast in regions of higher precipitation

Root IIIb: *Nassella pulchra* and *Leymus triticoides* stands with higher non-native grass cover and lower native and non-native forb cover, are found on higher gravel soils on steeper slopes further from the coast in regions of lower precipitation.

Root II illustrated factors which result in native grass stands with high conservation values. This root identifies factors that govern non-native grass and forb cover in the regions native grass stands. It indicates that non-native grasses and non-native forbs have different habitat preferences; non-native grass cover peaks in the more arid interior region *N. pulchra* stands, while non-native forb cover peaks in more mesic coastal native grass stands. That both native and non-native forb cover peaks in the same environment suggest that both guilds respond similarly to the same factors.

This root contrasted the native grass stands found on flatter sites with less gravel-rich soils in the coastal and montane regions, with *Nassella pulchra* and *Leymus triticoides* stands on more gravel rich soils and steeper slopes, in the more arid region. *N. pulchra* and *L. triticoides* stands are covered in more detail in canonical correlation II.

The long, low south facing slopes of the marine terraces in the coastal regions north of Santa Cruz contribute a unique environment. They contain most of the last remnants of flat or gently sloping grasslands in preserves left in the Santa Cruz Mountain region. Almost all of the gently sloping lands east of the Santa Cruz Mountains have been urbanized. Several of the stands associated with root IIIa occur on formerly cultivated sites.

Non-native grass cover is higher and native and non-native forb cover is lower in *N. pulchra* stands in the interior region than in native grass stands in the coastal and montane regions. The interior region presents near optimal growing conditions for annual grasses in the late winter and spring periods when the combination of wet soils, warm temperatures, and high light levels produce high annual grass growth rates (see Canonical correlation II).

Non-native grasses have a distinct competitive edge over native grasses in these productive grassland environments. They germinate earlier (Bartolome and Gemmill 1981, Jackson and Roy 1986), grow faster throughout the fall and winter periods (Jackson and Roy 1986), devote more resources to above-ground tissues (Pavlik 1983a,b, Dyer and Rice 1999), and establish canopy cover more quickly, thus depriving native grasses of adequate light (Turitzen 1978, Dyer and Rice 1999) and soil moisture resources (Dyer et. al. 1996, Dyer and Rice 1999). Native grass seedlings in dense annual grass stands often fail to survive the summer drought

(Dyer. et. al. 1996, Dyer and Rice 1997b) and native species richness is often low (Cook 1965, McNaughton 1969, Goode 1981). The most grass rich and forb poor environments surveyed in valley grasslands were south-facing slopes during dry years (Evans et. al. 1975).

Non-native grass cover is lower and native and non-native forb cover is higher in coastal native grass stands. The lower temperatures and light intensities found in the coastal regions result in later growth periods relative to the interior region. Many coastal sites are buried under a thick layer of thatch long after interior region sites have begun to green up (pers. obs.). Spring and summer temperatures are ameliorated in the coastal regions by the inflows of cool marine air and the frequent fogs that which blanket the area. The short intensely productive growing season found in the interior region gives way to a longer growing season in coastal regions. Cooler summer temperatures result in less rapid growth rates for non-native grasses and canopy closure occurs later in the season.

Non-native grasses are disadvantaged to some degree in climates with extended growing seasons (Jackson and Roy 1986). Unable to tolerate extended drought periods non-native grasses are drought evaders (Ewing and Menke 1983, Bick 1993). They grow during periods of high moisture availability and often senesce while soil moisture levels are still moderately high (Jackson and Roy 1986). They probably expire in the coastal region while soil moisture levels are still fairly high. Native grasses have longer growing seasons and take advantage of late-season moisture to build carbohydrate reserves and survive the summer drought (Sampson and McCarty 1930, Jackson and Roy 1986). Native grass seed production, seed size, and next year seedling size are all positively effected by abundant late season rainfall (Jackson and Roy 1986).

Native and non-native forbs attain higher relative cover rates in coastal native grass stands because of cooler temperatures, increased precipitation, and reduced non-native grass cover (Cook 1965, Janes 1969, Bartoleme et. al. 1980). A three year study indicated that the most forb rich stands in valley grasslands were found on north slopes during a cool year with abundant early rainfall and a long growing season (Evans et. al. 1975). These conditions mimic those found in the coastal region of the Santa Cruz Mountains where soil moisture stresses are similarly reduced. High forb richness and cover during years with high rainfall in the Santa Cruz Mountain region suggests that soil moisture levels are more limiting for forbs than light levels since annual grass productivity is high in those years as well (pers. obs.).

While both native and non-native forb cover is significantly higher in these grass stands, non-native forbs have about 50% higher cover than native forbs ($n=25$, native forbs, $mn=6.8\%$, $sd=10.5$, non-native forbs, $mn=10.4\%$, $sd=8.8$). Many non-native forbs occur as weeds in agricultural fields and are well adapted to productive environments (Baker 1986, 1989). Greater invasibility has been associated with more fertile sites in California grasslands (McNaughton 1968, Huenneke et. al. 1990) and elsewhere (McIntyre and Lavorel 1996, Stohlgren et. al. 1999). The non-native forb dominance in these stands underscores the degree to which native forbs as well as native grasses have been preempted in their native habitats (Baker 1978, Blumler 1992b).

Root IV: Coastal Prairie II

Root IVa: *Calamagrostis nutkaensis* stands with lower non-native grass cover, higher shrub cover, higher conservation values, and a more localized flora, occur closer to the coast and further from the bay, on sandier, less clay rich soils.

Root IVb: *Hordeum brachyantherum* stands with higher non-native grass cover, lower shrub cover, lower conservation values, and a more widespread species flora, occur further from the coast and closer to the bay, on less sandy, more clay rich soils.

Roots II and III indicated the role that soil texture plays a significant role in native species richness and cover in native grass stands in more mesic regions. Native grass stands on more gravelly substrates contain a more native species rich flora (Root II) - they form conservation hotspots; those on less gravelly substrates have greater native and non-native forb cover but a less rich flora overall (Root III). In this root native grass stands in mesic habitats in two distinctly different environments help to elucidate the factors that regulate native species abundance in this important habitat type.

This root contrasts two rare native grasses that are found in mesic habitats in two radically different environments. One (*Calamagrostis nutkaensis*) is restricted to the cool foggy regions of the bay, while the other (*Hordeum brachyantherum*) is found in bottomland habitats (in weak serpentinite soils) in the arid interior region. One more species (*Festuca rubra*) which occurred too rarely to be included in the canonical correlation, but which co-occurred with *C. nutkaensis* is included in this analysis.

Despite the fact that *C. nutkaensis* and *F. rubra* stands at San Pedro Point, in particular, are bisected and surrounded by a maze of trails which support abundant non-native grass populations, almost no introgression has occurred into the patches themselves. Apparently unless the substrate is directly impacted, the vegetation in these sites is almost impervious to non-native species invasion.

The high site uniqueness values indicate that native species found in *C.*

nutkaensis/*F. rubra* stands rarely occur in other native grass stands in the region. High conservation values indicate that these stands form "hotspots" of native species richness. Over one third of their native species found in these stands had a range of less than five geographic sub-regions (Hickman 1993). Most of the rarer species in both stands were limited to the central and north coastal geographic sub-regions in California.

These small stands exist on the fringes of the grassland environment. This is the only native grass grouping with high shrub cover values. Enveloped on steep slopes within a coastal scrub matrix, *C. nutkaensis* did not occur in any of the habitats thus far reported (beaches, dunes, woodlands (Greene 1993); areas with shallow water tables (Sawyer and Keeler-Wolf 1995). Sharing only 22% (4/18) of the species reported to occur in the *C. nutkaensis* series in the *Manual of California Vegetation*, these stands appeared atypical floristically as well (Sawyer and Keeler-Wolf 1995). Most of the species found within the Santa Cruz Mountain stands are allied with coastal scrub rather than the coastal prairie. Their rarity, small sizes, unusual location, and atypical species composition suggest that the *C. nutkaensis* and *F. rubra* stands in the Santa Cruz Mountain region preserves exist on the fringes of their respective species ranges.

Roots III and IV suggest that native grass cover in coastal prairies is largely a function of soil moisture levels. The most pristine coastal prairie grass stands (*Calamagrostis nutkanensis*, *Festuca rubra*) are found at the wettest end of the moisture gradient (Foin and Hektner 1977, Peart and Foin 1985), and the least pristine (*Danthonia californica*) are found in the most xeric of coastal prairie habitats (see Table 22).

