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Feral Pig Disturbance and Woody Species Seedling Regeneration and Abundance beneath Coast Live Oaks (*Quercus agrifolia*) on Santa Cruz Island, California

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Abstract. For more than 100 yr, introduced mammals have altered native vegetation patterns and species composition on Santa Cruz Island. Now, only feral pigs (*Sus scrofa*) remain and they are destroying woody-species seedlings beneath the canopy of coast live oaks (*Quercus agrifolia*) either by direct predation on acorns and seeds, or by trampling on the fragile young shoots of woody species such as island cherry (*Prunus ilicifolia* ssp. *lyonii*), island redberry (*Rhamnus pirifolia*), lemonadeberry (*Rhus integrifolia*), and toyon (*Heteromeles arbutifolia*). In 1989, permanent research sites were established beneath the canopies of 10 coast live oaks in the central valley of Santa Cruz Island, at locations ranging in elevation from 289 m to < 1 m. Beneath each of these trees, a fenced exclosure was constructed to prevent pig access, and a matching control plot, allowing pig access, was marked out. The results of paired t-tests indicate that there are significant differences in the total number of seedlings found in the exclosures and in the control plots.

Keywords: Santa Cruz Island; *Quercus agrifolia*; coast live oak; feral pig; *Sus scrofa*; woody species regeneration; California oak woodlands; drought.

Introduction

Feral pigs are relative newcomers to California (Barrett 1990) where their numbers are rapidly increasing. Pig activity caused extensive damage to the Chardonnay wine grape production in the Sonoma region last year and has become an increasing threat to agricultural land and crops in the Carmel Valley (M. Stromberg 1993, pers. comm.). Their range on the mainland currently extends from Gaviota State Beach to Tehama County in northern California and expansion is accelerating (R. Barrett 1993, pers. comm.). From 1956 through 1991, approximately 750,000 wild pigs were harvested statewide. The pig's high reproductive potential, game animal status, and ability to modify its environment ensure that management policies will become increasingly controversial (Barrett 1993). It has been suggested that feral pigs have their most disruptive ecosystem impact in California through seed and acorn consumption (De Neveres 1993). Pigs are omnivorous and opportunistic feeders, with a high preference for acorns, the keystone resource in the oak woodland food web. According to Barrett (1990) where feral pigs occur, acorn consumption usually approaches 100%.

In addition to feeding on acorns, fruits, and seeds, feral pig activity includes rooting the soil and leaf litter in search of tubers and insects, overturning the soil profile and uprooting newly germinated seedlings, exposing and drying their roots. Pigs trample vegetation underfoot as they move through the oak woodland, creating winding paths across hillsides that in turn facilitate soil erosion on steeper slopes.

Blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*) are both experiencing poor recruitment of saplings statewide, although both species are commonly good producers of acorns and seedlings (Chipping 1993). Recruitment of coast live oak (*Q. agrifolia*) is considered too low to maintain existing population numbers (Muick and Bartolome 1987), and the preservation of oak woodlands has become a major conservation issue statewide (Callaway and D'Antonio 1991). On the mainland, factors that limit regeneration of oaks and other woody species include urbanization, drought stress and seedling predation by deer, gophers and livestock.

On Santa Cruz Island, only drought stress and feral pigs inhibit oak and woody species regeneration. Schuyler (1988) determined that acorns of *Quercus* sp. and the cherries of *Prunus illicifolia* ssp. *lyonii* are preferred food items and that after passing through the pig's digestive tract, they are incapable of germination. The lack of Prunus regeneration on the island had already been noted by Baber in 1982. Recent feral pig research on Santa Cruz Island focused on population characteristics, home range and habitat use (Sterner 1990), but the impacts and consequences to specific vegetation communities has not been investigated.

California's Channel Islands have been impacted by nonnative species since the arrival of the Chumash peo-

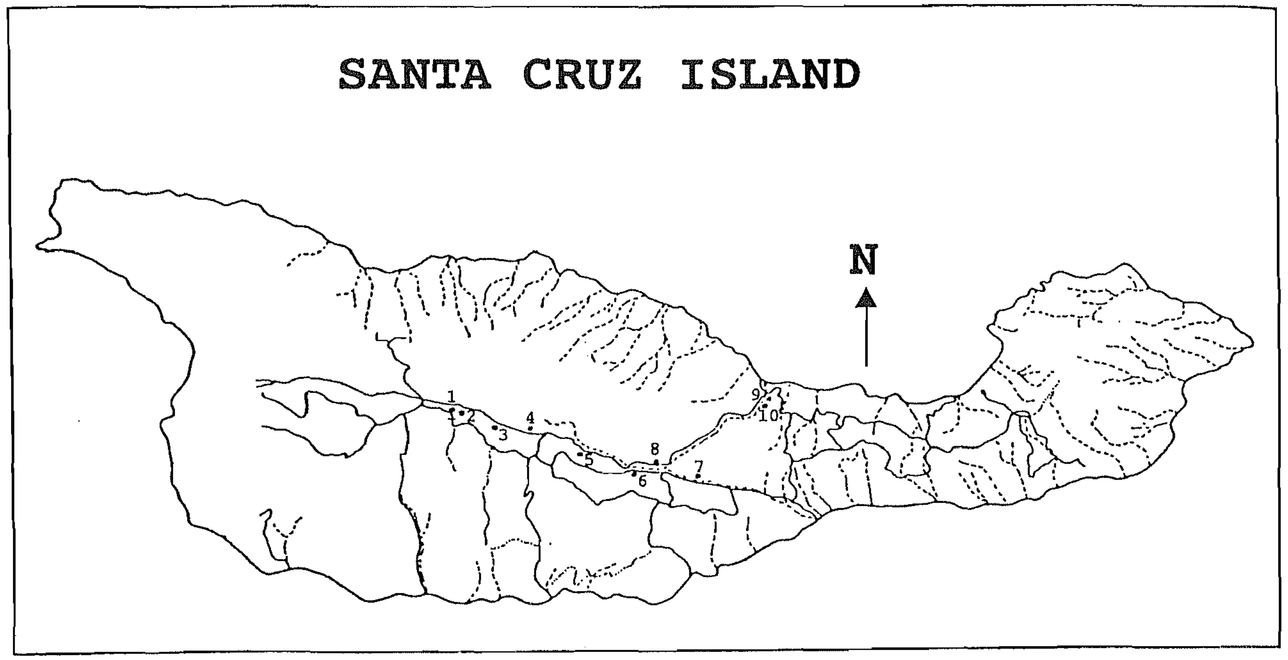


Figure 1. Map of Santa Cruz Island with study sites indicated. Elevation ranges from 289 m at Site 1 to < 1 m at Site 10.

