Recent Geomorphic and Vegetal Dynamics on Santa Cruz Island, California

Robert W. Brumbaugh

Department of Geography, University of California, Los Angeles, California 90024

INTRODUCTION

Santa Cruz Island landscape has undergone significant change over the past one hundred years, generally due to widespread sheep-grazing activities. The native plant communities of Santa Cruz Island have been substantially modified. Accelerated erosion phenomena, especially intense hillslope gully development, are common features on the denuded hillslopes. Historical accounts, old photographs, and field evidence indicate that prior to the onset of sheep grazing in the mid-nineteenth century some areas of the island, now nearly barren, supported more vegetation. However, recent sheep removal from portions of the island has accounted for vegetation recovery and reversal of the accelerated erosion processes. A map of Santa Cruz Island, with place names referred to in the text, is given in Figure 1.

Transcripts of the U.S. District Court Proceedings (1857) indicate that Dr. James B. Shaw introduced sheep, cattle, and horses in 1853. Lt. Comdr. James Alden of the U.S. Coast Survey indicated that Santa Cruz Island had a few cattle and no inhabitants in 1852 (Alden 1852). He made no mention of sheep on Santa Cruz, although the adjacent island of Santa Rosa was listed by Alden as having 10,000 sheep. However, a year later, Harris Newmark (Newmark 1930) mentions that "at the time of my arrival [in Los Angeles in 1853], most of the mutton then consumed in Los Angeles [came] from Santa Cruz Island . . . [which] had much larger herds, and steamers running to and from San Francisco often stopped there to take on sheep and sheep products." Newmark could have been referring to Santa Rosa Island, which was well stocked by then. In addition, Dunkle (1950) states that there were 200 sheep on Santa Cruz Island in 1852. Pigs, which, along with the sheep, are now wild on the island, may also have been introduced during this time (U.S. District Court Proc. 1857, Phillips 1927, Glassow 1977). By 1857, there were some 7,000 or 8,000 head of sheep on the island (Greenwell 1858), and by 1860 there were 15,000 sheep (U.S. Bureau of Census, Census of Agriculture 1860). In 1870, the sheep population had swelled to 45,000 (U.S. Census, Census of Agriculture 1870). Other estimates of the sheep population during the last half of the nineteenth century range between thirty and sixty thousand or more (Cromise 1868, Wheeler 1876, Carman *et al.* 1892, Towne and Wentworth 1945). In recent decades, sheep grazing has been curtailed over large areas of the island. Today, most of the feral sheep are confined by fences to the more rugged, less accessible northwest and northeast coastlands and mountain ranges. Fewer, fluctuating numbers of sheep remain on the hilly southern portion of the island.

NINETEENTH CENTURY LANDSCAPE CHANGES

Vegetation

As mentioned earlier, the vegetation of Santa Cruz Island changed significantly over the past century. Coastal sage scrub, island chaparral, valley and foothill grassland, and oak woodland communities have either been suppressed or modified. However, scientific literature yields little information regarding either the nature of these changes or the character of the vegetation before sheep were introduced. Some early scientific surveys make brief mentions of spreading *Opuntia*, disappearing grass, exposed barren ridges, and disappearing sagebrush (Wheeler