Hordeum brachyantherum stands occur in higher clay and lower sand rich soils in

Table 22.--The Native: Non-Native Species Interface in Coastal Prairie Native Grass Stands

Vegetation Component	<i>Danthonia californica</i> (n=8)	<i>D. caespitosa/ D. californica</i> (n=4)	<i>C. nutkaensis/ Festuca rubra</i> (n=5)
native grass cover	mn=44.5, sd=12.0	mn=75.8, sd=6.6	mn=41.0, sd=5.0
non-native grass cover	mn=38.3, sd=10.1	mn=11.5, sd=1.9	mn=4.3, sd=3.7
native forb cover	mn=2.1, sd=3.1	mn=4, sd=2.9	mn=28.2, sd=7.4
non-native forb cover	mn=12.3, sd=8.9	mn=4, sd=2.2	mn=.6, sd=.9
native shrub cover	mn=.33, sd=.5	mn=0	mn=19.7, ds=10.8
total native cover	mn=46.6	mn=79.8	mn=88.9
total non-native cover	mn= 50.6	mn=15.5	mn=4.2

in a hotter, more xeric environment. These very small stands occur in the midst of non-native grass dominated grasslands. While clay rich soils may be something of a refugia for some native grasses in more arid environments (Robinson 1968, Hull and Muller 1977, Savelle 1977, Bartoleme and Gemmill 1981, Stromberg and Griffin 1996), few other native species are able to persist on them. Non-native grass cover is significantly higher, conservation values and site uniqueness values are significantly lower than in the *C. nutkaensis* stands found in more mesic environments. The paucity of native species in these and other native grass stands in the interior region is striking.

Canonical Correlation II: *Nassella pulchra* Stands in Santa Cruz Mountain Region
Preserves

Root I: Interior and Coastal *N. pulchra* Stands

Root Ia: *Nassella pulchra* stands found less gravelly soils on steeper slopes in more arid environments further from the coast, are smaller, and have lower native grass and non-native forb cover, non-native grass richness, and conservation values, and higher *N. pulchra* and non-native grass cover.

Root Ib: *Nassella pulchra* stands on more gravelly soils on flatter slopes in wetter environments nearer to the coast, are larger, have higher native grass and non-native forb cover, non-native grass richness and conservation values, and lower *N. pulchra* and non-native grass cover.

Nassella pulchra stands occurring in the coastal (and montane) regions are contrasted with those occurring in the interior foothill region in this root. Coastal and interior stands occur in strikingly different climactic and edaphic environments. Coastal stands receive about twice as much rainfall, have a longer growing season, and enjoy a fog laden cool summer climate, while interior stands are much drier, have a shorter growing season and must endure temperatures often twenty degrees hotter during the summer. While coastal stands are found on long, mostly low sloping sandy marine terraces, interior stands are found on steeper slopes in more clay and gravel rich soils.

This root indicates that fundamental differences in habitat preferences exist between *N. pulchra* and the native grasses it co-exists with in the Santa Cruz Mountain. *Nassella pulchra* relative cover peaks in stands found in more arid regions on less gravelly soils on steeper, more southerly facing slopes, and native grass cover peaks in stands

found in more mesic regions on more gravel rich soils on less steep, more northerly facing slopes.

This root also indicates that non-native grass and *N. pulchra* cover are peak in the same environment, suggesting that in the Santa Cruz Mountain region as a whole, *N. pulchra* habitat preferences are closer to those of non-native grasses than native grasses. Lower conservation values in stands with higher *N. pulchra* cover indicate how little allied *N. pulchra* is with much of the native flora.

Climactic conditions on the east side of the Santa Cruz Mountain range undoubtedly play a large role in the increased non-native grass presence in the native grass stands found there. Warmer fall temperatures result in earlier germination times for non-native annual grasses (Young et. al. 1973, Ahmed 1983), most of which have broad germination requirements (Young et. al. 1973, Armstrong and Huennecke 1992), and are therefore well poised to dominate during the all important establishment period (Bartoleme 1979, Young et. al. 1981, Bartoleme and Gemmill 1981). Early germinating species typically garner the lions share of light, soil and moisture resources and tend to become dominant later on if climactic conditions remain stable. Vigorous early growth and an emphasis on shoot production (Pavlik 1983 a,b, Jackson and Roy 1986) allow non-native grasses to establish canopy cover rapidly, thus reducing soil moisture (Robinson 1968, Bartoleme and Gemmill 1981, Holmes and Rice 1996, Dyer and Rice 1999) and light levels (Pavlik 1983 a,b, Dyer et. al. 1996, Dyer and Rice 1999) markedly. *Nassella pulchra* seedlings in dense annual grass dominated environments have low below and

above ground biomass and usually expire before or during the summer drought period (Dyer et. al. 1996).

While interior region stands have greater non-native grass cover, frequent dominance by one non-native grass results in significantly reduced non-native grass richness relative to coastal native grass stands. The two most frequent dominants; *Lolium multiflorum* and *Brachypodium distachyon* form dense stands, and leave behind thick accumulations of thatch which many species find difficult to penetrate (Facelli et. al. 1987). One species dominates non-native grass cover (when dominance is defined as having three times the cover of the next most abundant species) in the majority (56%) of interior region *N. pulchra* stands. McNaughton (1968) also found low evenness in *N. pulchra* patches occurring on sandstone soils in the Santa Clara Valley. The average species richness of the interior region *N. pulchra* (n=40, mn=13.0, s.d.=4.0) is among the lowest recorded for grasslands in the state (White 1967, Savelle 1977, Bartoleme et. al. 1980, Heady et. al. 1991).

That *N. pulchra* stands nearer to the coast are larger and yet have lower average relative cover than more interior stands may seem paradoxical. Several factors may, however, explain this unusual abundance pattern. *Nassella pulchra* may be limited to smaller patches in the interior region because it usually occurs in more mesic habitat types (higher clay soils, slope bottoms, concave sections of slopes- pers. obs), where it is able to compete more effectively with non-native annual grasses. *Nassella pulchra* is almost never found in open grassland environments in the interior region. Instead it occurs in relatively small grasslands interspersed within a grassland/oak woodland matrix.

Nassella pulchra abundance has been linked to more mesic micro-habitats in valley grasslands several times (Robinson 1968, Hull and Muller 1977, Bartoleme and Gemmill 1981, Langstroth 1991, Keeley 1991, 1993, McCarten 1992, but see White 1967). Competition for soil moisture is one of the key processes limiting *N. pulchra* seedling survival (Bartoleme and Gemmill 1981, Jackson and Roy 1986, Holmes and Rice 1996). Robinson (1968) doubted that *N. pulchra* could survive in well-drained areas in the arid climates of the interior Coast Ranges. While mesic micro-environments habitats occur fairly frequently in grasslands in the interior region of the Santa Cruz Mountains, they are limited in extent and so patch size is lower than in the less biotically challenged coastal areas.

Historical factors may also play a role in limiting patch size and location in the interior regions. While most interior rangelands were converted (during the 'decade of wheat'; 1860-1870) to grain crops (Allen 1989, George and Fulgham 1989), dairy farming, a presumably less destructive use, persisted for many years as a major income producer in the coastal regions. *Nassella pulchra* may have been relegated to difficult to cultivate sites (steep slopes, clay-rich soils, etc.) in the interior region (Stromberg and Griffin 1996).

A further complication is the extensive type-conversion that has occurred in the foothill regions. Because all the open grasslands in the interior region occur in the foothills that originally supported chaparral, oak woodland, or savanna vegetation type rather than open grasslands (Broek 1932), it seems likely that most large open grassland areas in the interior region have been type converted (see Chapter 8). *Nassella pulchra*

patches may be largely restricted to small patches in the oak woodland matrix in the interior region because everywhere else either has been cultivated or type converted at some time. While *N. pulchra* in more arid valley grasslands is unable to penetrate formerly cultivated sites, native grasses in the more mesic coastal prairie can do so (see Chapter 9). The coastal grasslands found on the marine terraces may, on the other hand, be natural features.

That native grass and non-native grass cover peaks in the same interior region native grass stands indicates how grass dominated the interior region grasslands of the Santa Cruz Mountains are. The interior regions of the Coast Ranges may contain the most intensely competitive grassland environments found in California. These regions are wetter and have milder (but still warm) summer temperatures than Central Valley grasslands. Winter temperatures in the Santa Cruz Mountain region are mild enough that in warm years annual grasses can flower in the Santa Clara Valley in January (pers. obs). Mild temperatures in Central Valley grasslands are associated with optimum grassland productivity (Pitt and Heady 1978). Grass leaf size and leaf production are positively correlated with temperature and soil nutrient level (Langer 1972). Forb cover in interior region native grass stands is very low, and does not approach that found in Central Valley (Talbot et. al. 1939) or San Diego grasslands (Oberbauer 1978) (see Appendix Three). The very high grass cover, and the dominance of two species rarely mentioned as dominants in other grass environments (*Brachypodium distachyon*, *Lolium multiflorum*) (see Four Non-Natives), suggests that the species composition and structure of Central California grasslands may be substantially different from that of other valley grasslands.