ple between 6700 and 7100 yr BP. While it has yet to be documented, Chumash-ignited fires probably occurred on the California Channel Islands, but since the Chumash were pre-agrarian people, the use of fire to regularly clear for agriculture was presumably not a major factor in shaping Channel Islands ecosystems. It was the Anglo introduction of sheep, cattle, goats, and pigs in the early 1850s (Brumbaugh 1980) that led to a rapid alteration of the island ecosystems. Thorne (1969) noted that 48 species of native plants have vanished from Santa Catalina Island in this century, primarily due to the impacts of introduced herbivores such as goats, cattle, and bison.

Santa Cruz Island had been a working cattle ranch for more than 100 yr prior to its acquisition by The Nature Conservancy (TNC). In 1988, as the result of research on the severe erosional effects and ecological impacts of feral sheep activity on Santa Cruz Island (Brumbaugh 1980), sheep were eradicated from the 90% of the island under TNC administration. Following the removal of these sheep, the feral pig population increased and degradation of many of the island's ecosystems continued. Of the once extensive cattle herds that grazed the island's grass and woodlands, only about a dozen head remain and these are confined to a well-fenced pasture as part of a "living museum." The feral pig is the last free-ranging nonnative mammal on the island.

Pigs inhabit all 10 of the island's plant communities (Baber 1982) with chaparral and oak woodland the preferred habitats (Sterner 1990). The chaparral-oak woodland provides food, habitat and shelter for birds and mammals, and a protective canopy for other native plant species, as well as for young woody seedlings. On Santa Cruz Island, endemic terrestrial mammals—the spotted skunk (*Spilogale gracilis amphialus*), the Santa Cruz Island fox (*Urocyon littoralis santacruzae*)—as well as the endemic Santa Cruz Island scrub jay (*Aphelocoma coerulescens insularis*) rely heavily on acorns, manzanita (*Arcostaphylos* ssp.) berries, and island cherries to maintain their numbers. Feral pigs are in direct competition with these native insular species for the island's scarce food resources.

To test the hypothesis that woody species regeneration on Santa Cruz Island is being negatively impacted by feral pig activity, we established 10 permanent research sites dominated by a mature *Q. agrifolia* and documented woody-species seedling germination and survival for 5 yr, beginning in drought conditions in 1989 and continuing through post-drought recovery to the present. Research design involved 2 treatments; an experimental (fenced exclosure) area and a matching control (open, unfenced) area. A second hypothesis was suggested as a result of the drought from 1989 to 1992; that there would be no difference in the number of woody species seedlings in the exclosures and the open plots while the drought persisted, but that following recovery from drought conditions, woody-species seedling abundance would differ significantly between the fenced and unfenced treatments.

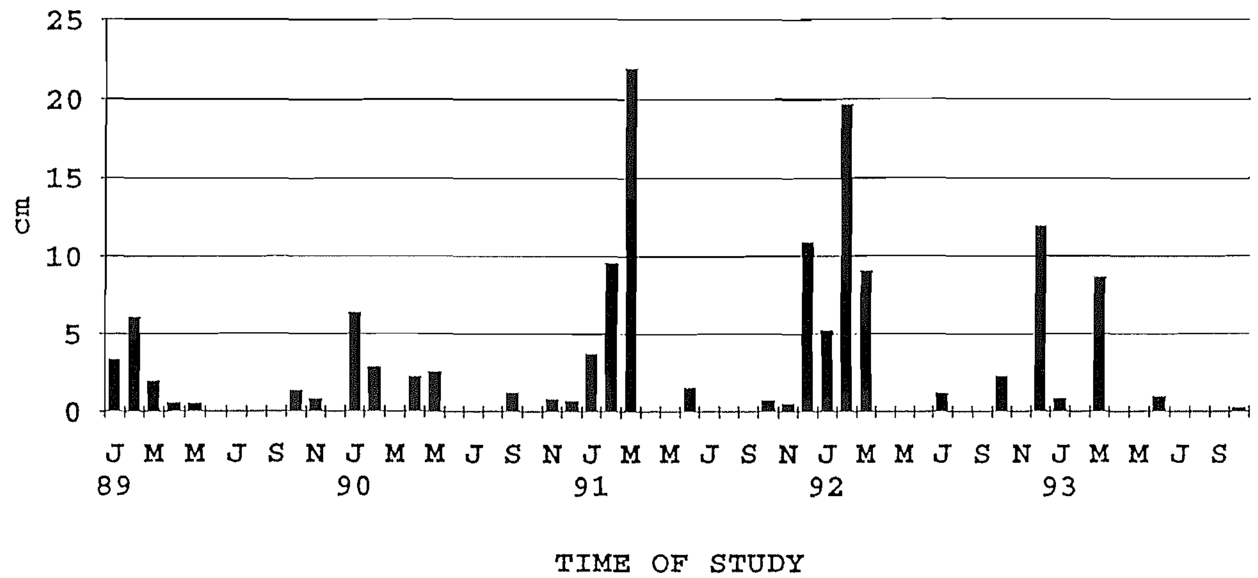


Figure 2. Precipitation on Santa Cruz Island (in centimeters) January 1989–October 1993. Records from the main ranch.

