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Trends in Vegetation Changes with Removal of Feral Animal Grazing Pressures on Santa Catalina Island

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Abstract. On the west end of Santa Catalina Island, feral animal control and removal programs have been ongoing for the past several years. Recently, increased efforts have greatly reduced the impact of nonnative grazers upon the vegetation of this region of the island. In 1990, we established for the Santa Catalina Island Conservancy a vegetation recovery monitoring protocol for the island's west end. This paper reports the analysis of data for 1990–1993. We conducted our analysis through stratification of the vegetation into 6 community types. Changes have varied according to community types. Vegetative cover has increased overall on the west end, mostly due to a steady increase in cover of introduced annual species. Especially important has been the increase in ground cover and the decrease of bare ground. Changes in species frequency and species diversity have also occurred. Considering all measured plots, the total number of species has almost doubled; most of this has been due to an increase in the number of native species.

Keywords: Santa Catalina Island; California Channel Islands; feral animals; feral goats; vegetation recovery; restoration; monitoring.

Introduction

Introduced species have impacted biotas worldwide (Duffy 1988; Soulé 1990). Concerns arise when these impacts involve negative effects upon native organisms (Soulé 1990; Temple 1990). Islands have been especially susceptible to invasion by nonnative species (Carlquist 1974; Brockie et al. 1988; Vitousek 1988), as have remnant continental ecosystems with island-like characteristics (Shafer 1990; Temple 1990). One important disruption of natural interactions within island ecosystems has been the introduction of grazing domestic mammals. Two species, sheep and goats, from unmanaged populations that all too often became feral, are now problems of worldwide significance (Rudge 1984). Island ecosystems are especially vulnerable because indigenous vegetation evolved in the absence of large grazing mammals (Carlquist 1974).

The vegetation of several of California's Channel Islands has been severely degraded by introduced animal populations. Historically, no large native grazing mammals have been documented, only small herbivores, mice and ground squirrels, and the fruit-eating island fox (Von Bloker 1967). Prehistorically, fossil evidence indicates only 1 large grazer on the northern Channel Islands, the dwarf mammoth (Cushing et al. 1984).

This grazing-free regime ended when Mexican landowners established ranching on these islands in the mid-1800s. Though specific earliest introduction dates are usually undocumented, by about 1860 most of the larger Channel Islands had cattle, horses, sheep, pigs, and/or goats on them (Coblentz 1977; Brumbaugh 1980) Later introductions included bison, deer, elk, burros, and rabbits on some islands (Von Bloker 1967). Many of these introduced animals established wild or feral populations on these islands, due in part to the ruggedness of island terrain, and in part to rangeland management strategies (or the lack thereof). The effects of feral animal populations on ecosystems of the Channel Islands have included reduced foliar cover, reduced species richness, and virtually no survivorship of propagules (Hobbs 1978, 1980; Hochberg et al. 1979; Brumbaugh 1980, 1983; Leishman 1980; Van Vuren and Coblentz 1987), along with increased erosion, loss of top soil (Brumbaugh 1980, 1983), and disturbance to cultural resources (Van Vuren 1982). Removal of feral animal populations from several of the Channel Islands has proceeded to differing degrees (Sterner and Barrett 1991; Schuyler, in press; C. Lombardo 1993, pers. comm.) and initial results indicate increased vegetative vigor, especially in basal sprouting, and increased vegetative ground cover (Coblentz 1977; Wehtje 1991; Klinger, this volume).

The focus of this paper is a preliminary evaluation of vegetation pattern changes following grazing reduction on the west end of Santa Catalina Island, 1 of the southern Channel Islands. On this island, feral and unmanaged populations include goats, pigs, and deer, whereas cattle, horses, and bison were and continue to be actively managed by the Santa Catalina Island Conservancy.

The impact of feral animal populations on Santa Catalina Island's vegetation has varied in differing parts of the island due to several factors including (1) grazing behavior, (2) length of time in area, (3) vegetation type grazed, (4) climatic fluctuations, (5) susceptibility of given terrain to erosion, (6) ruggedness and accessibility of terrain, and (7) suitability and frequency of human activities on various parts of the island.

By the late 1980s the Santa Catalina Island Conservancy realized that a more aggressive strategy was needed to retard the negative impacts of these feral animals, particularly that of feral goats and pigs. In 1989 the Santa Catalina Island Conservancy began a removal program for these species, as well as the bison, from the west end of the island, i.e. land west of the Isthmus. Previously, studies related to feral animals and grazing effects on Santa Catalina Island compared vegetation in goat-inhabited and goat-free areas (Coblentz 1977, 1978, 1980) and interpretations of habitat and cover using aerial photographs (Minnich 1980).