**Root II: *Nassella pulchra* Stands on and off Serpentine Soils and/or
North Facing Slopes in the Interior Region**

Root IIa: *Nassella pulchra* stands found further from the bay on less gravel rich soils on more south-facing slopes, have higher *N. pulchra* and non-native grass cover, non-native grass richness, and lower native forb cover, conservation values and a more common flora.

Root IIb: *Nassella pulchra* stands found closer to the bay on more gravel rich soils on more north-facing slopes have lower *N. pulchra* and non-native grass cover and non-native grass richness, and higher native forb cover, conservation values and a rarer flora.

The plot data indicates that this root primarily differentiates *N. pulchra* stands found on more gravelly soils at serpentine sites, or more north-facing slopes on valley grassland soils, which are closer to the bay, from stands on less gravelly sites on more southerly facing slopes, further from the bay. Because soil nutrient levels were not measured in this study, and they play an important part in determining species composition on serpentine soils, they may confound to some extent the other factors associated with serpentine soils in the correlation. North facing slopes in valley grasslands do harbor more remnants of serpentine grasslands than those on any other aspects (Feidler and Leidy 1987).

This root indicates not only indicates that *N. pulchra*'s habitat preferences are more closely allied with non-native grasses than with native grasses, but that they are not closely allied with other native species found in *N. pulchra* grass stands either. More

northerly facing slopes on more gravel rich soils closer to the bay support native grass stands with more native forb cover and higher conservation values but lower *N. pulchra* cover. The same variables (more gravelly, north facing slopes) were positively correlated with conservation values in the montane region, indicating that these factors play a large role in native forb persistence in valley grasslands in the Santa Cruz Mountain region (Fielder and Leidy 1987, Blumler 1992a, Evans et. al. 1975). Smaller leaves, later growth initiation, and later maturation dates for *N. pulchra* plants from serpentinite soils as opposed to non-serpentinite soils, indicated that serpentine soils are not an optimal environment for it (Huntsinger et. al. 1996).

That conservation values peak in different habitats than does non-native forb cover suggests that native and non-native forbs occupy different niches in the interior regions native grass stands. Mostly originating in the same region (Eurasia) as non-native grasses (Randall et. al. 1998), non-native forbs are most abundant in native grass stands on more productive (less gravelly) soils in more arid habitats (more south facing slopes, further from the bay). Native forbs, many of which are members of the Arcto-tertiary geoflora, are mostly confined to native grass stands in more mesic habitats (gravelly soils on more north-facing slopes closer to the bay) (Cook 1965, Evans et. al. 1975).

Root III: *Nassella pulchra* Stands on Different Soil Textures in the Interior Region

Root IIIa: *N. pulchra* stands found further from the bay on lower clay and higher sand and gravel soils, have lower *N. pulchra* and native grass, and higher non-native grass relative cover.

Root IIIb: *N. pulchra* stands found closer to the bay on higher clay and lower sand and gravel soils, have higher *N. pulchra* and native grass, and lower non-native grass relative cover.

Roots I and II indicated that *N. pulchra*'s habitat preferences were more similar to non-native grasses and forbs than to other native species found in its stands. In Root I *N. pulchra* cover and native grass cover peaked in different environments, and *N. pulchra* was seen to have similar habitat preferences as non-native grasses. By differentiating coastal and montane from interior stands, Root I distinguished broad habitat preferences that operate over the entire Santa Cruz Mountain region. Root II indicated the effects that slope and soil type (serpentinite soils) in the interior region have on conservation values, native forb cover and forb rarity. This root identifies factors that differentiate habitat preferences between native and non-native grasses in the interior region on the more productive soils that *N. pulchra* is usually found on in California.

The interior region with its hotter, more arid summers comes the closest of all the regions in the Santa Cruz Mountains to providing a template for Central Valley and Southern California grasslands. Within this region, the more coarse grained differentiation in habitat preferences between *N. pulchra* and the other native grasses in the Santa Cruz Mountain region at large breaks down, and the broad distributional patterns that characterize the native grass community as a whole in the Central Valley and Southern California type grassland environments becomes apparent.

This root indicates that a shift takes place in the interior region in *N. pulchra*'s abundance patterns relative to those of the native grass community. Within the confines of

the more soil moisture stressed interior region, both *N. pulchra* and native grass cover peaks on more productive (more clay-rich, less sandy, gravelly soils) rather than less productive soils (less clay-rich, sandier and more gravelly) (as in root I), and *N. pulchra* becomes allied with the rest of the native grass community in its habitat preferences. Non-native grass cover peaks in stands on less productive soils (less clay-rich, sandier, more gravelly) found in the hotter sections of the interior region furthest from the bay. As conditions get more arid *N. pulchra*'s limitations as a perennial grass can be clearly seen.

Higher clay soils have been linked to high *N. pulchra* cover before (Robinson 1968, Hull and Muller 1977, Savelle 1977, Bartoleme and Gemmill 1981, Keeley 1991, 1993, Stromberg and Griffin 1996). Because more clay rich soils retain greater soil moisture, moisture stress - a key factor in *N. pulchra* seedling mortality (Dyer et. al. 1996) - is reduced. Slope bottoms - a very common habitat for *N. pulchra*, in the interior region (pers. obs), - are typically clay-rich because the translocation of small clay particles over time results in higher accumulations of clay.

The mesic nature of clay soils in Mediterranean climates has, however, been called into question (Wells 1962, Noy-Meir 1973). Sandy soils are believed to be less xeric than clay soils in arid climates because the rapid water drainage in these soils results in greater water storage in the lower soil regions where evaporation does not occur. Water held near the surface in clay soils is believed to evaporate quickly resulting in, oddly enough, a more xeric environment in the soils which have the greatest moisture-holding capacities (Wells 1962, Noy-Meir 1973, Blumler 1992a). This 'inverse texture' effect explains annual

grass dominance on more clay rich soils and perennial grass dominance on more sandy soils in Mediterranean grasslands (Noy-Meir 1973, Blumler 1992a).

Nassella pulchra's greater cover values on more clay rich soils in the California grasslands indicates that a shift in the distribution patterns between the annual and perennial grass guilds in Mediterranean and California grasslands occurs. The extension of the 'inverse texture' theory to the semi-arid Mediterranean climate of the California Coast Ranges (Wells 1962, Blumler 1992a) suggests that *N. pulchra* stands, which are more abundant on clay soils, have been relegated to a more xeric environment.

That *N. pulchra* would persist in more xeric micro-environments seems untenable, however, for several reasons including its perennial form, its generally coastal distribution, and its longer growing season (Jackson and Roy 1986, Holmes and Rice 1996). *N. pulchra* distribution in the Coast Ranges has been tied in at least one, albeit small study, to clay-rich soils which upon examination proved to be more rather than less mesic than sandier soils at the end of the season (Robinson 1968). Because *N. pulchra* continues soil moisture uptake longer than non-native grasses any soil types which retain soil moisture longer into the season should benefit native grasses (Jackson and Rice 1986, Dyer and Rice 1999)

That clay soils provide more rather than less soil moisture than sandier soils as the growing season progresses was shown when perennial grasses (including *Festuca idahoensis*) had higher growth rates in late spring and early summer on more clay-rich soils than on sandier soils (Borman et. al. 1990, 1992). Soil moisture levels were also higher at the end of the growing season in unvegetated plots on more clay-rich soils, but

were lower on vegetated plots, indicating that not only did clay soils retain more soil moisture during the season, but that perennial grasses were able to extract more moisture from them than from sandy soils (Borman et. al. 1990,1992). Similar findings were found in the western United States, where grasses with longer growing seasons were confined to more clay-rich substrates (Dahl and Tisdale 1975).

The more southerly preserves in the Santa Cruz Mountain region are the first to green up in the fall and first to senesce in the summer (pers. obs.). They have the shortest growing seasons of all the preserves in the Santa Cruz Mountain region (pers. obs.). Non-native grasses, with their shorter life-spans are better adapted to survive the briefer growing seasons found on these preserves (Blumler 1992 a,b). As outlined in root I, non-native grasses, with their broad patterns of seed germination and rapid early growth, are well suited to take advantage of early fall growth periods. Because these preserves brown up so quickly, late season rains which can positively effect a number of factors in native grasses (Jackson and Roy 1986, Dyer et. al. 1996), probably enhance native grass populations less on these preserves than any others. Their sandier, more gravelly soils retain less soil moisture late in the season, as well, resulting in less late season native grass growth (Borman et. al. 1990, 1992). The combination of a more arid climate and a more arid substrate results in stands with lower *N. pulchra* and increased non-native grass cover.