Study Area

We conducted our research in the Central Valley and in Canyon del Puerto on Santa Cruz Island. The Central Valley is a clearly visible fault structure that divides the island longitudinally and has an upper valley between Centinela and Portazuela, and a lower valley that stretches from the base of Portazuela grade eastward to the Pacific Ocean. Canyon del Puerto is the island's main drainage area and runs northwest from the lower Central Valley to Prisoners Harbor. The vegetation in these areas is primarily chaparral and oak woodland, characterized by 2 species of oaks; coast live oak (*Quercus agrifolia*) and scrub oak (*Quercus berberdifolia*). Since the island's feral pigs prefer north-facing slopes (Sterner 1990), where cover is more dense and where acorns and cherries are seasonally available in the late summer and fall, we selected primarily north-facing slopes for our 10 permanent research site locations. The sites range in elevation from 289 m (Site 1) in the upper Central Valley just below Centinela, to < 1 m (Site 10), 400 m inland from Prisoners Harbor in Canada del Puerto (Fig. 1). Four sites are located in the upper Central Valley (Sites 1–4) in what had previously been cattle pasturage, 4 sites are in the lower Central Valley region (Sites 5–8), and 2 sites (9 and 10) are just north of Prisoners Harbor in Canyon del Puerto.

Methods

At each of the 10 *Q. agrifolia* study sites, a 36-m^2 fenced exclosure was constructed to prevent pig access and a matching unfenced control plot was staked out that allows normal pig activity. The fenced exclosures are constructed from standard bales of 13-cm^2 hog wire, buried 31 cm beneath the surface to prevent the pigs from digging underneath. A row of barbed wire runs around the base at ground level and above the top edge of the hog wire. Insects, rodents, skunks, foxes, and birds can move freely over and through these fences, which control only feral pig access. There are a total of 20 research plots; 10 fenced exclosures and 10 unfenced open plots.

All individual woody seedlings in the fenced and unfenced plots were recorded by height category (< 0.5 m; 0.5–1 m; > 1 m) and when possible, by species. (Seedlings are often difficult or impossible to identify at the cotyledon stage or when badly insect-chewed; and, as very young seedlings, *Q. agrifolia*, *Rhamnus pirifolia*, and *Heteromeles arbutifolia* are difficult to distinguish from one another (S. Junak 1992, pers. comm.).

The total number of individual woody-species seedlings within the fenced exclosures and unfenced open control plots has been recorded at 14 intervals during the past 5 yr, semi-annually 1989–1991 and quarterly in 1992 and 1993. Paired t-tests were performed by treatment (fenced or unfenced) and by drought condition to determine whether a significant relationship exists between seedling abundance and pig disturbance in the open and the fenced plots.

Pig disturbance is recorded on a disturbance scale (Daubermire 1968) of 1–6 depending on the severity of surface disruption in the open plots (1 = 0–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–95%; 6 = 95–100%). Disturbance consists of a range of impacts from traffic paths (usually 1–2 on the disturbance scale) to full-scale roto-tilling of surface material (5–6 on the scale).

Since we initiated this study in what was to become the third year of a 7-yr drought in California, we subsequently divided the data into 2 categories ("drought" and "no-drought") in order to separate the effects of this drought from the effects of pig activity. "Drought" data cover the period from March 1989 through June 1992, and are characterized by a dramatic decline in feral pig population (pers. obs.) as well as low precipitation levels (Fig. 2). The "no-drought" data cover October 1992 to October 1993, after the drought had been declared over by state officials, precipitation had reached normal levels and pig population began its rapid recovery (pers. obs.). Precipitation data recorded at the Santa Cruz Island main ranch were used for this study.

A square root transformation was performed on seedling count data in order to stabilize the variance and better satisfy the assumptions for the t-test. The square root was taken of every seedling value and the average over time determined for the site (1–10) and treatment (fenced/unfenced) combinations, separately for the drought and no-drought periods. Paired t-tests and 95% confidence intervals were then constructed for woody seedling abundance.

Results

The paired t-test for the data from the drought period (March 1989–June 1992) yielded a p-value of 0.1343; and the 95% confidence interval for the difference in the mean value of square root of seedling counts (fenced-unfenced) was (0.11, 0.70). The data provide no evidence of a difference in seedling counts between the fenced and unfenced treatments by site for the drought period. Following the drought, however, there is a significant difference between the fenced and unfenced treatments ($p = 0.002$); the 95% confidence interval for mean fenced-unfenced with the square root transformed data is (–0.99, 3.22). The means and standard deviations for the transformed data are given in Table 1. There was a dramatic increase in seedling counts for both fenced and unfenced treatments, but the increase in fenced treatments far outstripped the increase in unfenced treatments.

Table 1. Summary statistics for the number of woody seedlings.

	N	Mean	Std. Dev.
Drought			
Fenced	10	1.18	1.44
Unfenced	10	0.48	0.66
No-drought			
Fenced	10	18.54	20.81
Unfenced	10	5.74	11.44

Woody species abundance by plot treatment type ("fenced" or "unfenced") is shown for 5 yr, 1989–1993, in the upper half of Figure 3; the lower half of Figure 3 illustrates the level of pig disturbance in the open plots and reflects the pig population decline in response to drought from 1989 until June 1992. During the drought period, average pig disturbance of the surface area in the open plots remained 25% or less. No pig disturbance was recorded between June 1990 and June 1991, when the pig population reached its lowest levels (L. Laughrin 1994, pers. comm.). By October 1992, the average level of pig disturbance had increased to 50% of the surface in the open control plots, and the trend towards increasing disturbance is expected to continue.

