2005

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DOI: <https://doi.org/10.31979/etd.x2mj-8ppd>
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EFFECTS OF FERAL PIGS ON VEGETATION ON SANTA CRUZ ISLAND,
CALIFORNIA, USA

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Greg Yost

August 2005

UMI Number: 1429458

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ABSTRACT

EFFECTS OF FERAL PIGS ON VEGETATION ON SANTA CRUZ ISLAND, CALIFORNIA, USA

by Greg Yost

This study examined the impact of feral pigs, *Sus scrofa*, on the vegetation of Santa Cruz Island, California. Sixteen matched paired sites were established, with each site containing both a fenced exclusion plot and an unfenced plot that allowed access by pigs. Differences in vegetation characteristics were measured between the plots over a period of one year. The exclusion of pigs appeared to enhance the growth of fennel, *Foeniculum vulgare*; pig rooting behavior apparently was responsible for the reduced growth outside the fenced plots. To determine if pigs enhanced the spread of fennel by dispersing the seeds through their dung, 20 matched paired plots were established, with and without pig dung. Fennel growth was not enhanced in the immediate vicinity of pig dung.

ACKNOWLEDGMENTS

I wish to thank and acknowledge the efforts of Dr. Shannon Bros, who stayed with me and got me through it all; Wesley Colvin, for his support and advice; Brian Guererro, Jeff Howarth and Dr. Lyndal Laughrin of the Santa Cruz Island Reserve for their help in logistics on the island. Thanks go to The Nature Conservancy, which funded this study; and to the National Park Service, which provided island transportation. I wish to express gratitude to Sheila Covarrubias, Jerry Roe, Caroline Roudenbush, and Scott Slattery for their help in the actual construction of the experiment. Finally, to my family and friends for their endurance listening to me say that I was almost done for two years, and especially to my mom, who never got to see the finished product.

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INTRODUCTION

Activities of large mammals may cause a shift in species composition in plant communities from natives to exotics (Mack and D'Antonio 1998). Mammals introduced to an area may have a preference for native plant species which could lead to their extirpation (Van Vuren and Coblentz 1987, Vitousek 1988, Vitousek et al. 1996). Large mammals might also act to introduce exotic plant species if the seeds stick to their hides or hooves, or are present in their dung (Smith 1985, Stone 1985). Disturbances created by large mammals, such as feral pigs, *Sus scrofa*, may favor recruitment of adapted exotic plants over native species (Loope and Scowcroft 1985, Colvin and Gliessman 1999).

Feral pigs, in particular, may have great impact on ecosystems because of their high reproductive rate of one to two litters per year with up to five to six piglets per litter (Barrett 1978, Wood and Barrett, 1979, Baber and Coblentz 1986, Ray 1988, Beach 1993, Synatzske 1993). If unharvested, a pig population may theoretically double every four months (Katahira et al. 1993). In California, three boars and nine sows were introduced in Monterey County in 1925; by 1996, feral pigs had spread to 49 of California's 58 counties and 25% of California's total land area (Waithman et al. 1999).

Feral pigs are omnivorous. They prefer fruits, seeds, and mast, but will eat grass, forbs, bulbs, and roots. Pigs are voracious eaters and can consume one to two pounds of acorns per day (Martin, 1990). They will also eat berries, crops, eggs, earthworms, caterpillars, and other invertebrates when available. They opportunistically feed on

vertebrates, both live and as carrion (Pine and Gerdes 1973, Wood and Barrett 1979, Baber and Coblentz 1987, Hellgren 1993, Schauss et al. 1990).

In many ecosystems, feral pigs compete with native animals for food (Schauss et al. 1990, Sweitzer 1998). Their competitors include white-tailed deer, turkey, bear, and squirrels for oak mast (Wood and Barrett 1979, Ray 1988, Beach 1993, Synatzske 1993). Pigs have a competitive advantage over turkey and deer that feed by sight because they can smell buried acorns and further deplete the crop (Beach 1993).

Feral pigs create heavy disturbance by wallowing in water, which is necessary because pigs lack sweat glands and have poor thermoregulation (Baber and Coblentz 1986, Beach 1993, Hoehne 1994). This behavior can damage riparian corridors, collapse stream banks and muddy waterways. An increase in siltation from pig trampling and wallowing, along with contamination of the water from pig excrement, can have a negative impact on aquatic species (Beach 1993, Hoehne 1994).

Pig rooting can denude an area of vegetation and cause soil erosion, especially on hillsides, where up to 80 - 90% of the topsoil may be lost (Singer et al. 1984, Martin 1990, Beach 1993, Synatzske 1993). The constant soil disturbance can also lead to successional shifts, giving disturbance-adapted plants, such as exotic weeds, a competitive advantage over natives (Van Vuren and Coblentz 1987). As a consequence of rooting, the ground is left bare of vegetation, resulting in large fluctuations in temperature and correspondingly unfavorable growing conditions (Kotanen 1994). Rooting also disturbs the seed bank and may extirpate small mammals and herpetofauna living in the litter (Singer et al. 1984, Kotanen 1994). Disturbance from feral pigs have

economic consequences as well, with agricultural and ranching losses in the United States estimated at \$800 million per year (Bach and Conner 1993, Beach 1993, Pimentel et al. 2000).

The impacts of disturbance by feral pigs are especially noticeable on islands such as the Galapagos and the Hawaiian chain, with endemic species being especially impacted (Coblentz & Baber 1987, Vitousek 1988, Kathahira et al. 1993, Sweitzer 1998). Pigs may preferentially forage on native species because non-native species often have defenses which native species lack. Species indigenous to islands have no evolutionary history with large vertebrate herbivores and have not evolved defenses against grazing, such as noxious secondary chemical compounds or physical traits such as thorns or sclerotized leaves (Van Vuren and Coblentz 1987, Vitousek 1988, Kotanen 1995, Bowen and Van Vuren 1997). Furthermore, pigs may occur at much higher densities on islands (Sweitzer 1998). On Santa Catalina Island located off the coast of southern California, pig densities reached over 20/km² (Baber and Coblentz 1986). This is 10 times what is considered a high density in similar habitats on the mainland (Sweitzer and Van Vuren 2000).