Nassella pulchra and other native grass species have been linked to a variety of mostly unproductive habitat types in the San Francisco Bay area. They include thin rocky soils, road cuts, trail sides, salt windblast zones on sea bluffs, mesic areas, high clay soils,

serpentinite soils and steep north-facing slopes (McNaughton 1968, Edwards and Havlik 1984, Fielder and Leidy 1987, Murphy and Ehrlich 1989, Langstroth 1991). This root (and root II) indicates that infertile substrates in the more arid regions provide a poor growing environment for native grasses. Many sites in the interior region with low non-native grass cover and high forb richness, which appear from a competitive standpoint, to be prime native grass habitats, support no native grasses at all (pers. obs). Within stand abundance in the more arid habitats appears to follow Keeley's model, which postulates greater native grass abundance, as one would expect in a perennial grass, on deeper, more productive soils (Robinson 1968, Keeley 1991, 1993).

Nassella pulchra's historical abundance in the more xeric sections of the Central Valley have been repeatedly been called into question in the last two decades (Bartoleme 1981, Bartoleme and Gemmill 1981, Wester 1981, Edwards 1993, Blumler 1996, Hamilton 1997). The canonical correlation suggests that even within the relatively mild conditions of the Coast Ranges, aridity may play a significant factor in limiting *N. pulchra's* distribution. Native grasses that do persist in shallow rocky soils in the Santa Cruz Mountain region, do so in more mesic environments such as on the ridge tops and north facing slopes in the montane, coastal and bay regions, or on serpentinite soils.

Nassella pulchra: A Grass Apart

Nassella pulchra's ability to persist in environments virtually devoid of other native species indicates how unusual this native grass is. Not only is it much more

abundant than other native grasses but its abundance peaks in habitats that few native species can tolerate? What makes this native grass so different? Some clues may lie in its evolutionary origins.

Stipa, the genus, *N. pulchra* formerly belonged to, recently underwent a significant revision and was splintered into three genera (*Acnatherum*, *Hesperostipa*, *Nassella*). The split occurred because fossil evidence indicates that the species in the new *Nassella* genus are derived from the southern temperate regions while *Stipoid* species evolved in the Eurasian regions (Barkworth and Everett 1987, Stebbins 1998). *Nassella's* evolutionary history then, extends back not to the cool northern temperate regions which fostered the development of most of California's native grassland species (*Bromus*, *Danthonia*, *Elymus*, *Festuca*, *Hordeum*, *Poa*) but to the more tropical southern hemisphere (Stebbins 1998).

Out of the sixty-three native grass genera found in California, *Nassella* is a one of only thirteen which has a primarily southern tending distribution. *Nassella* species found outside of California occur to the east (Texas) and to the south (South America) rather than to the north. The two genera in California *Nassella* is most closely allied with (*Acnatherum*, *Hesperostipa*), find a home not within the coniferous forest and woodland habitats many other native grasses are associated with, but within the more arid sagebrush steppes and pinyon/juniper woodlands of the Great Basin (Barkworth 1993a,c).

Confined to the California Floristic Province, all three native California *Nassella* species have much more restricted ranges than most native grasses found in California (see Appendix Seven) (Barkworth 1993g) suggesting that more than other native grasses,

species in the *Nassella* genera are more tightly adapted to California's climactic and edaphic environments.

Several aspects of *N. pulchra*'s autecology are puzzling given its current dominance in the native grasslands. *Nassella pulchra*'s germination characteristics (Bartoleme and Gemmill 1981, Ahmed 1983), seed morphology (Langstroth 1991), seed size (Stromberg and Griffin 1996), early growth rates (Ahmed 1983), and disturbance tolerance (Ahmed 1983, Langstroth et. al. 1991, Dyer et. al. 1996) suggest that *N. pulchra* has much in common with opportunistic or 'weedy' species and little resembles a dominant or 'climax' grass (Bartoleme and Gemmill 1981).

Opportunistic species are usually short-lived species adapted to colonize sites opened up by disturbances (Baker 1986). They usually produce many small seeds with adaptations for dispersal (burrs, spines, wings, etc.) which allow them to be rapidly dispersed to newly disturbed sites. Maximal seed germination rates occur in the high light conditions found in most disturbed sites. Seed germination is often enhanced by disturbance agents. Seeds of chaparral species, for example, often require fire for maximal germination to occur (Keeley and Nitzberg 1984). Opportunistic species grow rapidly and reproduce quickly before they are dwarfed by the larger, taller species found in later successional stages.

Climax species, on the other hand, are adapted to grow in the sites already colonized by occupied by species. They usually produce larger seeds which are adapted to germinate and grow under a dense canopy layer. They grow less rapidly but are able to overtake successional species because of their larger size. They thrive in more stable habitats.

Nassella pulchra's seed germination characteristics, seed size, and seed morphology are particularly revealing. While *N. pulchra* seeds can germinate in low light conditions, optimal germination rates occur on bare soils with high light levels (Bartoleme and Gemmill 1981). *Nassella pulchra*'s seed size is small relative to most non-native grasses. Its seeds probably lack the resources needed for rapid growth in the low light conditions found under dense grass canopies (Stromberg and Griffin 1996).

Nassella pulchra's awn appears to be particularly poorly adapted to climax grassland environments. *Nassella pulchra* has a long, twisted, and bent hygroscopic awn which penetrates the ground with a corkscrew motion when moistened (Langstroth 1991). Well adapted to less friable patches of soil, *N. pulchra*'s seed is poorly adapted to dense grassland environments where the long awn becomes entangled in litter before it reaches the ground (Langstroth 1991). When it does reach the ground the corkscrew motion of the seed is inhibited by the dense litter accumulations. Grasses adapted to dense grassland environments generally have seeds with short awns which fall unimpeded to the ground. A survey of native and common non-native grasses found in California grasslands and chaparral indicates that species of the *Nassella* genus have particularly long awns relative to other grasses (see Table 23).

Avena spp. have long, hygroscopic awns as well (Holm et. al. 1991). Perhaps more opportunistic than climax species, they may have been the original non-native colonizers of California grasslands. Their early abundance and subsequent decline is a matter of historical record (Robbins 1940, Burcham 1957, 1975) and may reflect their usurpation by more climax type non-native grasses.

Nassella pulchra can be very long lived, but are also well adapted to disturbances, including grazing (Langstroth 1991, Edwards 1992, 1995, Dyer et. al. 1996, Huntsinger et. al. 1997), and fire (Ahmed 1983, Langstroth 1991). *Nassella pulchra*'s high abundance on trailsides – habitats with high disturbance and light intensity – has been noted before (Frenkel 1970, Edwards and Havlik 1984, Edwards 1995, pers. obs).

Nassella pulchra is particularly well adapted to fire. Burning was more effective than grazing in increasing *N. pulchra*'s seedling emergence (Ahmed 1983, Dyer et al.

Table 23: Awn Length in Native and Non-Native Grasses In California Grasslands

Approximate Awn Length	Species
0-5 mm.	Briza spp., Calamagrostis nutkaensis, Dactylis glomerata, Deschampsia caespitosa, Festuca idahoensis, F. rubra, Holcus lanatus, Hordeum brachyantherum, Koeleria macrantha, Leymus spp., Melica spp., Phalaris aquatica, Poa spp., Vulpia bromoides, V. microstachys, V. octoflora
5-10 mm.	Brachypodium distachyon, Bromus hordaceus, Danthonia californica, Vulpia myuros
10-25 mm.	Acnatherum spp., Bromus madritensis, Elymus glaucus, Hordeum marinum
25-50 mm.	Avena barbata, A. fatua, Bromus diandrus, Nassella lepida
30-100+ mm.	Elymus multisetus, Hesperostipa comata, Hordeum jubatum, Nassella cernua, N. pulchra, Taeniatherum caput-medusae

1996). Increased growth rates, tiller production, and root growth after burning were attributed to higher soil temperatures and increased light intensity (Dyer et. al. 1996).

Nassella pulchra's hygroscopic awns may have been particularly beneficial in penetrating the hardened, often crusty soils that fires left behind. If *N. pulchra*'s bunches

in more arid sites are not 'cleaned' regularly by grazing or fire, old culms can block new bud initiation, and the plants will become litter-ridden and senescent (Savelle 1977, Langstroth 1991, Edwards 1992, 1995).

Native grasses in steppe environments are also well adapted to fire (Blank and Young 1989). Heated soils, smoke, and a liquid slurry derived from burned soils applied to seeds from native grasses found in sagebrush steppe communities, resulted in increased seedling emergence and increased leaf production and elongation (Blank and Young 1998). Of the species tested, those from genera most closely allied taxonomically with *Nassella* (*Acnatherum*, *Hesperostipa*), exhibited the most positive response to heating or its equivalents (Blank and Young 1998). Interestingly, burning did not produce positive effects in the only non-native grass tested (Blank and Young 1998). Most of the native grasses in Table 23 with long awns occur in more arid grassland or chaparral environments.