There has been considerable variation in woody-species seedling abundance recorded in the fenced and unfenced plots at the 10 sites over the last 5 yr, with the greatest number of seedlings recorded at Site 6 in the lower Central Valley and the fewest at Site 1 in the upper Central Valley. At the inception of the study in March 1989 (Fig. 4a), a total of 18 woody seedlings were recorded for all 10 sites; 56% (10) in fenced exclosures, 44% (8) in unfenced plots. Pig disturbance was greatest at Site 9 in Canyon del Puerto, where approximately 85% of the surface had been overturned; 1 island cherry (*P. ilicifolia* ssp. *lyonii*) seedling was recorded in the unfenced open plot at Site 9. Thirty percent of the sites had no pig disturbance. In March 1990, after another year of below-average rainfall (less than 10 cm were recorded during the prior January and February), woody-seedling abundance was 50% (8) in the fenced plots and 50% in the unfenced plots. Pig disturbance ranged from 50 to 75% at Site 2, located in the upper Central Valley at the mouth of a deep, north-facing canyon, and at Site 10, near Site 9 in the Canyon del Puerto drainage into Prisoners Harbor. No pig disturbance was recorded at 70% of the sites. In March 1991, the third study year, only 4 sites had woody seedlings; 68% (8) in fenced exclosures, 38% (5) in unfenced open plots. All the seedlings were at sites in the lower Central Valley and in Canyon del Puerto, and no pig disturbance had occurred at any of the study sites.

In March 1992, 329 woody seedlings were recorded in March 1992 (Fig. 4b), the greatest seedling count of the study—a woody seedling "flush"—with 64% of the seedlings (210) in fenced plots and 36% (119) in unfenced plots. (This seedling flush followed rainfall measuring 34 cm for the previous 3-mo period as well as a masting season in the fall of 1991.) At Site 6 in the lower Central Valley, 82 seedlings were recorded in the unfenced plot, 47 seedlings in the fenced exclosure. Site 5, in Portazuela, had 76 seedlings in the fenced plot, 21 seedlings in the unfenced open plot. The only pig disturbance recorded in March 1992 was at the 2 lower elevation sites in Canyon del Puerto. The remaining 80% of the sites had no recorded pig activity.