Pigs have been considered a problem on Santa Cruz Island by the Nature Conservancy, which owns and manages it. Rooting activities were perceived as a potential threat to the endemic species of the island and pigs were suspected of spreading exotics plant species throughout the island. There was concern that their preference for natives may extirpate sensitive plant species from the island (Bowen and Van Vuren 1997). As the Nature Conservancy planned for the removal of the several thousand pigs

still on the island (National Park Service 2002) there was a need to know the impact of pig removal on the island's vegetation to help plan the restoration efforts.

The key goal of the present study was to assess the impact of Santa Cruz Island's largest free roaming mammal, the feral pig, on island vegetation. In an effort to determine how widespread the impacts of pigs are, the vegetation of the Santa Cruz Island's central valley was examined at both the population level and community level. At the population level, impacts of pig rooting and foraging were assessed by examining ground cover, vertical profile of plants, and plant height in areas where pigs were allowed access as compared to areas where they were not. Community level changes were assessed by measuring changes in species diversity and species composition relative to the presence or absence of pigs.

Also investigated was the possibility of a synergistic interaction between pig activity and the distribution and density of fennel, *Foeniculum vulgare*. Fennel is a highly invasive, disturbance-adapted perennial herb that can grow up to 3m high and crowd out other species, creating a fennel monoculture. Fennel has sticky seeds and pollen that easily adhere to pigs' fur and hooves when the animal travels through it. The concern was that areas disturbed by pigs gave fennel a substrate for recruitment which, in turn, provided cover for the pigs. To examine if interactions were indeed occurring, pig activity (rooting, dung counts, and distance from plot to pig trails) was measured and compared to the vegetation measurements to determine if there were correlations between these variables, and if the magnitude of pig activity was correlated with vegetation differences. Although rooting is a more accurate assessment tool for pig activity than

dung counts by themselves, measuring rooting and dung together gives a better idea of pig presence than either measure alone (Hone 1988, 1995, Hone and Warren 1998).

There is anecdotal evidence to suggest that pigs may facilitate the dispersal of fennel in their dung (S. Gleissman, Department Of Environmental Studies, University of California, Santa Cruz, CA 95064, Personal Communication, 1999). Fennel seeds may pass through the pig's gut intact, ending up in a nutrient rich medium. To investigate this possibility, an additional section of this project focused on the possibility that pig dung facilitates the dispersal of fennel.

MATERIALS AND METHODS

The study was conducted on Santa Cruz Island (Fig. 1), the largest of the Channel Islands, situated 30 km west of the southern coast of California at 34°N latitude, between 119° 40' and 119° 50'W longitude. The island dimensions are approximately 38 km long by 12 km at its maximum width, with an area of 249 square km (Junak, et al. 1995). The island was privately owned from the 1839 until 1978, when The Nature Conservancy purchased 90% of the island, and the National Park Service acquired the other 10%. It has had working ranches, farms, and a winery (Junak, et al. 1995). The island has a high level of diversity and is home to over 600 plant species and 200 bird species, of which 12 are endemic and 10 are endangered (National Park Service 2002, 2005). It is unique among the islands in that it has two mountain ridges that run west to east along both coasts, creating a central valley. The central valley is somewhat protected from the maritime influences and has a Mediterranean climate, with warm dry summers and an

average rainfall of 50 cm/year, falling from November to April. The valley floor is mostly composed of exotic grassland, with chaparral ringing the slopes.

Source: ESRI, GDT, USGS, NOAA, AP, Calif. Coastal Commission Chronicle Graphics

Figure 1: Location of study area on Santa Cruz Island. Reprinted with permission from the San Francisco Chronicle, 22 May 2002.

The study sites were located in the central valley, east of the main ranch and south of the wash. This area underwent a prescribed burned in the fall of 1997 and was then sprayed with Garlon 3A (triclopyr) during the springs of 1998 and 1999 (Gibson¹ 1999). The study sites were located there because more damage from the pigs had been observed

in this area than on the north side of the wash (S. Gleissman, personal communication 1999). There were 14 sites located between the east edge of the eucalyptus grove to about 1 km east of the grove, with two more sites located near the main ranch, for a total of 16 sites (Fig. 2). Each site contained two plots, one fenced exclusion plot and one unfenced plot that allowed for the occurrence of pigs. The precise locations of the sites were determined in September 2001 with a sub-meter differential GPS unit (Trimble Pro XR differential GPS receiver with TDC1 data logger, Fig. 3). The data were collected initially in May 2000, at three months (end of July 2000) and at one year (May 2001).

Figure 2: Site locations in the Central Valley. Part of main ranch is on the far left.

Plant cover, height, and relative abundance measurements were compared between plots that excluded pigs with fencing (exclusion plots) and unfenced plots that allowed the occurrence of pigs. To reduce the potential for variability, a randomized block design was used to minimize microhabitat variation.

Figure 3: Location of paired plots, showing individual plots (clockwise from bottom, plots 6, 7, 5 and 4). White line through middle of picture is the road.

Each plot measured 3 m x 4 m. At the corner of each plot, metal “T” stakes were driven into the ground leaving 1 m of the post above ground. In the fenced exclusion plots, 12 gauge, 1 m high “field fence” was strung around the posts. The unfenced plots that allowed pig access had only the metal posts and no fencing. The sampling area within a plot was restricted to a 1 m x 2.5 m area with a 0.75 m border between the boundary and the sampling plot (Fig. 4). To attempt to ensure that native species were available for recruitment, the plots were seeded at the end of August 2000 with native seeds gathered by Wesley Colvin of the University of California at Santa Cruz Agronomy laboratory (Appendix).

Figure 4: Plot design, showing fenced exclusion and unfenced access plots, along with sampling area.

A line intercept transect method (Barbour et al. 1999) was used to determine percent cover of plants at three different heights: ground level, 0.25 m, and 0.50 m above ground level. The transect line was oriented through the long axis of the plot and at the centerline. Estimates of cover were made to within 5 cm of the length of each patch (in each of the categories) that contacted the transect line.