In order to document and evaluate the effects of nonnative herbivore removal on Santa Catalina Island vegetation, a vegetation monitoring protocol was established during the beginning phases of the removal program. In this report were described the implementation, methodology, and results for the period 1990–1992. Though the long term intent is to analyze vegetation once grazing pressure has been eliminated, this elimination has not reached 100%. During 1990, a combination of drought conditions and intensive eradication efforts resulted in a great reduction in numbers of feral grazers. Therefore, 1990 vegetation observations represent the extreme impact conditions. Present estimates of remaining animal numbers on the west end are less than 100 goats, and less than 200 pigs (D. Garcelon 1993, pers. comm.).

Methods

Study area and location

The west end of Santa Catalina Island consists of about 20% of the island's area, approximately 38 km² or 3,800 ha. It is characterized by steep ridges and narrow canyons, especially on the southern exposures. Geologically, this section of the island consists of the blueschist phase of the metamorphic Catalina Schist (Rowland 1984). Highest elevation is 549.8 m (1,804 ft) at Silver Peak. Recent annual precipitation data for

Table 1. Mean annual rainfall in inches *(mm)* for west end of Santa Catalina Island, 1980–1993; Two Harbors = 15 m elevation, Airport = 550 m elevation.

Year	Two Harbors		Airport	
1980–1981	11.61	*(295)*	13.13	*(334)*
1981–1982	15.54	*(395)*	21.52	*(547)*
1982–1983	20.64	*(525)*	26.76	*(680)*
1983–1984	7.22	*(183)*	11.47	*(291)*
1984–1985	7.52	*(191)*	11.57	*(294)*
1985–1986	12.79	*(325)*	18.72	*(475)*
1986–1987	7.19	*(183)*	8.21	*(209)*
1987–1988	8.40	*(213)*	16.77	*(426)*
1988–1989	5.23	*(133)*	9.52	*(242)*
1989–1990	3.35	*(85)*	8.66	*(220)*
1990–1991	9.35	*(237)*	13.50	*(343)*
1991–1992	15.11	*(384)*	25.74	*(654)*
1992–1993	20.38	*(518)*	26.39	*(670)*
Mean	11.10	*(282)*	16.30	*(414)*

records near the west end are contained in Table 1. The Two Harbors site (Isthmus Cove) is at 15 m (50 ft) elevation and at the northeastern side of the study area. The Airport site is about 6.4 km east of the west end and about 487.6 m (1,600 ft) in elevation.

Vegetation of the west end consists primarily of maritime cactus scrub, coastal sage scrub, chaparral, and grassland, with woodlands occurring in patches. Island ironwood, *Lyonothanmus floribundus*, in its characteristically small groves is especially patchy in distribution. No current figures exist for plant community composition of the west end. Thorne (1967, 1969) discussed the vegetation and floristics of Santa Catalina Island in general. The most recent analysis of vegetation patterns is that of Minnich (1980), based upon aerial photography done in 1976. His analysis for the entire island showed vegetative community cover to be as follows: grassland 28%, coastal sage scrub 13%, cactus maritime scrub 7%, chaparral 42%, woodland 2%, and bare 4%. These proportions are probably not accurate for the west end due to a variety of reasons including higher concentrations of feral goats there, and microclimatic and topographical differences.

Monitoring methods

Two approaches have been taken to document vegetation changes following feral animal removal: (1) time sequence photos taken from permanent photo points and (2) vegetation analysis using permanent transect lines. Reported here are observations from the transect data for the period 1990–1992. The vegetation was stratified into

Table 2. Mean percent cover for habitats and west end, grouped, for years 1990–1992; student's paired t-test. (Habitats: n = 45 quadrats, except grasslands: n = 30. West end: n = 255.)

Significant comparisons: (*) = 1991 X 1990, or 1992 X 1990; $p < 0.05$.
(**) = 1991 X 1990, or 1992 X 1990; $p < 0.01$
(^) = 1992 X 1991; $p < 0.05$
(^^) = 1992 X 1991; $p < 0.01$

	Introduced			Native			Bare		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
Grassland	57	84**	77**	10	13	20**^^	32	8**	2**^^
Maritime Cactus Scrub	16	34*	42**^	8	14*	15*	76	51**	49**
Coastal Sage Scrub	31	50**	58**^^	23	37**	29^	48	16**	14**
Chaparral	45	78**	92**^^	3	22**	15**^	37	12**	2**^^
Ironwood	23	59**	71**^^	5	15**	11**	66	23**	18**
Woodland	42	79**	84**	5	6	6	53	17**	9**
West end (grouped)	34	63**	70**^^	9	18**	16**^	53	22**	16**^^