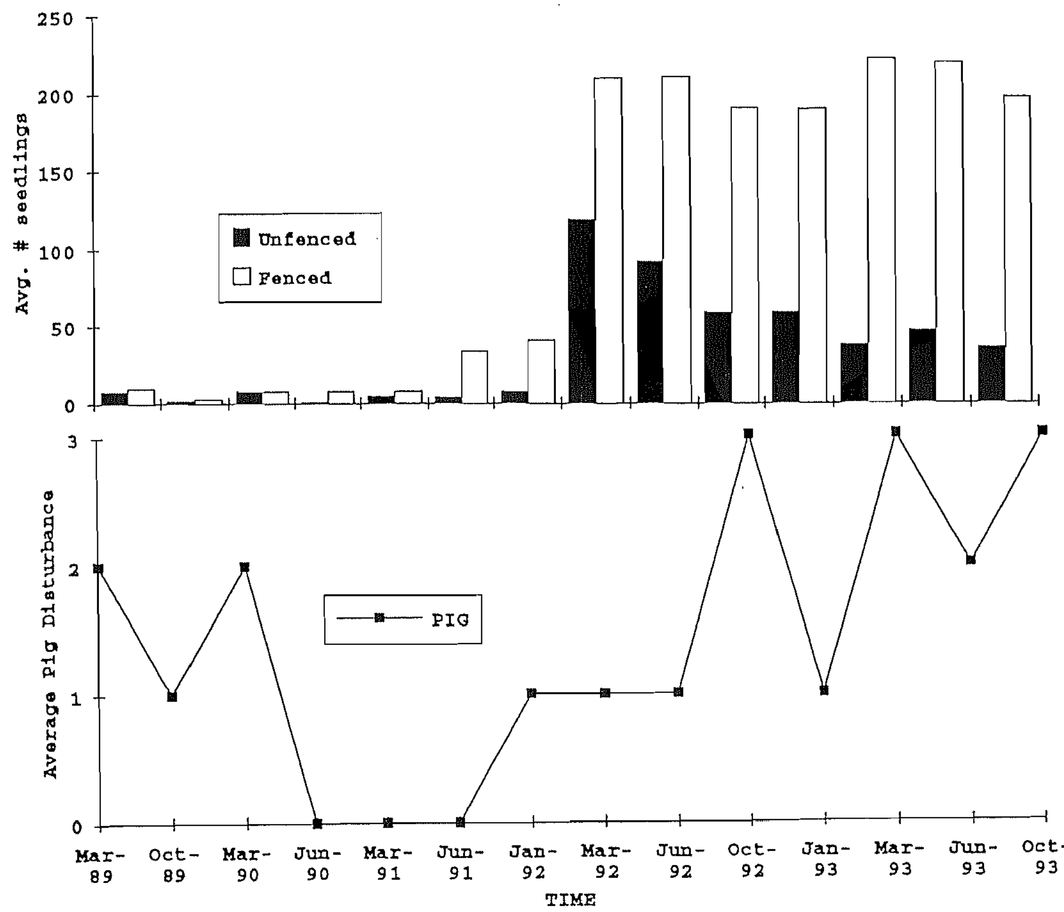


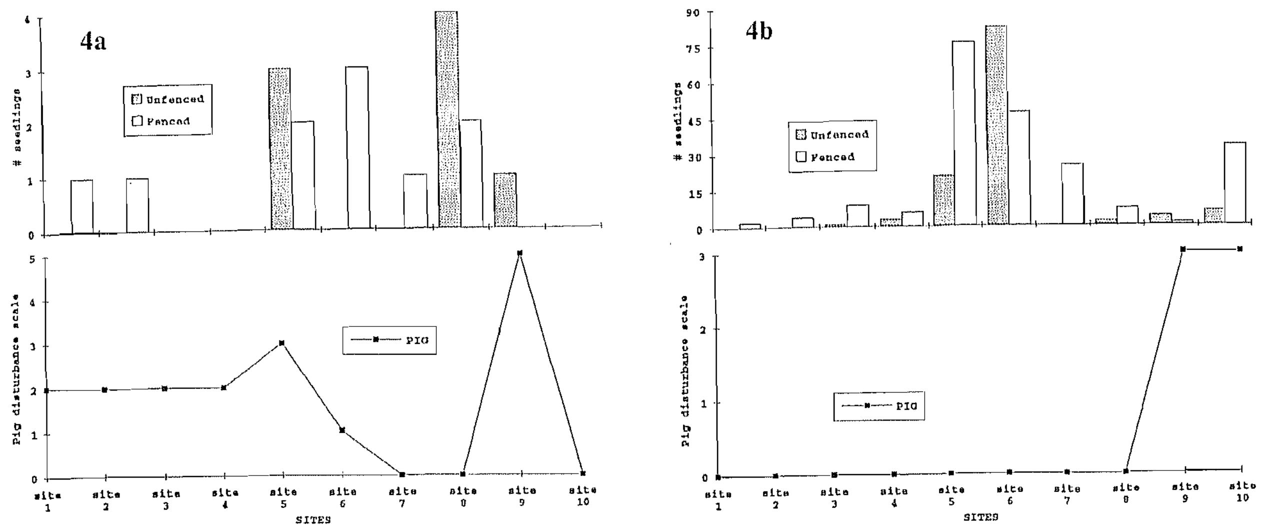
Figure 3. Average woody-species seedling abundance in 10 study sites for 5 yr; March 1989–October 1993 is displayed on the upper graph and the average level of feral pig disturbance in the unfenced plots is reflected on the lower graph.

By March 1993, year 5 of the study, total woody seedling count was 260, (a 21% decrease in total seedling numbers over the past year) (Fig. 4c). There were 222 seedlings (85%) in fenced exclosures (including 86 seedlings from the "flush cohort," representing a 45% survival rate from March 1992). Only 38 seedlings (15%) were recorded in the unfenced open plots (including 14 individuals from the "flush", representing a 13% survival rate of seedlings for March 1992 in the unfenced plots).

The trend in woody-species seedling abundance over the 5 yr of this study has varied within the sites located within the 3 geographical regions utilized; the upper Central Valley, the lower Central Valley and Canyon del Puerto. The fewest woody seedlings have been recorded at upper Central Valley sites; the greatest number of seedlings recorded in the lower Central Valley sites; and the highest and most consistent level of pig disturbance has been recorded at the sites in Canyon del Puerto.

Site 4 is located in the upper Central Valley, 3 km west of the top of Portazuela grade. It is a solitary coast live oak set in former pasture land dominated by introduced Mediterranean annual grasses and sweet fennel (*Foeniculum vulgare*). Woody seedlings began appearing in the fenced exclosure in June 1990 and have been steadily increasing in numbers up to the October 1993 count of 20 seedlings (Fig. 5). The March 1992 seedling flush did not add significantly to the number of seedlings in the exclosure, but in June 1993 the number rose from 13 to 20 seedlings, an increase of 35%. For the first 2 yr of the study, pigs disturbed < 25% of the surface in the unfenced plot in March. Disturbance dropped to 5% in June 1991, then ceased until October 1992. The first 3 seedlings were established in the unfenced open plot during the "flush" of March 1992. Despite increasing levels of pig disturbance of 50 to 75% of the surface area, 2 of these seedlings are still surviving.

Site 6 is in the lower Central Valley, less than 1 km west of the University of California at Santa Barbara field station where the Valley Road joins the Ridge Road. The March 1992 flush did have a significant effect on woody-species seedling abundance at this site, increasing seedling numbers by 276%—from 17 to 47—in the



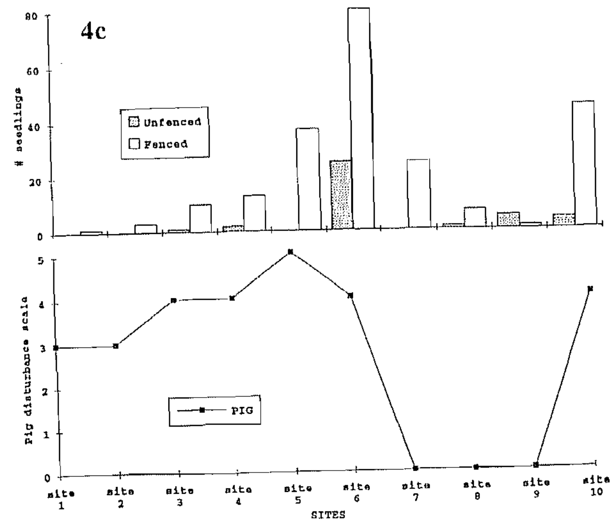


Figure 4. Average woody-seedling abundance and average pig disturbance by site March 1989 (**4A**), 1992 (**4B**), and 1993 (**4C**). Sites 1–4 are located in the upper Central Valley, Sites 5–8 in the lower Central Valley, and Sites 9 and 10 in Canyon del Puerto.

fenced exclosure and by over 1,000%— from 3 to 82 seedlings—in the unfenced open plot (Fig. 6). Pig activity, which had been negligible in the unfenced plot prior to October 1992, has been a constant factor since then to the present. Seedling count in the open plot dropped 37% from June to October 1992, from 67 (June) to 42 seedlings (October). By March of 1993, 1 yr later, seedling numbers in the open plot had diminished to 25, a decrease of 63%, and by October of that year only 15 seedlings remained. The seedlings in the fenced exclosure, however, have increased an additional 39%, to 77 seedlings, as of October 1993.