Measurements of ground cover, plant heights, and cover of plants at two different heights gave a measure of the patchiness and vertical profile of the plant community. At ground level, grasses and other herbaceous plants (forbs), fennel, rooting, litter, and amount of bare ground were measured. The vertical profile measurements (above ground cover and plant height) were made for three groups: grass, forbs, and fennel. Mean patch size was estimated by computing the mean length of the patches per plot. The patches for each category were summed to estimate a total cover per plot at each height. Relative abundances of plant species were used to determine species diversity and species composition of the plant community.

A line intercept transect was also used to measure plant height as above. The transect was divided into 15 equal length segments. Within each segment, the height of the tallest plant in each of three categories (grasses, forbs, and fennel) was measured. For each category, mean heights and standard deviations were computed.

The sum of patch size from the ground cover measurements was used to estimate biomass at ground level. Mean patch size and standard deviation of the patch size for the five groups (grass, forbs, fennel, bare ground, and litter) were used to measure the degree of patchiness in the system at ground level. Plant height and plant cover at 0.25 m and

0.50 m above ground level were measured, and changes in the vertical profile between the fenced and unfenced plots were recorded at the different time intervals. Mean plant height was used as a measure of the overall height of vegetation in the three groups (grass, forbs, and fennel). Standard deviation in plant height was used to measure uniformity in height. As with the ground cover measurements, the sum of patch size was used to estimate biomass above ground. The standard deviation was used to measure the degree of patchiness of the vertical profile above ground level. Changes in cover at 0.25 m and 0.50 m were used as estimates of above ground biomass at different heights.

A wood frame containing a grid with 40 cells, each 0.25 m x 0.25 m, was used to measure relative abundance of plants (Fig. 5). To keep from matting the vegetation, the grid was supported by four 1 m legs. All species present in a cell were recorded. Relative abundance at each plot was estimated as a proportion: number of cells in which a species is found, divided by the total number of cells (40).

A two-way Analysis of Variance (ANOVA) with a block (Krebs 1989, Zar 1999) was used to determine if changes occurred between fenced and unfenced plots over time. The dependent variables were heights of plants, percent cover for all the groups at the three heights, and the relative abundances of plant species. The two independent variables were fenced or unfenced, and time (0, 3, and 12 months). Site was used as a block in the analysis. A significant Fenced effect indicated the fenced and unfenced plots differed regardless of time. A significant Time effect indicated that the measured variable changed over time but did not differ between fenced and unfenced plots. A significant Block effect indicated the block design was necessary. A significant

Fenced*Time interaction indicated that differences between fenced and unfenced plots changed over time.

Figure 5: Sampling frame for measuring relative abundance.

Measures of species diversity and species composition were used to determine if community-level changes occurred between fenced and unfenced plots. A Two-Way Multivariate Analysis of Variance (MANOVA) with a block, (Zar 1999) was used to test

for differences in species diversity. The two independent variables were fenced or unfenced, and Time (0, 3, and 12 months). Site was used as the block. Species richness and evenness, components of species diversity, were used as the dependent variables in the analysis to determine which aspect of diversity was affected. Species richness per plot was computed as the number of species found in a plot per time period. The Shannon-Weiner diversity function (H') (Krebs 1989) was computed for all plots at all times (0, 3, and 12 months) and then used to estimate species evenness (J'):

$$H' = \sum (p \cdot \log_2(p))$$

where p = proportional abundance.

$$J' = H'/H'_{\text{MAX}} \text{ where}$$

$$H'_{\text{MAX}} = -S(1/S \log_2 1/S) = \log_2 S$$

and S is species richness

If a significant univariate Fenced*Time interaction occurred for richness and/or evenness, it indicated that the dependent variable differed between fenced and unfenced plots and that this difference changed over time. A significant multivariate Fenced*Time interaction indicated that evenness and richness changed between fenced and unfenced plots in different ways over time.

Percent Similarity (P_{XX}) (also known as the Renkonen Index, Krebs 1989) was used to compare species composition between fenced and unfenced plots over time because it is relatively unaffected by sample size and magnitude of diversity.

$$P_{12} = \sum \min(p_{1i}, p_{2i})$$

Where: p_{1i} = percentage of species in community sample 1 and p_{2i} = percentage of species i in community sample 2

Only relative abundances were used in the similarity comparisons. A paired t-test was used to analyze the differences in plot similarities between May 2000 and May 2001 to determine if the sites diverged in species composition.

Three measures of pig activity were made at each site in 2001 to determine if the magnitude of pig activity was related to differences in vegetation between the fenced and unfenced plots. The distance and direction of any pig trails within 10 m of the site were recorded. For analysis, distance to the trail was averaged at each site. All pig dung within a 3 m perimeter of a site was counted. The presence of rooting in the plots was also recorded. Differences between fenced and unfenced values for all vegetation measures were computed and then compared to the pig activity measurements with Pearson's Product Moment Correlation Coefficient (Zar 1999) to determine if magnitude of pig activity was related to the degree of difference in vegetation between fenced and unfenced sites. Percent similarity was also correlated with pig activity by subtracting the year 2000 similarities from the year 2001 similarities, and then correlating the difference with the pig activity variables.

A matched pair design was used to determine if pig dung enhanced fennel growth. Areas surrounding the plots were examined for the presence of pig dung. When a dung sample was located it was enclosed in a hardware cloth "basket" that measured 0.25 m x 0.25 m to protect the dung from destruction by birds, pigs, or other animals. The baskets were staked down with landscape staples. As a control, an additional 0.25 m x 0.25 m area, located near the dung plot but containing no dung, was enclosed. The control plot was visually matched so that the plant species composition was similar to the

corresponding dung plot. Twenty pairs of baskets were set out in the beginning of October 2000. The dung was left in place, rather than be removed to a remote location for grow-out under artificial conditions. In May of 2001, relative abundances of fennel and non-fennel species were recorded for both the dung and control baskets and a two-way ANOVA was used to test for differences between the dung and control plots. Site was used as a block.

RESULTS

The results indicated that a block design was essential for examining all effects of the presence or absence of pigs on vegetation. Highly significant block effects occurred in most of the two-way ANOVAs for ground cover, vertical profile and relative abundance measurements as well as in the multivariate tests for species diversity and composition (Tables 1, 2, 3, and 4). This indicated that the habitat was highly variable, and that blocking was needed to extract differences that would otherwise be lost to random variation.