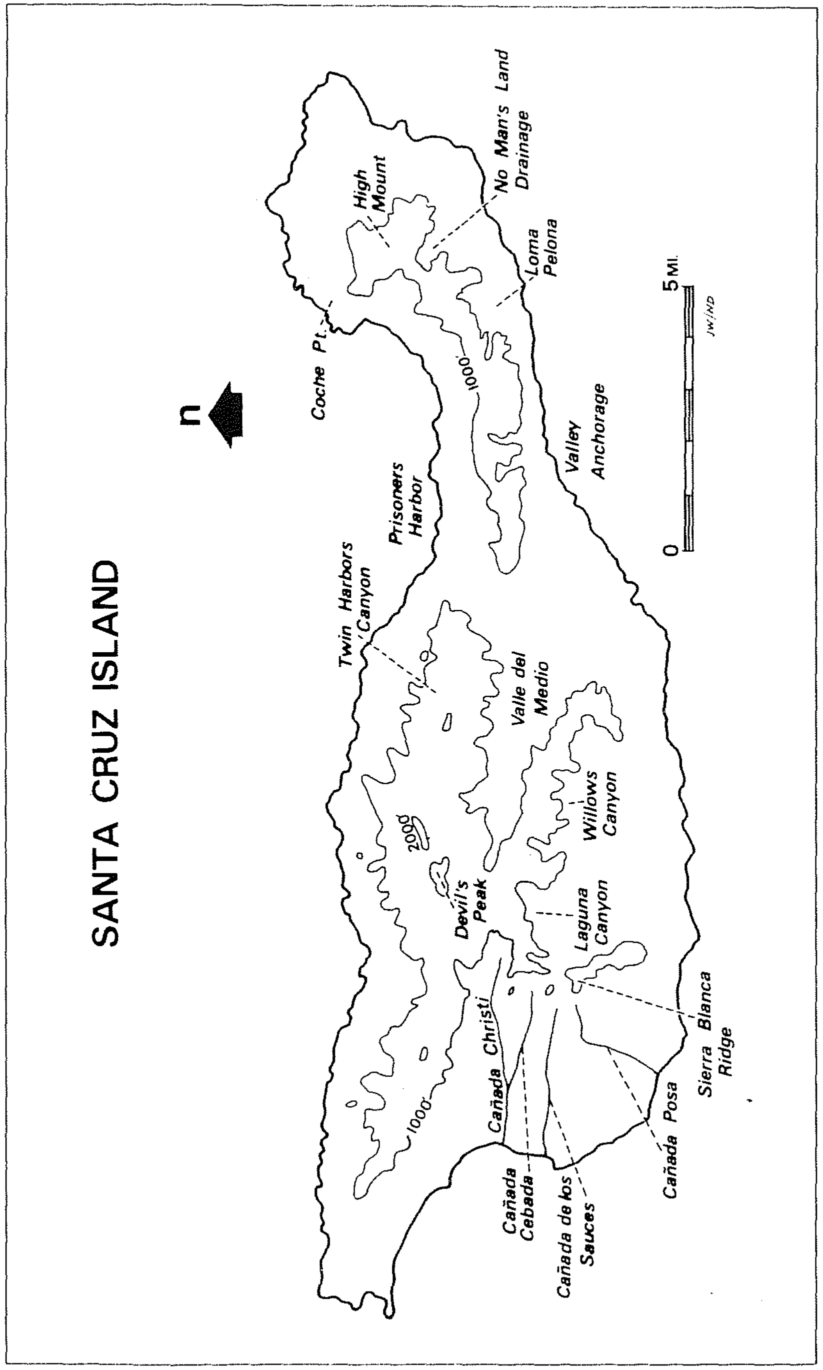

FIGURE 1. *Map of Santa Cruz Island, California.*

FIGURE 2. **Top:** *Sketch map of Coche Point in 1856 (Greenwell 1857). Courtesy of the National Archives.* **Bottom:** *1929 aerial photograph of Coche Point; arrow points to location of Coche Point Signal Station. Fairchild photo, courtesy of Whittier College Geology Dept.*

1876, Schumacher 1877), but the observations provide no accurate assessment of actual vegetation changes; some descriptions are obviously based on poor landscape interpretation. However, U.S. Coast Survey accounts detail several salient features of vegetation denudation on Santa Cruz Island during the mid-nineteenth century. Northeast portions may have undergone severe vegetal destruction. Greenwell (1857:62) describes Coche Point as follows: "The point is covered with a thick growth of dwarf oak, but the signal stands on a little knoll partly free of this." Aerial photographs (Fig. 2) show this knoll was clear of brush by 1929; it remains grassland today although the bluffs are partially covered with scrub oak. It is evident, however, that vegetal attrition has taken place on the bluffs at Coche Point since 1929; there was much more sage cover in 1929 than there is now. A year after Greenwell's observation, Davidson (1859) described portions of this northeastern part of the island as barren. Greenwell (1857:66) also described the ridge containing High Mount and El Montañon on the east part of the island isthmus: "Looking from Prisoner's Harbor to eastward is a high range of wooded mountains running apparently across the island." An accompanying sketch map of High Mount (Fig. 3) shows it to be very wooded on all sides. At present, many of these slopes are not wooded, and