Site 10, the most consistently and extensively pig-damaged site, is just inland and south of Prisoners Harbor in Canyon del Puerto. The open plots were experiencing an average of > 35% damage to the surface area in late 1989 and early 1990 (Fig. 7). During the period when no pig disturbance was measured, only 1 seedling was recorded in the open plot (in March 1991), but it had perished by the following June. No additional seedlings germinated until the flush in March 1992, when 6 were recorded. Seedling numbers had decreased by 33% the following March, diminished from 6 to 4 seedlings. In June of 1993, 9 new seedlings in the open plot increased the total count to 13, an almost 70% gain in woody-seedling abundance. Pig disturbance in the open plot precipitated a 15% decline in seedling numbers from 13 to 11 seedlings by October 1993. As at Site 6, the March 1992 seedling flush dramatically increased seedling numbers in the fenced exclosure at Site 10. Six seedlings were recorded in January 1992, but by March, the count had risen to 33, a 550% increase in seedling abundance. An additional 45% increase to 45 seedlings was recorded in the fenced exclosure by October 1993.

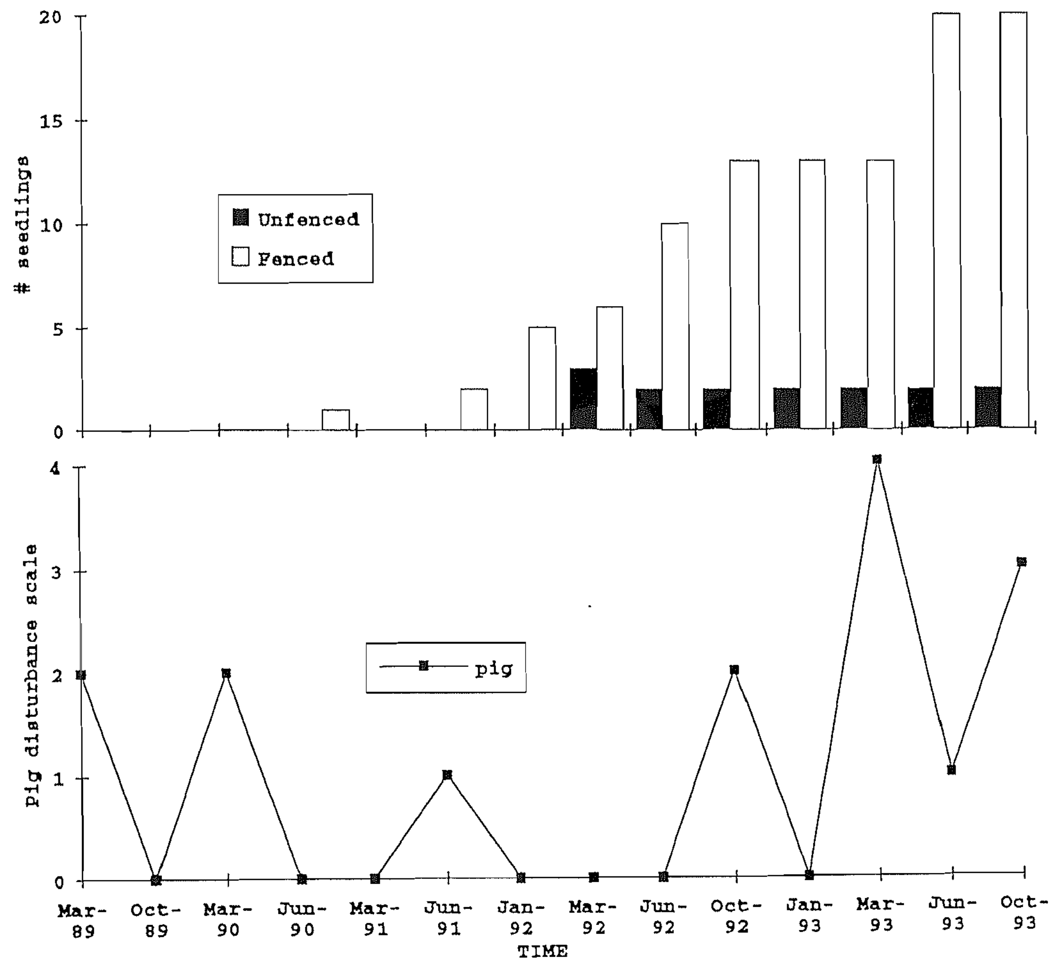


Figure 5. Average level of feral pig disturbance and woody-seedling abundance at Site 4 (upper Central Valley), 1989–1993. Seedling abundance is displayed in the upper graph; pig disturbance on the lower graph.

Discussion and Conclusions

Our data clearly indicate that feral pig activity on Santa Cruz Island is negatively affecting woody-species abundance and regeneration in the chaparral-oak woodland. For the first 3 yr of this 5-yr study, seedling abundance was fairly evenly distributed between the fenced and unfenced plot treatments, primarily as a result of drought that inhibited both seedling germination rates and pig population. With release from drought conditions, a flush of woody-seedling germination occurred, and the pigs began increasing their drought-reduced numbers. Seedling abundance rapidly became significantly greater in the fenced plots (85%), than in the open, unfenced plots (15%). These findings clearly support both our research hypotheses.

The different rates of seedling germination and seedling abundance in the 3 Central Valley permanent study site locations (the upper Central Valley, lower Central Valley and Canyon del Medio) are probably the result of such factors as slope, aspect, soil characteristics, and community dynamics. Microclimate conditions in the upper Central Valley and a less dense oak population may have been underlying causes for the lower response to the March 1992 seedling flush. The higher seedling germination response rate at sites in the lower Central Valley, particularly Site 6, may be the result of Santa Cruz Island scrub jay (*Aphelocoma coerulescens insularis*) activity around the UCSB field station nearby this site. The jays play an important role in acorn and cherry seed dispersal on Santa Cruz Island, and on the California mainland, scrub jay (*A. coerulescens*) caching of acorns has been recorded during the fall season at 5,000 acorns per bird at Hastings Reserve, and while most of these are re-located and consumed, some are inevitably left to germinate (Griffin 1976). Further investigation is necessary in order to reveal the role of the variables mentioned above in determining the variability of seedling germination and abundance rates at the different sites.