Litter patch size increased significantly in areas where pigs were excluded (fenced plots) and decreased in areas where pigs were present (unfenced plots). These effects increased over the year long study period, as shown by the significant ($p = 0.021$) Fenced*Time interaction (Table 1, Fig. 6). The two-way ANOVA of data for ground cover for the other four categories (grass, forbs, fennel, and bare ground) showed no significant Fenced, Time, or Fenced*Time effects. This indicates that, other than litter, pigs did not have a great effect on the physical characteristics of the plants at ground level (Table 1).

Table 1: Partial Two-Way ANOVA (with block) for ground cover measurements. Factors are Fenced, Time, and Block. The table is arranged by effect rather than by measured variable. Significant effects are emphasized in bold.

Source	<u>Fenced</u>			<u>Time</u>			<u>Block</u>			<u>Fenced*Time</u>		
	df	F	p	df	F	p	df	F	p	df	F	p
Bare Ground – sum of patch	1	1.030	0.326	2	1.209	0.313	15	6.968	<0.001	2	0.423	0.659
Bare Ground – mean patch size*	1	0.652	0.432	1	1.539	0.234	15	3.140	0.017	1	0.256	0.620
Fennel – sum of patches	1	1.000	0.333	2	1.000	0.380	15	3.571	0.001	2	1.000	0.380
Forb – sum of patches	1	0.991	0.335	2	1.211	0.312	15	5.581	<0.001	2	1.427	0.256
Grass – sum of patches	1	1.952	0.183	2	2.116	0.138	15	1.593	0.135	2	0.592	0.560
Litter – sum of patches	1	1.654	0.218	2	1.052	0.362	15	54.115	<0.001	2	2.778	0.078
Litter – mean patch size*	1	0.300	0.592	1	0.699	0.416	15	4.248	0.004	1	6.694	0.021
Litter – SD of patch size*	1	0.003	0.954	1	0.597	0.452	15	2.413	0.049	1	3.949	0.065

*No measurement at t = 0

Figure 6: Significant Fenced*Time interaction from the Two-Way ANOVA on mean litter patch size.

($p = 0.021$)

Pigs had a negative effect on grasses, as shown by the analyses of vertical profile transects (which included plant height and above ground cover for grass, forbs, and fennel, Table 2). The two-way ANOVA showed that the mean height of grass increased significantly over time in the plots where pigs were excluded versus the plots where pigs were allowed access ($p = 0.009$, Fig. 7). The sum of patches of grass at 0.25 m was also significantly different over time between the fenced exclusion plots and the unfenced plots ($p = 0.002$, Fig. 8). The unfenced plots where pigs were allowed to roam showed more variation than in the fenced plots, with the sum of patches at 0.25 m in the unfenced areas decreasing more than in the fenced plots in the summer, and then recovering to a greater size by the next spring. The three-month measurements, taken in July 2000, show a greatly reduced vertical profile because most of the grasses had died. Fennel, however, remained relatively unaffected because it continued to grow through the fall. There were no significant Fenced or Fenced*Time effects for either forbs or fennel.

Table 2: Partial Two-Way ANOVA (with block) for vertical profile measurements. Factors are Fenced, Time, and Block. The table is arranged by effect rather than by measured variable. Significant effects are emphasized in bold.

Source	Fenced			Time			Block			Fenced*Time		
	df	F	p	df	F	p	df	F	p	df	F	p
Fennel – mean height	1	4.022	0.063	2	2.140	0.135	15	3.087	0.004	2	1.656	0.208
Fennel – mean patch size at 0.50 m*	1	1.974	0.180	1	1.815	0.198	15	1.000	0.500	1	1.974	0.180
Fennel – mean patch size at 0.25 m*	1	1.968	0.181	1	1.744	0.206	15	28.182	<0.001	1	0.982	0.338
Fennel – sum of patches at 0.50 m	1	4.133	0.060	2	0.556	0.579	15	2.628	0.012	2	0.556	0.579
Fennel – sum of patches at 0.25 m	1	3.297	0.089	2	2.288	0.119	15	4.67	<0.001	2	2.942	0.068
Fennel height – SD	1	3.989	0.064	2	3.163	0.057	15	5.707	<0.001	2	2.448	0.104
Forb – mean height	1	0.158	0.697	2	1.988	0.155	15	6.966	<0.001	2	1.190	0.318
Forb – mean patch size at 0.50 m*	1	0.372	0.551	1	1.974	0.180	15	1.000	0.500	1	0.372	0.551
Forb – mean patch size at 0.25 m*	1	0.147	0.707	1	1.573	0.229	15	1.000	0.500	1	0.147	0.707
Forb – sum of patches at 0.50 m	1	0.025	0.876	2	1.707	0.199	15	2.010	0.051	2	0.196	0.823
Forb – sum of patches at 0.25 m	1	0.044	0.837	2	0.983	0.386	15	1.369	0.225	2	1.054	0.361
Forb height – SD	1	0.926	0.351	2	2.181	0.130	15	5.009	<0.001	2	0.376	0.690
Grass – mean height	1	4.661	0.047	2	7.461	0.002	15	22.005	<0.001	2	5.574	0.009
Grass – mean patch size at 0.50 m*	1	0.165	0.690	1	18.493	0.001	15	1.073	0.447	1	2.290	0.151
Grass – mean patch size at 0.25 m*	1	0.577	0.459	1	4.621	0.048	15	1.213	0.357	1	0.910	0.355
Grass – sum of patches at 0.50 m	1	<0.001	0.984	2	4.956	0.014	15	0.565	<0.001	2	1.558	0.227
Grass – sum of patches at 0.25 m	1	0.401	0.536	2	27.597	<0.001	15	2.625	0.012	2	7.548	0.002
Grass height – SD	1	2.231	0.156	2	2.146	0.135	15	2.756	0.009	2	0.300	0.743
Grass – SD of patch size at 0.50 m*	1	0.111	0.743	1	2.506	0.134	15	1.653	0.171	1	0.654	0.431
Grass – SD of patch size at 0.25 m*	1	0.922	0.352	1	1.279	0.276	15	1.283	0.318	1	0.558	0.467

* No measurements at t = 0

Figure 7: Significant Fenced*Time interaction from the Two-Way ANOVA on mean grass height.