Nassella pulchra was probably an opportunistic species adapted to persist in the openings caused by disturbances in the chaparral and oak woodlands of the Pliocene. As summer rainfall diminished and the vegetation continued to dry out, and lightning fires became more frequent and destructive, *N. pulchra* was able to exploit the ever larger openings available. Extensive burning by Native Americans later further increased its abundance.

Is it possible that there were no native grass species with the characteristics of a climax species, which were adapted to the more arid conditions that ultimately prevailed in California's grasslands (Bartoleme and Gemmill 1981). Historical factors can play a large / role in determining regional species diversity (Ricklef and Schuler 1993). 'Depauperate'

floras and unexploited niches occur in many parts of the world, and can account for much of the success that non-native species have had in the last two hundred years (Ricklefs and Schuler 1993). Many non-native species invasions result because non-natives are able to exploit open niches which the native flora or fauna has been unable to fill (Stohlgren et. al. 1999). In California grasslands, one niche, among others, included early germinating annual grasses able to tolerate dense litter environments.

If 'climax ' type native grass species existed in the California flora, it may be they were part of the Arcto-tertiary geoflora, which was poorly adapted to more arid environments. *Bromus carinatus*, *Calamagrostis nutkaensis*, *Danthonia californica*, *Deschampsia caespitosa* and *Festuca californica* are all tall or densely bunched, short awned native grasses which appear to favor dense grassland environments.

CHAPTER TWELVE

SUGGESTIONS FOR FUTURE RESEARCH

1. Effects of stand size on stand viability should be investigated to determine if reproductive factors (fecundity, seed size, seed viability, seedling vigor, seedling mortality) are effected by the typically small stand sizes.

2. Given native grasses small average stand size and the future perturbations that California grasslands are likely to face as a result of new invaders and climate change, long term monitoring is essential, particularly of the rarer native grasses.

3. Baseline studies and long term monitoring efforts in newly acquired preserves which will undergo changed disturbance regimes are critical to understanding the proper management of public preserves.

4. More regional studies of native grass abundance are needed to identify critically rare native grasses at the regional level, to continue fleshing out native grass abundance patterns statewide, and to continue refining native grass range. After surveys identify native grass stands, sampling should take place to identify the main non-native species invaders. Eventually a list of non-native species invasive in native grass stands as opposed to California grasslands should results. Periodic re-sampling across a wide range of native grass types (and therefore habitats) would identify which native grass stands and types are stable, and which are not, and which invasive species pose the greatest threats.

5. Comparative floristic analyses of native and non-native grass stands are needed to determine if native grass associations harbor distinct assemblages.

6. More studies of the competitive interactions between native grasses and non-native species (particularly of more recent arrivals) are needed to identify the most aggressive invaders. Such studies would particularly benefit land managers of public preserves (especially those managing newer acquisitions) who may be confronted with increased abundances of aggressive invaders because of the changed disturbance regimes which often accompany preserve acquisition.

7. Detailed historical investigations (including surveyors records, land records, old photographs, aerial photographs, interviews, phytolith analyses, etc.) and edaphic analyses, of sets of grasslands with differing native grass resources, would be invaluable in discerning historical and/or edaphic factors which effect native grass abundance. This thesis found that three of the 160 native grass stands contained the majority of native grass area found. Ideally phytolith analyses across a broad range of grassland types would be undertaken to ascertain where native grasses have existed in the past.

8. Taxonomic research into the more morphologically variable native grasses is needed to determine if undifferentiated species or subspecies exist, as has been conjectured.

9. Determining the effects of vegetation conversion and cultivation on native grass abundance will further elucidate patterns of native grass richness and abundance and will aid in determining appropriate sites for restoration work.

APPENDIX ONE

NATIVE GRASSES IN SANTA CRUZ
MOUNTAIN GRASSLANDS, MEADOWS, AND DUNES

Agrostis blasdalei, *A. densiflora*, *A. idahoensis*, *A. microphylla*, *A. pallens*

Alopecurus aequalis, *A. saccatus*

Bromus carinatus var *carinatus*, *B. carinatus* var *maritima*

Calamagrostis koelerioides, *C. nutkaensis*, *C. ophiditis*, *C. stricta* ssp. *inexpansa*

Danthonia californica var *americana*, *D. californica* var *californica*

Deshampsia caespitosa ssp. *caespitosa*, *D. caespitosa* ssp. *holciformis*

Distichlis spicata

Elymus glaucus ssp. *glaucus*, *E. multisetus*, *E. trachycaulus*

Eragrostis mexicana ssp. *mexicana*, *E. mexicana* ssp. *virescens*

E. pectinacea ssp. *pectinacea*

Festuca idahoensis, *F. rubra*

Hordeum brachyantherum ssp. *brachyantherum*, *H. jubatum*

Koeleria macrantha

Leymus condensatus, *L. mollis*, *L. multiflorus*, *L. pacificus*, *L. triticoides*,

L. vancouverensis

Melica californica, *M. geyeri*, *M. harfordii*, *M. imperfecta*

Nassella cernua, *N. lepida*, *N. pulchra*

Phalaris arundinacea, *P. californica*, *P. douglasii*, *P. secunda* ssp. *secunda*, *P.*

tenerrima, *P. unilateralis*

Puccinella nutkaensis, *P. nuttaliana*

Vulpia microstachys var *ciliata*, *V. microstachys* var *confusa*, *V. microstachys* var

microstachys, *V. microstachys* var *octoflora*

APPENDIX TWO

**NATIVE GRASS STAND ABUNDANCE
IN PRESERVES IN THE SANTA CRUZ MOUNTAIN REGION**

<u>Region/Preserve</u>	<u>C/I**</u>	<u>Grass Area Surveyed***</u>	<u>Native Grass Area</u>	<u>% Native Grass</u>
<i>Interior Region</i>				
Almaden Quicksilver CP****.	I	60	0.2	0.1
Arastradero Preserve	C	160	0.3	0.2
Calero Reservoir CP	C	160	1.3 (1.6)*	1.0
Edgewood CP	I	40	0.1	0.3
Fremont Older OSP.	C	40	0	0
Rancho San Antonio CP/OSP.	C	80	1 (1.2)	1.5
Santa Teresa CP	C	360	0.9 (1.2)	0.3
Sierra Azul OSP.	C	10	0	0
Stanford Academic Reserve	C	<u>160</u>	<u>3.0 (3.6)</u>	<u>1.5</u>
		1070	7.4	0.7
<i>Interior region (serpentinite soils)</i>				
Edgewood County Park	C	40	30	>85
Santa Teresa County Park.	C	3	1.85	>85
Sierra Azul Open Space Preserve (Mt Umunhum).	C	0.2	0.1	>50
Water Department lands	C	<u>30</u>	<u>1 (15)</u>	<u>≥50</u>
		78	47	>50%
<i>Montane Region</i>				
Long Ridge OSP	I	40	1.2 (2)	5.0
Los Trancos OSP.	I	20	0 (.8)	4.0
Monte Bello OSP.	C	360	1.2	0.3
Russian Ridge OSP	C	320	0.5 (2)	0.5
Saratoga Gap OSP.	C	20	0	0
Skyline Ridge)SP	C	40	0.1	0.25
Windy Hill OSP.	C	160	0	0

Wunderlich CP.	C	<u>10</u> 990	<u>.4</u> 6.9	<u>4.4</u> 0.7
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Coastal region

Ano Nuevo/ Cascade Ranch SP.	I	120	20	25
University of California at Santa Cruz.	C	200	0.8 (2.0)	2
Wilder Ranch SP.	C	<u>450</u> 780	<u>6.5</u> 28.5	<u>1.5</u> 3.7

Bay region

Milagra Ridge NRA	C	70	0.6	0.9
San Bruno CP/SP.	I	140	1.8	1.3
San Pedro Point	C	0.2	0.2	100
Sweeney Ridge NRA	C	<u>20</u> 230	<u>0.4</u> 2.9	<u>2.2</u> 1.3
Total - Non-Serpentine Stands . . .		3040	46	1.5
- Serpentine Stands.		<u>80</u>	<u>47</u>	<u>≥50</u>
Total		@ 3120	@ 93	@ 3

*() includes native grass stands noted during the survey but not sampled

**survey complete (C) or incomplete (I)

***all area in hectares

****abbreviations - CP= County Park, SP = State Park, OSP = Open Space
Preserve, NRA=National Recreation Area

APPENDIX THREE

FREQUENCY AND MEAN RELATIVE COVER OF THE MOST
COMMONLY OCCURRING NON-NATIVE GRASSES AND FORBS
IN NATIVE GRASS STANDS IN SANTA CRUZ MOUNTAIN REGION PRESERVES