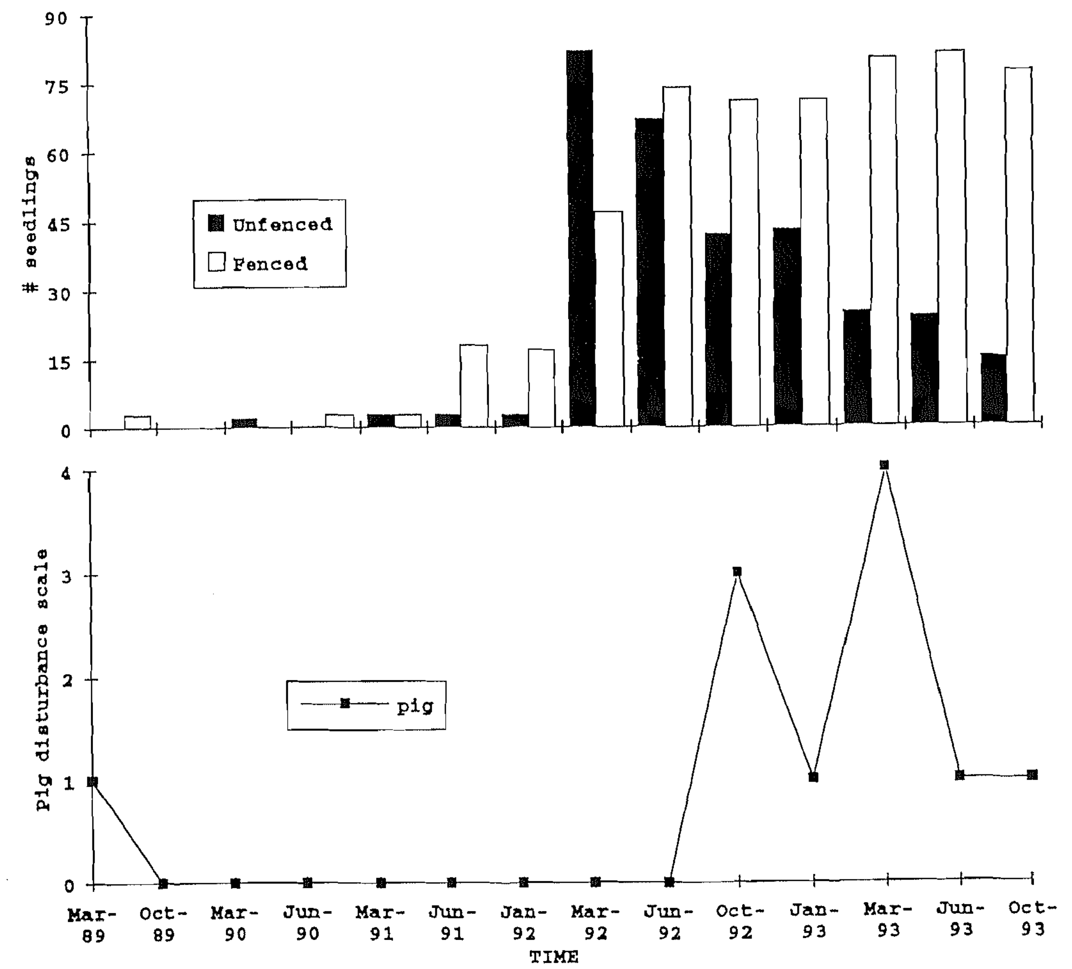


Figure 6. Average level of feral pig disturbance and woody-seedling abundance at Site 6 (lower Central Valley), 1989–1993. Seedling abundance is displayed in the upper graph; pig disturbance on the lower graph.

Why pig disturbance was more consistent and seemingly greater at the Canyon del Puerto sites was not investigated as a part of this project. Perhaps there is a water source deep in a nearby canyon that persisted during drought; perhaps the microclimate effects of the nearby Pacific Ocean and the lower elevation at these sites are factors. Throughout the study period, we could always count on at least hearing pig activity at these sites.

Previous research has shown that feral pigs are highly dependent upon acorn (mast) production to provide seasonal fat reserves and assure reproductive success (Barrett 1978). With a stable food base, feral pigs, which have an extremely high reproduction potential, can conservatively be expected to double their numbers at least twice a year. They mature quickly and are capable of reproduction between 6 and 8 mo of age, the sows producing litters ranging in size from 4 to 7 piglets (Mayer and Brisbin 1991).

The pigs on Santa Cruz Island depend not only on mast, but on many other components of the complex island food web, such as Manzanita berries, island cherries, roots and tubers, and insects (B. Burhans 1994, pers. comm.)—resources also vitally important to endemic island species. As long as the pigs participate in this fragile web, other island species will be negatively impacted as they struggle to maintain their numbers with reduced resources. Feral pig disturbance will continue to degrade island habitat and retard recovery from a century of grazing, as well as severely limit woody-species regeneration in the oak woodland.

In conclusion, since feral pig disturbance on Santa Cruz Island is retarding woody-species regeneration, including *Q. agrifolia*, it seems reasonable to suggest that this may also be occurring on the mainland. As research continues in California to determine the causes of poor regeneration in several native oak species including the