($p = 0.009$)

Figure 8: Significant Fenced*Time interaction from the Two-Way ANOVA on sum of grass patches at 0.25

m. ($p = 0.002$)

The two-way ANOVA for the vertical profile of plants showed that, regardless of the presence or absence of pigs, grass patch size and cover decreased in July 2000 but returned to previous levels by May 2001. Mean patch size of grass at 0.50 m increased significantly over time ($p = 0.001$, Fig. 9). The sum of patches of grasses at 0.50 m also showed significant Time effects ($p = 0.014$, Fig. 10).

Figure 9: Significant Time effect from the Two-Way ANOVA on mean patch size of grasses at 0.50 m ($p = 0.001$)

Figure 10: Significant Time effect from the Two-Way ANOVAs on sum of patches at 0.50 m. ($p = 0.014$)

The presence of pigs had varying effects on the relative abundance of the various plant species found originally in the plots. None of the seeded native species (Appendix) grew in any plot during the length of the study. A significant Fenced*Time effect for the relative abundance of fennel showed that the difference in relative abundance of fennel increased over time between fenced and unfenced plots ($p = 0.037$); fennel tended to be more abundant in the fenced plots (Fig. 11).

Figure 11: Fenced*Time effect from Two-Way ANOVA on the relative abundance of fennel. ($p = 0.037$)

For the remaining 12 species, there were no apparent changes in relative abundance because of the exclosures; neither Fence nor Fence*Time effects were significant (Table 3). Several annual grasses had significant time effects in relative abundance. *Avena sp.*, *Bromus diandrus*, *Bromus hordeaceus* and *Hordeum murinum* all showed a decrease in July 2000 from May 2000, but returned to previous levels by May 2001 (Fig. 12, 13). *Lolium multiflorum* showed a similar pattern but was much higher in abundance in 2000,

and did not fully return to previous levels in 2001 (Fig. 13). The relative abundance of forbs did not change significantly over time.

Figure 12: Significant Time effects from Two-Way ANOVAs on the relative abundances of *Avena* spp. ($p < 0.001$) and *Bromus diandrus* ($p < 0.001$).

Figure 13: Significant Time effects from Two-Way ANOVAs on the relative abundances of *Bromus hordeaceus* ($p = 0.007$), *Hordeum murinum* ($p = 0.008$) and *Lolium multiflorum* ($p < 0.001$).

Table 3: Partial Two-Way ANOVA (with block) for relative abundance measurements. Factors are Fenced, Time, and Block. The table is arranged by effect rather than by measured variable. Significant effects are emphasized in bold.

<u>Source</u>	<u>Fenced</u>			<u>Time</u>			<u>Block</u>			<u>Fenced*Time</u>		
	df	F	p	df	F	p	df	F	p	df	F	p
<i>Avena</i> spp.	1	0.007	0.935	2	63.778	<0.001	15	7.489	<0.001	2	0.495	0.615
<i>Bromus carinatus</i>	1	0.212	0.652	2	3.321	0.050	15	13.738	<0.001	2	2.79	0.077
<i>Bromus diandrus</i>	1	2.335	0.147	2	108.24	<0.001	15	14.662	<0.001	2	1.601	0.218
<i>Bromus hordeaceus</i>	1	0.376	0.549	2	5.819	0.007	15	6.635	<0.001	2	1.663	0.207
<i>Elymus glaucus</i>	1	0.958	0.343	2	1.669	0.205	15	1.749	0.094	2	0.797	0.460
<i>Erodium</i> spp.	1	0.547	0.471	2	2.604	0.091	15	5.463	<0.001	2	0.916	0.411
<i>Foeniculum vulgare</i>	1	2.186	0.160	2	0.975	0.389	15	29.625	<0.001	2	3.677	0.037
<i>Hordeum murinum</i>	1	1.162	0.298	2	5.619	0.008	15	19.881	<0.001	2	1.331	0.279
<i>Lolium multiflorum</i>	1	0.034	0.856	2	43.058	<0.001	15	12.503	<0.001	2	1.947	0.160
<i>Medicago polymorpha</i>	1	2.853	0.112	2	2.612	0.090	15	27.317	<0.001	2	2.854	0.073
<i>Convolvulus arvensis</i>	1	0.954	0.344	2	0.774	0.470	15	13.747	<0.001	2	0.157	0.855
<i>Centaurea solstitialis</i>	1	0.002	0.966	2	1.950	0.160	15	10.022	<0.001	2	0.002	0.998

The presence of pigs impacted species composition but not species diversity (Table 4, Fig. 14). Species composition decreased significantly in similarity ($p = 0.027$) between fenced and unfenced plots, using the Renkonen similarity index ($t = -2.547$, $df = 15$, Fig. 14). Eleven sites decreased in similarity from 2000 to 2001, four sites increased in similarity, and one remained unchanged. This shift was caused primarily by an increase in abundance of fennel in the fenced plots. The MANOVA showed no measurable impact of pig presence on plant species diversity as measured by species richness and species evenness (Table 4). There was, however, a significant decrease in species evenness over time, independent of the presence of pigs (Table 4, Fig. 15).

Evidence of pig activity was present at all sites. The number of pig trails per plot was fairly consistent at two to three per site. The amount of pig dung and rooting were variable among sites. There were two correlations between the magnitude of pig activity and the effects caused by the pigs. There was a high correlation between relative abundance of fennel and the relative abundance of rooting between the fenced and unfenced plots ($r = 0.917$, Fig. 16); however, the strong correlation was heavily influenced by a single data point. There was also a strong correlation between relative abundance of rooting and the difference of sum of litter patches ($r = 0.907$, Fig. 17).

Apparently, passage through the digestive tract of pigs did not have a positive effect on fennel growth. In the experiment on the importance of pig dung in the dispersal of fennel, there was no evidence of fennel in the treatment or control dung cages after a full growing season. Since no fennel was found, no analysis was performed.

Table 4: Partial Two-Way ANOVA (with block) for species diversity, as measured by species richness and evenness. Factors are Fenced, Time, and Block. Partial Two-Way MANOVA (with block). Significant effects are emphasized in bold.