Non-Native Grasses

<u>Species</u>	<u>Number of Occurrences</u>	<u>Mean Relative Cover</u>	<u>Standard Deviation</u>
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INTERIOR REGION (n= 60)

<i>Bromus hordaceous</i>	44	9.2	6.3
<i>Lolium multiflorum</i>	41	12.0	12.0
<i>Avena fatua</i>	41	11.4	14.6
<i>Brachypodium distachyon</i>	33	27.8	22.0
<i>Bromus diandrus</i>	26	4.5	6.3
<i>Avena barbata</i>	19	10.0	11.3
<i>Vulpia bromoides</i>	11	2.8	1.5

INTERIOR SERPENTINE (n= 18)

<i>Lolium multiflorum</i>	22	22.7	16.5
<i>Bromus hordaceous</i>	17	6.8	6.3
<i>Avena barbata</i>	8	4.1	6.6
<i>Bromus diandrus</i>	8	3.7	6.1

MONTANE (n=40)

<i>Bromus hordaceous</i>	39	7.5	6.1
<i>Vulpia bromoides</i>	34	5.0	4.2
<i>Avena barbata</i>	28	4.8	4.6
<i>Bromus diandrus</i>	28	7.1	7.6
<i>Brachypodium distachyon</i>	12	4.4	4.6
<i>Lolium multiflorum</i>	7	1.7	2.4

COASTAL (n=20)

<i>Bromus hordaceous</i>	12	2.3	1.9
<i>Lolium multiflorum</i>	11	6.0	7.9
<i>Holcus lanatus</i>	10	2.9	4.4
<i>Briza major</i>	9	5.9	7.9
<i>Avena barbata</i>	8	5.7	7.6

<i>Brachypodium distachyon</i>	7	29.7	13.2
<i>Vulpia bromoides</i>	7	8.3	4.2

BAY (n= 25)

<i>Aira caryophylla</i>	14	7.5	6.4
<i>Vulpia bromoides</i>	14	10.4	9.2
<i>Bromus hordaceus</i>	11	2.5	3.4
<i>Brachypodium distachyon</i>	9	24.7	27.8
<i>Avena fatua</i>	9	7.2	5.4
<i>Bromus diandrus</i>	8	2.9	3.7
<i>Avena barbata</i>	7	8.9	10.9
<i>Lolium multiflorum</i>	6	3.2	3.8

Non-Native Forbs

<u>Species</u>	<u>Number of Occurences</u>	<u>Mean Relative Cover</u>	<u>Standard Deviation</u>
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INTERIOR (n=60)

<i>Centaurea solstitialis</i>	20	3.4	4.9
<i>Carduus pycnocephalus</i>	18	5.1	7.3
<i>Erodium botrys</i>	14	3.3	4.1
<i>Crepis vesicaria</i> ssp. <i>taraxacifolia</i>	10	2.1	2.9
<i>Geranium dissectum</i>	9	3.7	3.7
<i>Torilis nodosa</i>	8	1.8	2.4
<i>Brassica nigra</i>	6	3.0	.5

INTERIOR SERPENTINE (n=18)

<i>Centaurea solstitialis</i>	3	1	1
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MONTANE (n=40)

<i>Rumex acetosella</i>	29	3.7	4.2
<i>Geranium dissectum</i>	27	4.0	3.2
<i>Crepis vesicaria</i> ssp. <i>taraxacifolia</i>	16	3.6	3.5
<i>Sonchus asper</i>	12	.3	.5

<i>Torilis nodosa</i>	9	1.8	2.2
<i>Centaurea solstitialis</i>	8	1.0	3.9
<i>Carduus pycnocephalus</i>	8	.6	1.2

COASTAL (n= 20)

<i>Sonchus asper</i>	15	1.3	2.1
<i>Rumex acetosella</i>	14	1.8	1.9
<i>Linum bienne</i>	14	.7	.9
<i>Hypochaeris radicata</i>	14	.3	.6
<i>Geranium dissectum</i>	12	2.8	3.5
<i>Anagallis arvensis</i>	12	.6	.4
<i>Plantago lanceolata</i>	9	4.1	5.9
<i>Cirsium vulgare</i>	9	.7	.5
<i>Carduus pycnocephalus</i>	8	.5	.5

BAY (N=25)

<i>Rumex acetosella</i>	10	1.3	.8
<i>Anagallis arvensis</i>	8	0	0
<i>Sonchus asper</i>	7	3.1	4.8
<i>Cardus pycnocephalus</i>	7	.6	.5
<i>Erodium botrys</i>	6	2.7	4.4
<i>Urospermum picroides</i>	6	1.7	1.4

APPENDIX FOUR

CANONICAL LOADINGS

Canonical Correlation I: Root I

Physical Variables

slope.	.347*
cose	.278
precipitation	-.269
distance to the coast	.205
sand	.080
clay.	-.195
gravel	.269
rock	.956*

Vegetation Variables

native grass cover.	.050
non-native grass cover	.256
native forb cover.	-.397*
non-native forb cover.	.276
shrub	-.074
conservation value.	-.323*
rarity	.109
<i>Bromus carinatus</i> .**	.149
<i>Calamagrostis nutkaensis</i>	-.224
<i>Danthonia californica</i>	.183
<i>Deschampsia caespitosa</i>	.098
<i>E. multisetus</i>	-.059
<i>Hordeum brachyantherum</i>	-.052
<i>Leymus mollis</i>	-.004
<i>L. triticoides</i>	.094
<i>Melica torreyana</i>	-.824*
<i>Nassella pulchra</i>	.112

*>.300 used in analysis

**relative cover

Canonical Correlation I: Root II***Physical Variables***

slope.	.326*
cose.	.407*
precipitation	.763*
distance to the coast	-.008
distance to the bay.	-.435*
sand	-.271
clay.	.170
gravel	.351*
rock	.053

Vegetation Variables

native grass cover	-.335*
non-native grass cover.	.021
native forb cover.	.210
non-native forb cover.	.202
shrub	.067
conservation value.	.507*
rarity	-.053

<i>Bromus carinatus</i> .**	.510*
<i>Calamagrostis nutkaensis</i>	.228
<i>Danthonia californica</i>	-.139
<i>Deschampsia caespitosa</i>	-.150
<i>Elymus glaucus</i>	.343*
<i>E. multisetus</i>	.329*
<i>Hordeum brachyantherum</i>	-.117
<i>Leymus molli s.</i>	-.260
<i>L. triticoides</i>	-.263
<i>Melica torreyana</i>	-.071
<i>Nassella pulchra</i>	-.353*

*>300, used in analysis

** relative cover

Canonical Correlation I: Root III***Physical Variables***

slope.	-515*
cose.	.016
precipitation.	.520*
distance to the coast	-.361*
distance to the bay.	-.536*
sand.	.222
clay.	-.153
gravel.	-.434*
rock.	.022

Vegetation Variables

native grass cover.	.153
non-native grass cover.	-.459*
native forb cover.	.411*
non-native forb cover.	.373*
shrub.	-.282
conservation value.	.198
rarity.	-.030
<i>Bromus carinatus</i> *.	.178
<i>Calamagrostis nutkaensis</i>	-.284
<i>Danthonia californica</i>	.544*
<i>Deschampsia caespitosa</i>	.349*
<i>Elymus glaucus</i>	.178
<i>E. multisetus</i>	.044
<i>Hordeum brachyantherum</i> . . .	-.009
<i>Leymus mollis</i>	.462*
<i>L. triticoides</i>	-.147
<i>Melica torreyana</i>	.098
<i>Nassella pulchra</i>	-.603*

*>.300, used in analysis

**relative cover

Canonical Correlation I: Root IV

Canonical loadings:

Physical Variables

slope.	-.214
cose.	.231
precipitation.	-.115
distance to the coast.	.774*
distance to the bay.	-.452*
sand	-.396*
clay.	.507*
gravel.	.071
rock	-.118

Vegetation Variables

native grass cover	-.270
non-native grass cover.	.529*
native forb cover.	-.224
non-native forb cover	-.077
shrub.	-.558*
conservation value.	-.482*
rarity.	-.607*
<i>Bromus carinatus</i> .*.	-.046
<i>Calamagrostis nutkaensis</i>	-.462*
<i>Danthonia californica</i>	-.154
<i>Deschampsia caespitosa</i>	-.095
<i>Elymus glaucus</i>	.236
<i>E. multisetus</i>	.031
<i>Hordeum brachyantherum</i>	.517*
<i>Leymus mollis</i>	-.281
<i>L. triticoides</i>	-.003
<i>Melica torreyana</i>	.050
<i>Nassella pulchra</i>	.015