6 vegetation types: ironwood groves, woodland, chaparral, coastal sage scrub, maritime cactus scrub, and grassland. Three 30-m transect lines were established in each type; 1 grassland transect was vandalized the first year and not re-established. Fifteen 1-m² quadrats were alternately placed 1 m apart on each side of the line. Density and percentage of cover (including canopy) were recorded for each species, as well as percent bare ground. Canopy species were defined as those shrubs greater than 2 m tall that had roots or trunks inside or outside of the quadrats but with overhanging branches and leaves.

Results and Discussion

Results from our analysis of vegetative cover during the years 1990, 1991, and 1992, for all transect habitat types and the entire west end considered as a unit, are presented in Table 2. Cover data are categorized by introduced species cover, non-canopy native species cover, and bare ground (this includes areas disturbed by feral pigs). Changes in vegetation that were significant are noted in Table 2. The discussion of individual species' contributions to percent cover is limited to the 4 highest ranked introduced and native species in each habitat type with choice and ranking based upon vegetation cover during 1992 (Table 3). Comparisons of species richness were analyzed from the results presented in Table 4. This table presents numbers of native and introduced annual, herbaceous perennial, and woody species for each habitat studied.

Cover

Grouped west end. Mean cover of both introduced and native species increased very significantly from 1990 to 1991 and from 1990 to 1992, and conversely, bare ground declined (Table 2). Introduced species and bare ground exhibited similar trends from 1991 to 1992, but cover of native species slightly decreased during that interval. Thus overall on the west end, vegetation cover increased and bare ground decreased for the 2-yr period.

Habitats. For all habitat types, vegetation cover increased and bare ground decreased from 1990 to 1992. Most habitats showed significant changes for the 3 categories.

Native cover showed a significant increase in maritime cactus scrub and a very significant increase in coastal sage scrub, chaparral, and ironwood habitats from 1990 to 1991. Changes were insignificant the first year for grassland and woodland habitats. By 1992, native cover in woodland had still not changed and native cover had decreased significantly enough in coastal sage scrub that it was no longer significantly different from 1990. In fact, native cover also declined significantly from 1991 to 1992 in chaparral, though it was still very significantly higher than in 1990. In grassland by 1992, the amount of native cover had increased very significantly from that of 1990 and 1991. Coastal sage scrub had the greatest cover by native vegetation of all 6 habitats during each year of measurement.

The most dramatic increases in cover were exhibited by introduced species, mostly annuals, for all habitats. An increase in introduced cover was significant for maritime cactus scrub from 1990 to 1991 and very significant in this habitat from 1990 to 1992. In all other habitats the increase in introduced cover was very significant from 1990 to 1991 and from 1990 to 1992. For the period 1991–1992, there were significant increases in introduced cover in maritime cactus scrub and very significant increases in coastal sage scrub, chaparral, and ironwood habitats.

Table 3. Contributions of highest ranked species to percent cover for habitat transects on west end, Santa Catalina Island, California. Ranking based upon 1992 data.

	1990	1991	1992
Grassland			
Introduced			
Brachipodium distachyon	1.4	36.3	45.1
Avena barbata	20.4	35.2	20.9
Vulpia myuros	20.7	1.1	16.9
Bromus diandrus	0.2	2.0	3.2
Native			
Nassella pulchra	10.4	11.5	19.6
Bloomeria crocea	0.0	1.6	0.4
Dichelostemma capitatum	0.0	0.1	0.2
Hemizonia fasciculata	0.0	0.1	0.0
Bare	64.1	14.9	1.8
Coastal Sage Scrub			
Introduced			
Brachipodium distachyon	2.3	18.4	30.2
Avena barbata	1.3	9.9	14.1
Vulpia myuros	0.0	0.4	4.9
Bromus diandrus	0.0	1.8	4.6
Native			
Opuntia littoralis	10.8	15.3	11.6
Artemesia californica	2.2	4.0	5.1
Nassella lepida	1.6	1.5	5.0
Sanicula arguta	0.0	0.7	2.6
Bare	72.6	17.5	14.5
Ironwood			
Introduced			
Vulpia myuros	0.2	7.2	21.8
Avena barbata	0.7	6.4	13.2
Brachipodium distachyon	0.2	3.3	8.2
Bromus madritensis	3.1	18.8	5.8
Native			
Lyonothamnus floribundus	3.7	4.7	5.1
Plantago erecta	0.0	0.8	1.4
Chenopodium californicum	0.1	0.2	0.7
Nassella lepida	0.3	0.2	0.4
Bare	83.1	23.6	19.5