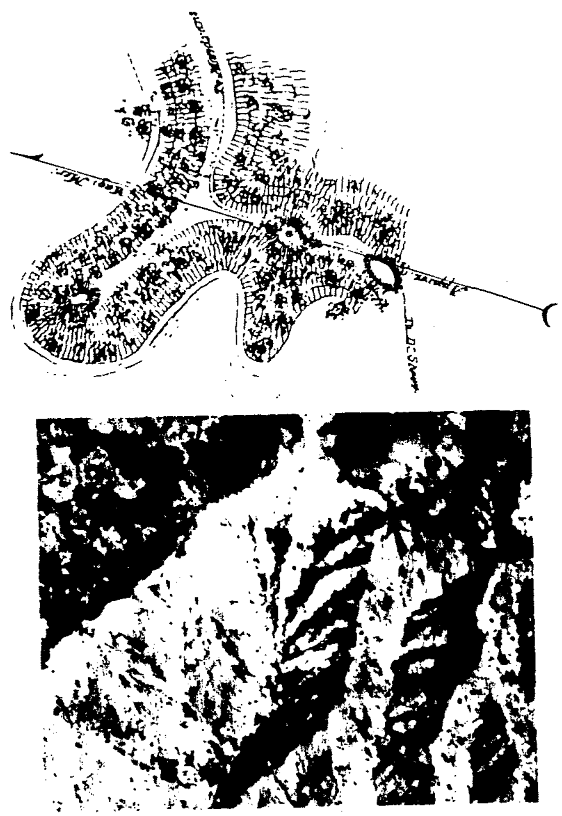

FIGURE 3. Top: *Sketch map of High Mount in 1856 (Greenwell 1857). Courtesy of the National Archives.* **Bottom:** *1929 aerial photography of High Mount; arrow points to summit.*

they were equally sparsely vegetated by 1929, as indicated by aerial photographs (Fig. 3). The slopes immediately west of Prisoners Harbor also have undergone severe destruction. A letter from U.S. Coast Survey Sub-Assistant W. M. Johnson to W. E. Greenwell (Johnson 1858) describes the area as:

> . . . so completely overgrown with high brush, that it will be impossible to get through it with the instrument; in putting up our signals the men were forced, in very many places, to move for considerable distances on their hands and knees, . . . [and] would find themselves at the end of that time, only about one-third of a mile from where they had started.

Today these slopes, covered with scattered chaparral patches, *Lyonothamnus* groves, and stands of *Pinus muricata*, have a much more open appearance than was described in 1858. The vegetal reduction may be due, in part, to fires on the slopes early in this century (Hobbs 1980). Sub-Assistant Johnson continues (in the same letter), "The country east of the harbor [has] little or no brush," a description which also applies to its present appearance. Government documents have been used elsewhere as a historical source of nineteenth-century landscape conditions (Buffington and Herbel 1965, Johnson 1972, Stoiber 1973, Cooke and Reeves 1976).

Early photographs of Santa Cruz Island yield the best information regarding vegetation denudation. Comparison of present-day vegetation with that shown in 1869 photographs

indicates that coastal sage scrub on the south-facing slope north of the Valle del Medio has been greatly reduced (Figs. 4 and 5). Scattered *Quercus dumosa, Cercocarpus betuloides, Prunus lyonii, Rhus integrifolia, Heteromeles arbutifolia, Adenostoma fasciculatum,* and *Ceanothus* spp. presently are distributed on these xeric sheep-grazed slopes (Fig. 6). However, in 1869 these slopes were fully clad with coastal sage species (probably *Artemisia californica, Eriogonum* spp., *Salvia mellifera, Encelia californica*), providing a contiguous understory for the previously mentioned chaparral trees and shrubs (Figs. 4 and 5) that are now undergoing slow attrition. Today these coastal sage plants are either sparse or very limited in distribution. These photographs show little vegetational disturbance by sheep grazing by 1869 in the areas bordering the Valle del Medio, in contrast to possible earlier vegetation disturbances on the northeast portions of the island. However, these same chaparral plants lacked the arborescence and pruning in 1869 (Fig. 7) that is characteristic of much of the present-day chaparral and woodland. Indeed, the 1869 vegetation is not unlike that of the mainland chaparral, with respect to lack of arborescence. This similarity may suggest that fire played a more prominent role on the island prior to the advent of sheep grazing. The slopes bordering the Valle del Medio have not experienced fire during the twentieth century (recent fires on the island have been documented by Dr. Carey Stanton, pers. comm.). Thus, chaparral plants on the island have not experienced recurring wildfires recently. Most of the mainland chaparral experiences recurring wildfires with a frequency of every ten to forty years (Bauer 1936, Muller *et al.* 1968, Byrne *et al.* 1977, Vogl 1977). Perhaps at the time the 1869 photographs were taken the chaparral bordering the Valle del Medio had been recently burned (within the previous forty years). This would account for the lack of arborescence in 1869, an arborescence that is present today, although chaparral vegetation generally stagnates with little annual growth after sixty years (Hanes 1971, Mooney and Parsons 1973).