<u>ANOVA</u>	<u>Fenced</u>			<u>Time</u>			<u>Block</u>			<u>Fenced*Time</u>		
	df	F	p	df	F	p	df	F	p	df	F	p
Species Richness	1	0.031	0.862	1	3.947	0.066	15	6.843	<0.001	1	2.288	0.151
Species Evenness	1	0.002	0.966	1	8.791	0.010	15	9.506	<0.001	1	3.608	0.077
<u>MANOVA</u>	2,14	0.104	0.902	2,14	4.364	0.034	30,26	5.326	<0.001	2, 14	1.963	0.177

Figure 14: Changes in Percent Similarity per site between fenced and unfenced plots from May 2000 to May 2001. The lines are graphical representations of the changes in similarities between each set of paired plots from 2000 to 2001. A lower number indicates less similarity between plots.

Figure 15: Significant Time effect from the Two-Way ANOVA for Species Evenness (J).

Figure 16: Correlation between relative abundance of rooting and the difference (between fenced and unfenced) in relative abundance of fennel. Points at zero jittered to show all points.

Figure 17: Correlation between relative abundance of rooting and the difference (between fenced and unfenced) in the sum of litter patches. Points at zero jittered to show all points.

DISCUSSION

The design elements of the experiment were important in facilitating the detection of impacts from pigs. The small scale of the plots allowed detection of small changes in the physical characteristics and species composition of the vegetation. If monitoring had been performed on a larger scale, with larger exclosures, the ability to detect small changes might have been lost due to the larger amount of noise, making it more difficult to measure small changes in community structure. With the smaller scale, it was possible, with sufficient sample size, to observe changes in a shorter time span (Loope and Scowcroft 1985). Because variability in habitat between plots was high, blocking treatments within similar microhabitats was important to increase the power of the experimental design (Buffon² 1994).

This study showed that pigs have impacts on the physical structure of the vegetation in the central valley of Santa Cruz Island and that the findings were not an artifact of the experimental design. There was evidence of pig activity at all sites, so any changes in vegetation were due to pig activity, not habitat variability. Over the period of the study, pigs had the greatest impact on litter, vertical profile of grasses, and fennel. The litter layer was deeper and the grass was taller in the fenced plots. Fennel was both taller and denser in the fenced plots. Singer, et al. (1984) found significantly greater litter and plant cover when pigs were excluded from previously heavily rooted areas. Sweitzer and Van Vuren (2000), in their study of pig rooting effects on oak recruitment, found that oak seedlings were more abundant and larger in areas excluded from pigs. There was only a slight relationship between the differences in vegetation and the magnitude of pig

activity. Perhaps the range in magnitude was not large enough to detect these relationships. Hone and Stone (1989) also found vegetation changes from pigs that did not correlate with the magnitude of pig activity.

The rooting and trampling habits of pigs altered the species composition of the vegetation. Plant species composition became more dissimilar over time between the fenced and unfenced plots, primarily due to changes in the abundance of fennel. While the number of plant species (species richness) was not significantly different between plots over time, the distribution of plant species (species evenness) diminished over time, whether or not the plots were excluded from pigs. Therefore, while the changes in composition were attributable to pigs, any changes in diversity were not.

Pig activities had a negative impact on fennel growth. It is likely that pigs were responsible for the decrease of fennel in the unfenced plots because the decrease in fennel appeared to be correlated with rooting. The difference in relative abundance of fennel between the fenced and unfenced plots, while only marginally significant during the period of the study, increased over time. Approximately 16 months later, the fennel was taller and denser in the fenced exclosures (personal observation, Fig. 18). The same trend was observed in the fenced portion of a paired plot experiment from a previous study on Santa Cruz Island (Peart 1994 et al.); after a period of 10 years, it was clear that fennel was much greater in height and density in the fenced exclosures than in the surrounding grassland.

In this study, the effects on the vegetation were caused primarily by pig activities and not by cows, the other large mammals on the island. There were several times in

Figure 18: Fennel growing abundantly inside fenced plot 16, whereas only two fennel plants grew in unfenced plot 16. Photo taken 16 months after the end of the study.

2001 where cows escaped from a fenced pasture near the main ranch and roamed freely about the valley. However, it is unlikely that the presence of cows affected the results in a significant way. The majority of the sites were situated 1 to 2 km away from pasture where the cows were kept and cow dung was observed only three times near the study sites during the study.

No evidence was found to support the hypothesis that pig dung facilitates the dispersal of fennel on the island. There were no fennel plants found growing in any of the pig dung plots. Grasses and forbs, however, were found growing successfully in all the pig dung plots. Apparently, the fennel seeds are not preferentially passed through the pigs' guts, and do not have a benefit over other seeds of growing in pig dung.

It was hoped that the introduction of native seeds in areas where pigs have foraged might help recovery of the native vegetation but the seeding efforts were apparently not

successful. During the period of the study, none of the native species that were seeded was observed in either the fenced or unfenced plots. Other long term seeding studies on the island also have not shown much growth by native species (Colvin and Gliessman 1999, W. Colvin, Department Of Environmental Studies, University of California, Santa Cruz, CA 95064, Personal Communication, 2000). It appears that factors other than pigs have caused failure of the seeds to grow

Removal of pigs from the island as part of an effort to restore the native vegetation will have complex and unanticipated effects, both positive and negative. As shown in this study, when pigs are excluded from the grassland areas of the central valley, fennel is denser than in areas exposed to the pigs. This release of fennel was also observed in 1988 when most of the cows were removed from the island. By 1991, 10% of the island was covered by fennel (Beatty and Licari 1992, Brenton & Klinger 1994). It is likely that after the pigs are removed there will be an increase in fennel abundance. Therefore, fennel monitoring and removal efforts may have to be increased after the pigs are removed.

Unanticipated effects are not unusual. In a study similar to this one, Buffon² (1994) found that deer heavily browsed both native and exotic plant species. Singer et al. (1984), Synatzske (1993), and Kotanen (1994, 1995) all cited mixed effects of pig rooting, some were positive while some caused damage. This suggests that exotic/native interactions are complex. Therefore, it is essential to conduct matched pair studies like this one, the results of which will give managers a better idea of what to expect and how to effectively plan for restoration projects.