*>.300 used in analysis

**relative cover

Canonical Correlation II: Root I***Physical Variables***

slope	.411*
cose.	-.135
precipitation	-.750*
distance to the coast	.548*
distance to the bay	.037
sand.	.173
clay	.211
gravel.	-.450*

Vegetation Variables

patch size	.380*
conservation value.	.346*
native grass cover	.385*
non-native grass cover.	-.511*
native forb cover.	.164
non-native forb cover.	.473*
non-native grass richness	.556*
forb rarity	-.143
<i>Nassella pulchra</i>	-.334**

* indicates significant variable (>.300)

**relative cover

Canonical Correlation II: Root II***Physical Variables***

slope	.253
cose	-.462*
precipitation.	.202
distance to the coast.	.262
distance to the bay	.594*
sand	.232
clay.	.198
gravel	-.738*

Vegetation Variables

patch size.	.007
conservation value	-.619*
native grass cover.	.038
non-native grass cover	.349*
native forb cover.	-.736*
non-native forb cover	.106
non-native grass richness.	.431*
forb rarity.	.685*
 <i>Nassella pulchra</i>	 .381**

* indicates significant variable (>.300)

** relative cover

Canonical Correlation II: Root III***Physical Variables***

slope	.251
cose	-.168
precipitation	.139
distance to the coast	.089
distance to the bay	.594*
sand.	.312*
clay.	-.309*
gravel	.426*

Vegetation Variables

patch size.	.123
conservation value.	.056
native grass cover.	.572*
non-native grass cover	-.436*
native forb cover	.206
non-native forb cover.	.022
non-native grass richness	.071
forb rarity.	-.270
 <i>Nassella pulchra</i>	 .649**

* indicates significant variable (>.300)

APPENDIX FIVE

FLORA

<u>Species</u>	<u>Native/Non-native</u>	<u>Range*</u>
<i>Abronia latifolia</i>	n	3+
<i>Acaena pinnatifida</i>	n	3
<i>Acer macrophyllum</i>	n	17+
<i>Achillea millefolium</i>	n	23+
<i>Achyrachaena mollis</i>	n	17+
<i>Agoseris aparagoides</i> var.		
<i>aparagoides</i>	n	3
<i>Agoseris grandiflora</i>	n	15+
<i>Agrostis densiflora</i>	n	3
<i>A. microphylla</i>	n	4+
<i>A. pallens</i>	n	17+
<i>A. stolonifera</i>	non	12+
<i>Aira caryophylla</i>	non	10 +
<i>Aira elegantissima</i>	non	4
<i>Allium fimbriatum</i> var.		
<i>fimbriatum</i>	n	14+
<i>A. lacunosum</i> var.		
<i>lacunosum</i>	n	4
<i>A. serra</i>	n	3
<i>Ambrosia chamissonis</i>	n	4+
<i>Ammophila arenaria</i>	non	3
<i>Amsinckia lycopsoides</i>	n	17+
<i>A. menziesii</i> var.		
<i>intermdia</i>	n	24+
<i>menziesii</i>	n	24+
<i>Anagalis arvensis</i>	non	17+
<i>Anaphalis margaritacea</i>	n	10+
<i>Angelica hendersonii</i>	n	2
<i>Anseria chamissonis</i>	n	4+
<i>Arctostaphylos imbricata</i>	n	1
<i>Arrhenatherum elatius</i>	non	9+
<i>Aster chilensis</i>	n	7+
<i>Artemesia californica</i>	n	8+
<i>A. pycnocephala</i>	n	2+

* number of subregions (Hickman 1993)

Astragalus gambelianus	n	17+
Avena barbata	non	19+
A. fatua	non	19
A. sativa	non	17
Baccharis pilularis	n	10+
Bellardia trixago	non	3
Brachypodium distachyon	non	10
Brassica nigra	non	17
Briza major	non	6
B. minor	non	8+
Brodiaea coronaria ssp.		
coronaria	n	5
B. elegans ssp. elegans	n	6+
B. terrestris ssp.		
terrestris	n	8+
Bromus carinatus	n	22
B. diandrus	non	24 +
B. hordaceus	non	24 +
B. japonicus	non	24 +
B. madritensis	non	24 +
B. tectorum	non	24+
B. trinii	non	16+
Cakile maritima	non	3+
Calamagrostis nutkaensis	n	3
Calochortus albus	n	5
C. luteus	n	10
C. superbus	n	11
C. venustus	n	6
Calycadenia		
multiglandosa	n	8+
Calystegia collina ssp.		
collina	n	2
C. macrostegia ssp.		
cyclostegia	n	2
C. purpurata	n	9
C. subacaulis ssp.		
subacaulis	n	2
Camissonia cheiranthifolia		
ssp. cheiranthifolia	n	3
C. ovata	n	6+
C. strigulosa	n	11+
Carduus pycnocephalus	non	5+

<i>C. tenuiflorus</i>	non	10
<i>Carex</i> spp.	n	
<i>Carpobrotus edulis</i>	non	4+
<i>Castilleja applegatei</i>	n	24+
<i>C. densiflora</i>	n	9
<i>C. exserta</i> ssp.		
<i>exserta</i>	n	13+
<i>C. latifolia</i>	n	1
<i>C. rubicunda</i> ssp.		
<i>lithospermoides</i>	n	2*
<i>C. wightii</i>	n	3
<i>Caulanthus coulteri</i> var.		
<i>lemmonii</i>	n	4
<i>Ceanothus thyrsiflorus</i>	n	5+
<i>Centaurea melitensis</i>	non	20
<i>C. solstitialis</i>	non	17+
<i>Chlorogalum pomerid-</i>		
<i>ianum</i>	n	14+
<i>C. pomeridianum</i> var.		
<i>divercatum</i>	n	2
<i>Cirsium quercetorum</i>	n	5
<i>C. vulgare</i>	non	18+
<i>Clarkia gracilis</i> ssp.		
<i>gracilis</i>	n	7+
<i>C. densiflora</i>	n	8
<i>C. purpurea</i> ssp.		
<i>quadrivulnera</i>	n	17+
<i>C. rubicunda</i>	n	2
<i>Claytonia exigua</i> ssp.		
<i>exigua</i>	n	11+
<i>C. perfoliata</i> ssp.		
<i>perfoliata</i>	n	22+
<i>Conium maculatum</i>	non	17+
<i>Convulvus arvensis</i>	non	24+
<i>Crepis bursiflora</i>	non	1
<i>C. capillaris</i>	non	9
<i>C. vesicaria</i> ssp.		
<i>taraxacifolia</i>	non	3
<i>Cynosaurus echinatus</i>	non g	8+
<i>Dactylis glomerata</i>	non g	21+
<i>Danthonia californica</i>	ng	14+
<i>Daucus carota</i>	non	9+
<i>D. pusillus</i>	n	14

Delphinium decorum ssp.		
tracyi	n	4*
D. gracilentum		
(=patens patens?)	n	2*
D. variegatum		
ssp. variegatum	n	7
Deschampsia caespitosa		
ssp. caespitosa	n	11+
Dichelostemma capitatum		
var. capitatum	n	24+
D. congestum	n	6*+
Dipsacus sativa	non	5
Disticchlis spicata	n	24+
Elymus glaucus	n	24+
E. glaucus		
ssp. virescens	n	5+
E. multisetus	n	24 +
Ericameria ericoides	n	4
Erigeron glaucus	n	4+
Eriogonum latifolium	n	2+
E. nudum var		
auriculatum	n	6
E. nudum var. nudum	n	9+
Eriophyllum confertiflorum		
var. confertiflorum	n	9
E. staechadifolium	n	3+
Eryngium armatum	n	2
Erodium botrys	non	17
E. brachycarpum	non	17+
E. cicutarium	non	24+
E. macrophyllum	n	7+
E. malacroides	non	2
E. moschatum	non	17
Eschscholzia californica	n	18+
Festuca californica	n	12+
F. idahoensis	n	13+
F. rubra	n	11+
Foeniculum vulgare	non	17
Fragaria chiloensis	n	2+
Galium aparine	n	17+
G. californicum ssp.		

californicum	n	3
G. parisiense	non	6
G. triflorum	n	9
Gastridium ventricosum	non	18+
Geranium bicknelli	n	5+
G. dissectum	non	17+
G. molle	non	24+
Gnaphalium		
G. californicum	n	15+
G. canescens ssp.		
beneolens	n	10
G. ramosissimum	n	10
Grindelia camporum var.		
camporum	n	9
G. hirsutula var.		
hirsutula	n	4
G. stricta var. platyphylla	n	4
G. stricta var. stricta	n	1+
Heracleum lanatum	n	21+
Hesperolinon		
micranthum	n	17+
Heteromeles arbutifolia	n	17+
Heterotheca sessiflora ssp.		
bolanderi	n	2
Heuchera micrantha	n	11+
Holcus lanatus	non	23+
Hordeum		
brachyantherum	n	21+
H. marinum ssp.		
gussoneanum	non	24+
H. murninum ssp.		
murinum	non	24+
Horkeila californica	n	7
H. californica ssp.		
californica	n	2
H. marinensis	n	2
Hypochaeris radicata	non	10
Iris longipetala	n	4
I. purdyi	n	4*
Juncus balticus	n	24+
J. effusus var. pacificus	n	21+