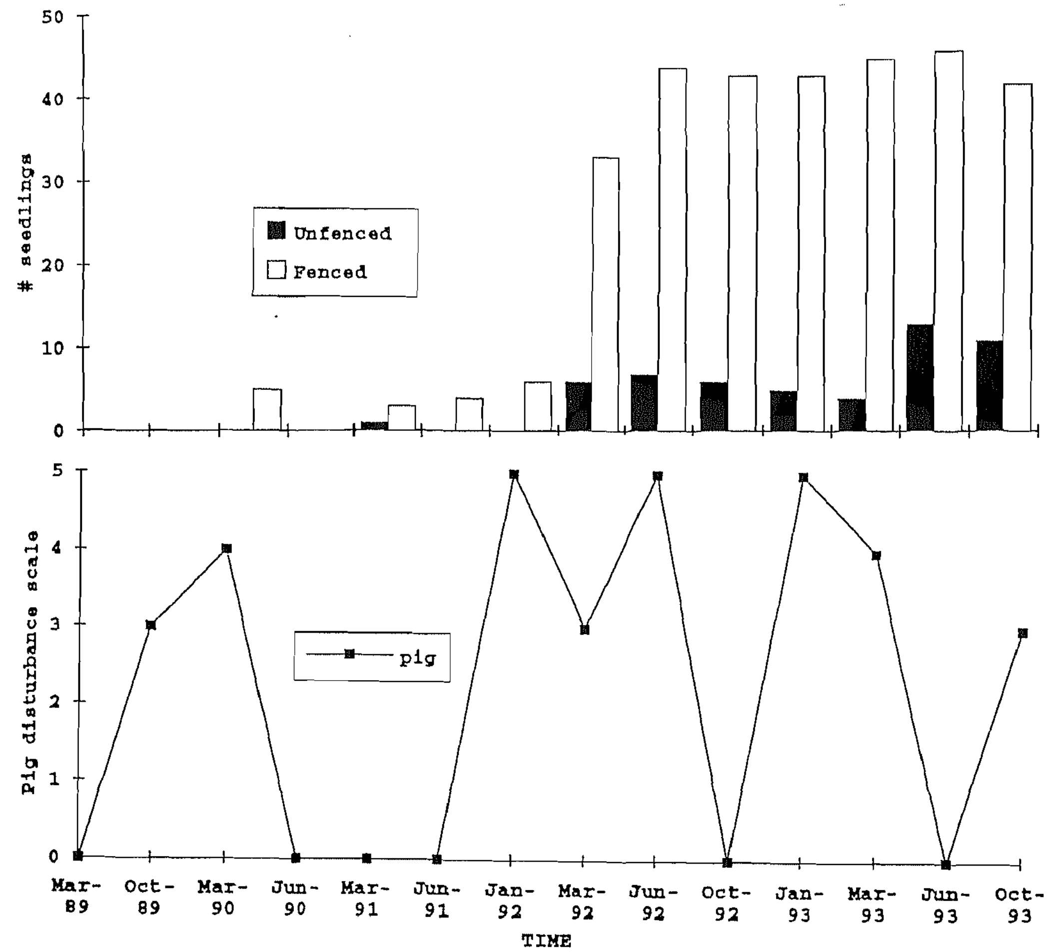


Figure 7. Average level of feral pig disturbance and woody-seedling abundance at Site 10 (Canyon del Puerto), 1989–1993. Seedling abundance is displayed in the upper graph; pig disturbance on the lower graph.

coast live oak (*Q. agrifolia*), and efforts to effectively manage hardwood resources continue, it would seem appropriate to direct attention toward the role played by the increasing number of feral pigs statewide. It is also suggested that consideration be given to removing pigs from game animal status and efforts focused on their eradication.

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Ecology of Feral Goats Eradicated on San Clemente Island, California

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Abstract. Feral goats (*Capra hircus*) severely degraded endemic biota on San Clemente Island, resulting in the listing of 4 plants, 2 birds, and 1 reptile as threatened or endangered. The U.S. Navy instituted an intensive feral goat eradication program in 1972. After 17 yr, remnant groups of feral goats were still present and the "Judas" goat technique, exploiting the gregarious nature of the goats, was implemented in June 1989. Between June 1989 and April 1991, 263 feral goats had been killed on San Clemente Island. Natality, survivorship, and physiological condition of San Clemente Island goats were higher and mortality rates lower than other feral goat populations, presumably because of the unusually low density of goats on San Clemente Island. This feral goat population exhibited a compensatory rate of increase as a result of eradication efforts.

Keywords: *Capra hircus*; eradication; feral; goat; goats; Judas; radio-telemetry; San Clemente Island.

Introduction

The U.S. Navy instituted an intensive feral goat eradication program on San Clemente Island, California, in 1972. Despite the removal of more than 28,000 goats between 1972 and 1989, feral goats persisted and continued to damage native flora and fauna (J. K. Larson 1993, pers. comm.). Eradication planning and implementation did not include data collection of population characteristics or goat ecology. Consequently, no data, other than numbers removed and costs of control efforts, were available. Traditional eradication methods were not effective on San Clemente Island, and goat population responses to these methods are unknown. To better understand feral goat responses to population reductions, an intensive sustained control effort was implemented using the Judas goat technique (Taylor and Katahira 1988). This procedure allowed remnant feral goats to be located and eliminated on San Clemente Island.

Hunting can be a form of compensatory mortality if breeding stock and their subsequent reproductive rates are unaffected (Peek 1986). For San Clemente Island goats, the intent was for hunting mortality to be additive, that is, causing mortality in excess of the populations' ability to compensate through increased natality or survivorship, and thereby reducing feral goat population densities.

Feral goats have a relatively high reproductive potential for an ungulate; gestation is 150 dy and goats reach sexual maturity at 6 mo of age (Yocum 1967). Multiple births are common (Rudge 1969; Baker and Reeser 1972; Parkes 1984) and females may give birth twice a year (Rudge 1969; Ohashi and Schemnitz 1987). These reproductive traits allow feral goats to respond to population reductions with increased natality (Coblentz 1982; Parkes 1984). Parkes (1984) documented an increase in goat productivity after population reduction on Raoul Island, New Zealand. Furthermore, Rudge and Smit (1970), using a fixed value for rate of increase, predicted that a goat population reduced by 80% could rebound to 90% of the original level in only 4 yr. Feral goats have a considerable capacity to increase in number and respond to control efforts in a compensatory manner. Unless control programs are financially insured in perpetuity, protection of a natural community from the negative effects of goats requires complete eradication of feral populations. Furthermore, considering long term effects, eradication is probably less expensive and more ecologically efficient than perpetual control.

The Judas goat technique helped eliminate 263 feral goats on San Clemente Island between June 1989 and April 1991 (Keegan et al. 1994). Two-hundred and nineteen carcasses were examined to determine if natality,