LITERATURE CITED

- Baber, D. W., and B. E. Coblentz. 1986. Density, home range, habitat use, and reproduction in feral pigs on Santa Catalina Island. *Journal of Mammalogy*. 67:512-525.
- Baber, D. W., and B. E. Coblentz. 1987. Diet, nutrition, and conception in feral pigs on Santa Catalina Island. *Journal of Wildlife Management*. 51:306-317.
- Bach, J.P. and J.R. Conner. 1993. Economics and human interactions of the wild hog in Texas. Pages 88-100 *in*: C. W. Hanselka and J.F. Cadenhead, editors. *Feral Swine: A Compendium For Resource Managers*. Proceedings of a Conference held 24 March to 25 March 1993.
- Barbour, M.G., J.H. Burk, F.S. Gilliam, W.D. Pitts, and S.W. Schwartz. 1999. *Terrestrial Plant Ecology*. Benjamin/Cummings Pub. Co., Third Edition. 210-238.
- Barrett, R. H. 1978. The feral hog at Dye Creek Ranch, California. *Hilgardia*. 46(9):283-355.
- Beach, R. 1993. Depredation problems involving feral hogs. Pages 67-75 *in*: C. W. Hanselka and J.F. Cadenhead, editors. *Feral swine: A Compendium For Resource Managers*. Proceedings of a Conference held 24 March to 25 March 1993.
- Beatty, S.W. and D.L. Licari. 1992. Invasion of fennel, *Foeniculum vulgare*, into shrub communities on Santa Cruz Island, California. *Madrono*. 39(1):54-66.
- Bowen, L. and D. Van Vuren. 1997. Insular endemic plants lack defenses against herbivores. *Conservation Biology*. 11(5) 1249-1254.

- Brenton, B. and R. Klinger. 1994. Modeling the expansion of fennel, *Foeniculum vulgare*, on the Channel Islands. Pages 497-504 in: Halvorson, W., and G. Meander, editors. The Fourth Channel Islands Symposium: Update on the Status of Resources. Santa Barbara Museum of Natural History: Santa Barbara, California.
- Coblentz, B.E. and D.W. Baber. 1987. Biology and control of feral pigs on Isla Santiago, Galapagos, Ecuador. The Journal Of Applied Ecology. 24:403-418.
- Colvin III, W.I. and S.R. Gliessman. 1999. Fennel, *Foeniculum Vulgare*, management and native species enhancement on Santa Cruz Island, California. Pages 184-189 in: Browne, D. R., K. L. Mitchell, and H. W. Chaney, editors. Proceedings of the Fifth California Islands Symposium, 29 March to 1 April 1999. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Hellgren, E.C. 1993. Biology of Feral Hogs *Sus scrofa* in Texas. Pages 50-58 in: C. W. Hanselka and J.F. Cadenhead, editors. Feral Swine: A Compendium for Resource Managers. Proceedings of a Conference held 24 March to 25 March 1993.
- Hoehne, V.M. 1994. Wild pigs in Santa Cruz County. Fremontia. 22(2):18-19.
- Hone, J. 1988. Evaluation of methods for ground survey of feral pigs and their signs. Acta Theriologica. 33:451-465.
- Hone, J. and C. P. Stone. 1989. A comparison and evaluation of feral pig management in two national parks. Wildlife Society Bulletin. 17:419-425.
- Hone, J. 1995. Spatial and temporal aspects of vertebrate pest damage with emphasis on feral pigs. Journal of Applied Ecology. 32:311-319.

- Hone, J. and W. Martin. 1998. A study of dung decay and plot size for surveying feral pigs using dung counts. *Wildlife Research*. 25:255-260.
- Junak, S., T. Ayers, R. Scott, D. Wilken and D. Young. 1995. A Flora of Santa Cruz Island. Santa Barbara Botanic Garden, Santa Barbara, California.
- Kathahira, L.K., P. Finnegan, C.P. Stone. 1993. Eradicating feral pigs in montane mesic habitat at Hawaii Volcanoes National Park. *Wildlife Society Bulletin*. 21:269-274.
- Kotanen, P. 1994. Effects of feral pigs on grasslands. *Fremontia*. 22(2):14-17.
- Kotanen, P. 1995. Responses of vegetation to changing regime of disturbance: effects of feral pigs in a California coastal prairie. *Ecography* 18(2):190-198.
- Krebs, C.S. 1989. *Ecological Methodologies*. Harper & Row New York. Pages 272, 291-370.
- Loope, L.L. and P.G. Scowcroft. 1985. Vegetation response within exclosures in Hawai'i: A review. Pages 377-402 *in*: Stone, C.P. and J. M. Scott, editors. Hawai'i's Terrestrial Ecosystems: Preservation and Management. Proceedings of a symposium held June 5-6, 1984 at Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit, University Of Hawaii, Honolulu.
- Mack, C.M and C. M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. *Trends in Ecology & Evolution*. 13(5): 195-198.
- Martin, G. 1990. Hog wild: From suburban flower beds to golf courses, ravenous pigs are eating their way through California. *Discover Magazine*. 11(6):42-46.
- National Park Service. 2002. Santa Cruz Island primary restoration plan. Final

- environmental impact statement. U.S. Department of the Interior. Channel Islands National Park, Ventura, California.
- National Park Service. 2005. Santa Cruz Island – Ecological and Cultural Significance. U.S. Department of the Interior. Channel Islands National Park, Ventura, California.
- Peart, D., D.T. Patten and S.L. Lohr. 1994. Feral pig disturbance and woody species seedling regeneration and abundance beneath Coast Live Oaks (*Quercus agrifolia*) on Santa Cruz Island, California. Pages 313-322 *in*: Halvorson, W., and G. Meander, editors. The Fourth Channel Islands Symposium: Update on The Status of Resources. Santa Barbara Museum of Natural History: Santa Barbara, California.
- Pimentel, D., L. Lach, R. Zuniga and D. Morrison. 2000. Environmental and economic costs associated with nonindigenous species in the United States. *BioScience*. 50(1):53-65.
- Pine, D. S., and G. L. Gerdes. 1973. Wild pigs in Monterey County, California. *California Fish and Game*. 59(2):126-137.
- Ray, J. C. 1988. Wild pigs in California: a major threat in California. *Fremontia*. 16(1):3-8.
- Schauss, M. E., H. J. Coletto, and M. J. Kutilek. 1990. Population characteristics of wild pigs, *Sus scrofa*, in eastern Santa Clara County, California. *California Fish and Game*. 76:68-77.