<i>J. leseurii</i>	n	2
<i>J. mexicanus</i>	n	23+
<i>J. patens</i>	n	9+
<i>J. phaeocephalus</i> var.		
<i>paniculatus</i>	n	5
<i>Juglans regia</i>	non	9+
<i>Koeleria macrantha</i>	n	15+
<i>Lactuca saligna</i>	non	5
<i>L. serriola</i>	non	24
<i>Lamium purpureum</i>	non	2+
<i>Lasthenia californica</i>	n	18+
<i>L. glabrata</i> ssp.		
<i>glabrata</i>	n	11
<i>L. micrantha</i> ssp. <i>micrantha</i>	n	2
<i>Lathyrus cicera</i>	non	17
<i>L. vestitus</i>	n	10
<i>Layia platyglossa</i>	n	12
<i>Leontodon taraxacifolia</i> ssp.		
<i>longistiros</i>	non	8
<i>Leymus condensatus</i>	n	9+
<i>L. mollis</i>	n	2+
<i>Lxmultiflorus</i>	n	4
<i>L. triticoides</i>	n	21+
<i>Lessingia hololeuca</i>	n	3
<i>Ligusticum apiifolium</i>	n	2+
<i>Linanthus ambiguus</i>	n	2
<i>L. androsaceus</i>	n	2
<i>L. bicolor</i>	n	6
<i>L. parviflorus</i>	n	17+
<i>Linum bienne</i>	non	2+S\
<i>Lolium multiflorum</i>	non	21+
<i>L. perenne</i>	non	21+
<i>Lomatium utriculatum</i>	n	17+
<i>Lonicera hispidula</i> var.		
<i>vaccillans</i>	n	13+
<i>Lotus corniculatus</i>	non	21+
<i>L. formosissimus</i>	n	5
<i>L. humistratus</i>	n	23
<i>L. micrantha</i>	n	9+
<i>L. scoparius</i>	n	8+
<i>L. strigosus</i>	n	17
<i>L. wrangelianus</i>	n	17+

Lupinus adsurgens	n	4+
L. albifrons ssp		
albifrons	n	6
L. albifrons ssp. collinus	n	7
L. arboreus	n	2
L. bicolor	n	17+
L. formosus var		
formosus	n	17+
L. nanus	n	17+
L. variicolor	n	2
Lythrum californicum	n	15+
L. hyssopifolium	non	17+
Madia gracilis	n	19+
M. sativa	n	10+
Medicago lupinula	non	21+
M. polymorpha	non	17+
Melica californica	n	9
M. torreyana	n	9
Melilotus alba	non	21+
M. indica	non	21
M. officinalis	non	21+
Mentha spicata var spicata	non	17+
Mimulus aurantiacus	n	17
Monardella douglassii ssp.		
douglasii	n	3
M. undulata	n	2
M. villosa ssp.		
franciscana	n	3
M. villosa ssp. ovilosa	n	6
Muilla maritima	n	13
Naseslla lepida	n	10
N. pulchra	n	13
Onopordium acanthium ssp.		
acanthium	non	18
Oxalis laxa	non	2
O. pes-caprae	non	6
Panicum acuminatum var.		
acuminatum	n	17+
Parentucellia viscosa	non	2
Pellea andromedifolia	n	12

Pentachaeta bellidiflora	n	1
Pentagramma triangularis		
ssp. triangularis	n	19+
Perideridia kelloggii	n	5
Perideridia spp.	n	
Phacelia imbricata var.		
imbricata	n	9+
Phalaris aquatica	non	8+
P. paradoxa	non	6*
Picris echoides	non	17+
Plagiobothrys glytocalpus		
var. glyptocarpus	n	6*
P. nothofulvus	n	17+
Plantago erecta	n	17+
P. lanceolata	non	17+
P. major	non	17+
P. maritima	n	4+
P. ovata	n	11+
P. subnuda	n	5+
P. virginica	non	2+
Platystemon californica	n	22+
Polypodium californicum	n	6+
Prunella vulgaris var.		
lanceolata	n	18+
Poa secunda	n	24+
P. tenerrima	n	4
P. unilateralis	n	3*
Polygala californica	n	8+
Polypogon australis	non	9+o
Pteridium aquilinum var.		
pubescens	non	16+
Quercus agrifolia	n	8
Q. berberidifolia	n	9+
Q. douglasii	n	17+
Q. lobata	n	12
Ranunculus californicus	n	17+
Raphanus sativus	non	17+
Rhamnus californica	n	10+
Rubus discolor	non	17+
R. ursinus	n	17+
Rumex acetosella	non	17+
R. conglomeratus	non	17

<i>R. crispus</i>	non	24+
<i>R. pulcher</i>	non	24
<i>Salvia spathacea</i>	n	6
<i>Sanguisorba minor</i> ssp.		
<i>muricata</i>	non	16+
<i>Sanicula bipinnatifida</i>	n	13+
<i>S. crassicaulis</i>	n	11+
<i>Scandix pecten-veneris</i>	non	17
<i>Scrophularia californica</i>		
ssp. <i>californica</i>	n	3+
<i>Sedum spathulifolium</i>	n	12+
<i>Senecio vulgaris</i>	non	21
<i>Sherardia arvensis</i>	non	6
<i>Sidalcea diploscypha</i>	n	6
<i>S. malvaeflora</i> ssp.		
<i>lacinata</i>	n	5
<i>S. malvaeflora</i> ssp.		
<i>malvaeflora</i>	n	6
<i>S. malvaeflora</i> ssp.		
<i>purpurea</i>	n	2
<i>Silene gallica</i>	non	17+
<i>Silybum marianum</i>	non	7
<i>Sinapis arvensis</i>	non	16+
<i>Sisyrinchium bellum</i>	n	24+
<i>Solanum douglasii</i>	n	10+
<i>Sonchus asper</i> ssp. <i>asper</i>	non	24+
<i>S. oleraceus</i>	non	24+
<i>Stachys ajugoides</i>		
var. <i>rigida</i>	n	24+
<i>S. bullata</i>	n	7
<i>Streptanthus albidus</i> ssp.		
<i>peramoenus</i>	n	2
<i>Symphiocarpus albus</i> var.		
<i>laevigatus</i>	n	13+
<i>Taeniatherum caput-medusae</i>	non	9+
<i>Torilis nodosa</i>	non	14
<i>Toxicodendron diversilobum</i>	n	17+
<i>Tragopogon porriflorus</i>	non	21
<i>Trichostema lanceolatus</i>	n	24
<i>Trifolium albopurpureum</i>		
var. <i>albopurpureum</i>	n	17+

<i>T. barbigerum</i>	n	10+
<i>T. campestre</i>	non	10+
<i>T. depauperatum</i> ssp. <i>depauperatum</i>	n	7+
<i>T. dubium</i>	non	17
<i>T. gracilentus</i>	n	24+
<i>T. microdon</i>	n	10+
<i>T. microcephalon</i>	n	12+*
<i>T. oliganthum</i>	n	9+
<i>T. variegatum</i>	n	18+
<i>T. wildenovii</i>	n	17+s
<i>Tritelia hyacinthina</i>	n	12+
<i>T. ixoides</i> ssp. <i>ixoides</i>	n	3
<i>T laxa</i>	n	12+
<i>Urospermum picriodes</i>	non	2
<i>Vaccinium ovatum</i>	n	10+
<i>Vicia americana</i> var. <i>americana</i>	n	17+
<i>V. hirsuta</i>	non	7
<i>V. lathyroides</i>	non	2*
<i>V. sativa</i> ssp. <i>nigra</i>	n	17+
<i>V. sativa</i> ssp. <i>sativa</i>	non	17+
<i>V. villosa</i> ssp. <i>villosa</i>	non	17+
<i>Viola pedunculata</i>	n	9
<i>V. purpurea</i>	n	18+
<i>Vulpia bromoides</i>	non	17+
<i>V. microstachys</i> var. <i>microstachys</i> var. <i>pauciflora</i>	n n	24+ 20+
<i>V. myuros</i> var. <i>myuros</i>	non	17+
<i>V. octoflora</i> var. <i>octoflora</i>	n	14+
<i>Wyethia glabra</i>	n	2
<i>W. helenoides</i>	n	3
<i>Yabea microcarpa</i>	n	17+
<i>Zigandenus venenosus</i> var. <i>venenosus</i>	n	16+

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