	1990	1991	1992
Maritime Cactus Scrub			
Introduced			
Vulpia myuros	0.6	6.5	20.5
Avena barbata	0.8	2.6	6.6
Bromus madritensis	0.6	4.9	3.8
Hypochoeris glabra	0.3	2.9	3.5
Native			
Nassella pulchra	1.1	4.2	4.8
Isocoma menziesii	2.5	1.7	2.4
Opuntia littoralis	1.3	1.8	1.5
Baccharis pilularis	0.0	0.3	1.1
Bare	85.7	53.6	48.6
Chaparral			
Introduced			
Brachipodium distachyon	0.4	41.3	42.5
Vulpia myuros	1.1	24.1	37.5
Avena barbata	4.1	5.7	7.1
Silene gallica	0.1	1.6	2.2
Native			
Adenostoma fasciculatum	5.8	9.2	6.5
Bloomeria crocea	0.0	1.3	1.7
Rhus integrifolia	0.2	2.9	1.6
Sanicula arguta	0.0	1.0	1.0
Bare	61.0	13.8	1.8
Woodland			
Introduced			
Bromus diandrus	3.8	20.1	37.1
Brachipodium distachyon	4.7	25.5	35.8
Avena barbata	17.8	9.4	9.2
Bromus madritensis	3.4	2.5	0.7
Native			
Opuntia littoralis	2.7	1.0	2.8
Pholistoma racemosum	0.0	2.1	1.1
Rhus integrifolia	0.3	0.0	0.7
Prunus ilicifolia seedling	0.0	0.0	0.4
Bare	54.0	18.0	9.0

Table 4. Number of species for 6 west end habitats (1990–1992).

	Grassland			Maritime Cactus Scrub			Coastal Sage Scrub			Chaparral		
	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992
Introduced												
Annuals	9	11	11	11	17	17	8	20	16	11	16	15
Herbaceous perennials	1	2	2	0	0	1	1	0	1	0	0	0
Woody perennials	0	0	0	0	0	0	0 s		0	0	0	0
Total introduced	10	13	13	11	17	18	9	20	17	11	16	15
Native												
Annuals	0	2	0	1	13	10	1	22	14	5	9	18
Herbaceous perennials	1	3	3	3	5	7	5	9	8	9	10	11
Woody perennials	0	0	0	2	4	4	4	4	4	6	5	6
Total native	1	5	3	6	22	21	10	35	26	20	24	33
Total species	11	18	16	17	39	39	19	55	43	31	40	48

	Ironwood			Woodland			West end (grouped)		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
Introduced									
Annuals	12	21	20	4	14	16	19	29	26
Herbaceous perennials	0	0	0	0	0	0	1	2	3
Woody perennials	0	0	0	0	0	0	0	0	0
Total introduced	12	21	20	4	14	16	20	31	29
Native									
Annuals	1	19	18	0	7	8	6	36	33
Herbaceous perennials	5	5	6	1	3	2	11	12	16
Woody perennials	3	2	3	4	5	5	1	13	14
Total native	9	26	27	5	15	15	28	61	63
Total species	21	47	47	9	29	31	48	92	92

An increase in cover by weedy annuals has been well documented for many areas that have been intensely disturbed (Talbot et al. 1939; Robbins 1940; Burcham 1956; Heady 1958; Hochberg et al. 1980). In some cases native species have gradually reclaimed the site, although the presence of allelopathic toxins in the foliage of introduced grasses can inhibit this process (Tinnin and Muller 1971; Muller and Chou 1972; Tinnin 1972).

Because of high populations of feral goats prior to 1990, vegetation cover was often eaten right down to the ground; erosion of topsoil accelerated the denuding process. Reduction in feral animal numbers in 1990 resulted in a continuingly significant decrease in percentage of bare ground in all habitats through 1992 when compared to 1990. The habitats with the greatest initial percentages of bare ground were maritime cactus scrub, coastal sage scrub, ironwood, and woodland.

Species contributions. In 1990, the greatest extent of total cover was in the grassland habitat, primarily due to the greater cover of introduced annual species, especially grasses (Table 2, 3). The other habitats had low percentages of cover that were a combination of introduced annual grasses and woody perennial native species. By 1992, all habitats had higher cover of introduced annual grasses, although small but steady increases in cover by natives, especially herbaceous perennials, was evident.