- Singer, F.J., W.T. Swank, and E.E.C. Clebsch. 1984. Effects of wild pig rooting in a deciduous forest. *Journal of Wildlife Management*. 48(2):464-473.
- Smith, C.W. 1985. Impact of alien plants on Hawai'i's native biota. Pages 180-250 *in*: Stone, C.P. and J. M. Scott, editors. *Hawai'i's Terrestrial Ecosystems: Preservation and Management*. Proceedings of a symposium held June 5-6, 1984 at Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit, University Of Hawaii, Honolulu.
- Stone, C.P. 1985. Alien animals in Hawai'i's native ecosystem: toward controlling the adverse effects of introduced vertebrates. Pages 251-297 *in*: Stone, C.P. and J. M. Scott, editors. *Hawai'i's Terrestrial Ecosystems: Preservation and Management*. Proceedings of a symposium held June 5-6, 1984 at Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit, University Of Hawaii, Honolulu.
- Sweitzer, R.A. 1998. Conservation implications of feral pigs in island and mainland ecosystems and a case study of feral pig expansion in California. Pages 26-34 *in*: Baker, R.O. and A.C. Crabb, editors. *Proceedings of the 18th Vertebrate Pest Conference 18*. University of California, Davis.
- Sweitzer, R.A. and D. Van Vuren. 2000. Rooting and foraging effects of wild pigs on tree regeneration and acorn survival in California's oak woodland ecosystems. USDA Forest Service General Technical Report PSW-GTR-xxx-2000.

- Synatzske, D.R. 1993. The ecological impacts of feral swine. Pages 59-66 *in*: C. W. Hanselka and J.F. Cadenhead, editors. Feral swine: A Compendium For Resource Managers. Proceedings of a conference held 24 March to 25 March 1993.
- Van Vuren, D. and B.E. Coblenz. 1987. Some ecological effects of feral sheep on Santa Cruz Island, California, USA. *Biological Conservation*. 41:253-268.
- Vitousek, P. 1988 Diversity and biological invasions of oceanic islands. Pages 181-189 *in*: Wilson, E.O., editor. *Biodiversity*. National Academic Press.
- Vitousek, P., C. M. D'Antonio, Loope, L.L., R. Westbrooks. 1996. Biological invasions as global environmental change. *American Scientist*. 84:468-478.
- Waithman, J.D., R.A. Sweitzer, D. Van Vuren, J.D. Drew, A.J. Brinkhaus, I.A. Gardner, and W.M. Boyce. 1999. Range expansion, population sizes, and management of wild pigs in California. *Journal of Wildlife Management*. 63(1):298-308.
- Wood, G.W. and R.H. Barrett. 1979. Status of wild pigs in the United States. *Wildlife Society Bulletin*. 7:236-246.
- Zar, J.H. 1999. *Biostatistical Analysis*. Prentice-Hall NJ. Pages 178-179, 189-195, 250-255.

FOOTNOTES

- ¹Gibson, J.1999. Factors influencing the distribution and abundance of lizards following the removal of an invasive non-native weed on Santa Cruz Island. San Jose State University. Unpublished report to The Nature Conservancy.
- ²Buffon, E.J. (1994) Effects of black-tailed deer (*Odocoileus hemionus*) on the understory vegetation at Asilomar State Beach and Conference Grounds. Master's Thesis, San Jose State University, San Jose, CA 40 pp.

APPENDIX

Native plant seeds were collected throughout the central valley of Santa Cruz Island by Wesley Colvin of the University of California at Santa Cruz Agronomy laboratory. These seeds were then distributed among the plots at the end of August 2000 in the amounts shown below.

<u>Species</u>	<u>Amt. of Propagule</u>	<u>Common Name</u>
<i>Gnaphalium canescens</i>	4 g of seed head/ plot	Everlasting
<i>Eriogonum arborescens</i>	20 g of seed head/ plot	Buckwheat
<i>Acourtia microcephala</i>	1 g of seed head/ plot	Sacapellote
<i>Heterotheca grandiflora</i>	4 g of seed head/ plot	Telegraph Weed
<i>Comarostaphylos diversifolia planifolia</i>	2 g of fruit/ plot	Summer Holly
<i>Rhamnus crocea</i>	8 g of fruit/ plot	Buckthorn
<i>Rhus integrifolia</i>	3 g of fruit/ plot	Lemonade Berry
<i>Rosa californica</i>	2 g of rose hips/ plot	California Rose
<i>Baccharis pilularis</i>	1 g of seed head/ plot	Coyote Bush
<i>Arctostaphylos insularis</i>	4 berries/ plot	Santa Cruz Is. Manzanita
<i>Arctostaphylos insularis</i>	0.2 g of seed/ plot	Santa Cruz Is. Manzanita
<i>Cercocarpus betuloides var. blanchae</i>	0.2 g/ plot	Mountain Mahogany

Subj: **RE: Permission to use map from article**
Date: 4/4/2005 4:10:56 P.M. Pacific Standard Time
From: DPerlman@sfchronicle.com
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Sure, use it, but be sure to say it's from The Chronicle. Good luck!

-----Original Message-----

From: Misujerr@aol.com [mailto: Misujerr@aol.com]
Sent: Monday, April 04, 2005 3:20 PM
To: Perlman, David
Subject: Permission to use map from article

Dear Mr. Perlman,
I am finishing up my thesis on feral pig effects on vegetation on Santa Cruz Island, and would really like to use the map that was in this article:

Nurturing nature
Biologists try to restore fox, bald eagle populations on Santa Cruz Island

URL:
<http://www.sfgate.com/cgi-bin/article.cgi?file=/chronicle/archive/2002/05/22/BA25765.DTL>

This is the map:
http://www.sfgate.com/c/pictures/2002/05/22/ba_islandmap.jpg

I wrote the author, Michael McCabe, some time ago, and never heard back from him. Since you are the editor, I figured that you would be the one to give the OK.
Thank you for your consideration,
Greg Yost
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