Grassland: introduced annual grasses dominated from 1990 to 1992, though the particular species changed ranks. *Nasella pulchra* was 1 of the native species present; it doubled in cover by 1992. A few perennials appeared in small numbers in 1991 and 1992 and probably had been present in small numbers for many years.

Maritime cactus scrub: the initial vegetative cover was very low and still remained low in 1992, except for the great increase in *Vulpia* during 1992. There was little change for the native species, although the size of *Nassella* individuals and clumps increased slightly.

Coastal sage scrub: bare ground predominated in 1990, except for existing stands of *Opuntia* and a few scattered *Artemesia*, especially those protected in the middle of an *Opuntia* patch. By 1992, 2 introduced annual grasses, *Brachipodium* and *Avena,* were most common, though natives such as *Nassella* and *Artemesia* that produced many seedlings were beginning to show a slight increase in cover.

Chaparral: pre-existing individuals of *Adenostoma* contributed most of the shrub cover in chaparral habitats in 1990, surrounded by bare ground and patches of introduced grasses. By 1992, cover by introduced annual grasses had dramatically increased, whereas there was only a slight increase for native species.

Ironwood: in 1990, the ironwood sites consisted of isolated stands of ironwoods with little understory and surrounded by bare ground. Cover by introduced annual grasses increased manyfold by 1992. Very little increase in native cover occurred by 1992, though *Lyonothamnus* cover increased, mostly due to abundant sucker sprouts on trunks. Field observations by Laughrin in the fall of 1993 noted several surviving *Lyonothamnus* seedlings (8 in 1 grove, 5 in another). A greater number of seedlings had been observed in the spring of 1993 after the rainfall season (M. Gay 1993, pers. comm.). The germination and survivorship of seedlings for this species is especially noteworthy as it is the first documented occurrence for Santa Catalina Island and only the second for the Channel Islands.

Woodland: like ironwood groves, stands of woodlands dominated by large trees or shrubs with little understory, much bare ground and introduced grasses (primarily *Avena*) was the norm in 1990. By 1992, *Avena* had been largely replaced by other introduced annual grasses, *Brachipodium distachyon* and *Bromus diandrus*, as the most common species. Field observations in fall of 1993 by Laughrin found extremely high numbers of seedlings for *Prunus lyonii* (approximately 100/m^2).

Species numbers

Species diversity increased dramatically from 1990 to 1992 for both native and introduced species (Table 4). The total number of species within transects in most of the habitat types and for the entire west end almost doubled. The proportional increase was greatest for the native species and most of this was due to the increasing number of annual species. The habitats that showed the least changes in diversity were grassland and chaparral, although chaparral had a greater diversity of species at the beginning of this study (1990) than any other habitat. Native perennial species increased slightly, but regeneration of these species is slow and by 1992 they still did not contribute greatly to percentage cover. Scowcroft (1987) found that native vegetation recovery was still slow after 3 yr following goat exclosure on the island of Hawai'i.

General

Numbers of feral grazing animals have been significantly reduced on the west end of Santa Catalina Island, and the changes in vegetation observed are in part due to this reduction. However, grazing and disturbance impacts have not been totally eliminated; a few goats persist in localized areas. Feral pigs still range over the whole area. Deer have not been reduced and even though they are browsers, they remain a nonnative influence. Reduced grazing will contribute to increases in germination and seedling survivorship in the future as the seed bank begins to build up.

Another factor that probably had a positive influence on vegetation regeneration was the cessation of a long period of drought. This occurred in the period between the 1990 and 1991 observations. Two wet winters (1990–91 and 1991–92) undoubtedly increased germination and seedling establishment. Comparative observations during this period in a heavily goat-impacted area would have helped to evaluate the above factors.

The absence and/or control of fire on the island, especially in the presence of grazing, has probably favored the introduced annual species (Minnich 1982). Fire history on the Channel Islands has been influenced by human activity and grazing practices (Carroll et al., in press), and as vegetation cover increases an increase in fire frequency is predicted. This may increase species richness and in the long term increase the proportion of native species and cover.

Conclusions

An analysis of changes in vegetative cover on the west end of Santa Catalina Island from 1990 to 1992, following reduction in feral animal numbers, reveals a decrease in percentage of bare ground and an increase in cover for introduced annual grasses. There has been an increase in numbers of native species but the contribution to total cover has been low. Long-term monitoring is needed to evaluate vegetation recovery of this severely impacted island ecosystem in order to continue to make informed management decisions that will ensure the preservation of Santa Catalina Island's vegetation and flora.

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