Certainly the possibility of prehistoric wildfire on the island cannot be discounted. There is abundant charcoal in late Holocene sediments over much of the island that may be the result of wildfires. University of California at Los Angeles (UCLA) radiocarbon dates of three charcoal samples from stream bank sediments are 400 ±80, 14,400 ±300, and 395 ±80 years B.P. (UCLA-2075, 2078, and 2089, respectively). In addition, charcoal is present in much older island sediments, for example, in mudstones of the Miocene San Onofre Breccia (upper Cañada de los Sauces). It does not matter, of course, whether the wildfires are natural or caused by man. Johnson (1972) has documented fire (Pleistocene to present) on nearby San Miguel Island and investigated the possibility of both lightning-caused fires and aboriginal burning on the Channel Islands. In addition, fire may purposely have been used to remove the low brush from portions of Santa Cruz Island in order to better facilitate sheep grazing during the middle and late nineteenth century (Minnich 1980). Stockmen often burned woody vegetation in California during the last half of the nineteenth century (Sampson 1944). The practice of brush burning is especially well-founded in the southern Mediterranean region of Europe (Traband 1977, LeHouerou 1974, Robertson 1977). The early ranch managers were European: Dr. Shaw was from England (U.S. Bureau of Census 1860, Ellison 1937), and Justinian Caire was from the Department of Hautes-Alpes in southern France (Towne and Wentworth 1945). Indeed, the Caire family extended many traditions of their homeland to their new domain (Hillinger 1958; Justinian Caire, II, 1978, "As I remember it," Oral History Research Office, Univ. California, Santa Barbara).

Other factors may also have been important in late nineteenth-century vegetation changes. Severe droughts plagued the Channel Islands during much of that time. Johnson (1972) has chronicled these droughts, especially those during the years of 1863-64, 1870-72, 1877, and 1893-1904. Johnson cites the following statement from the Santa Barbara *Index*, March 22, 1877: "twenty five thousand sheep [were] slaughtered on Santa Cruz Island . . . [because of]

FIGURE 4. *North slopes of Valle del Medio in 1869. Hillslopes in left background have dense cover of coastal sage scrub and chaparral. Photograph courtesy of Dr. Carey Stanton; reproduction by Ron Morgan.*

FIGURE 5. *North slopes of Valle del Medio in 1869 (Slightly west of Figure 4). Note lack of pruning of* Quercus dumosa *on footslopes. Photograph courtesy of Dr. Carey Stanton; reproduction by Ron Morgan.*

FIGURE 6. *North slopes of Valle del Medio at present. Slopes in left background are noticeably barren of low brush cover.*

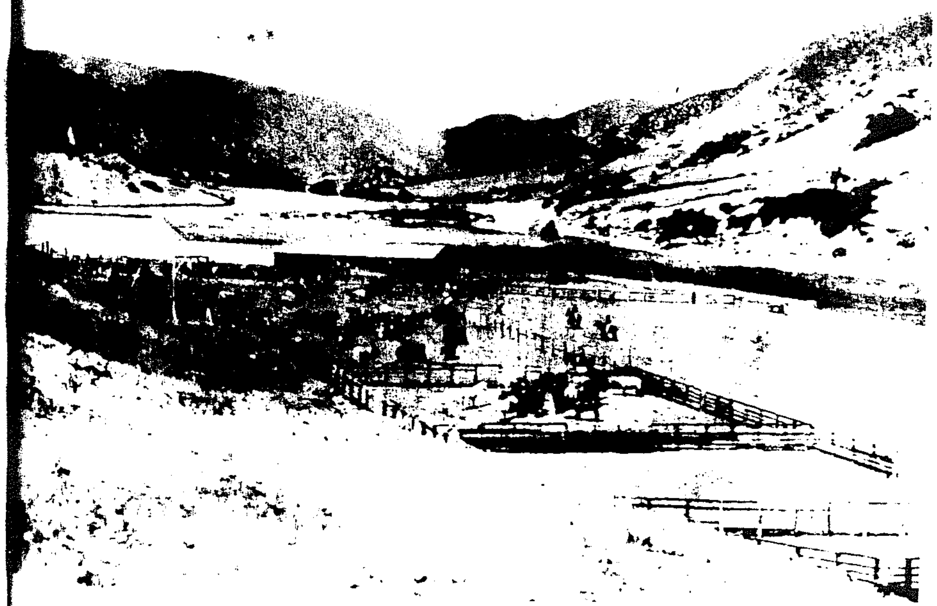

FIGURE 7. *View westward along Valle del Medio in 1869. Note that the heavily vegetated north slopes lack the arborescent character evident today. Photograph courtesy of Dr. Carey Stanton; reproduction by Ron Morgan.*

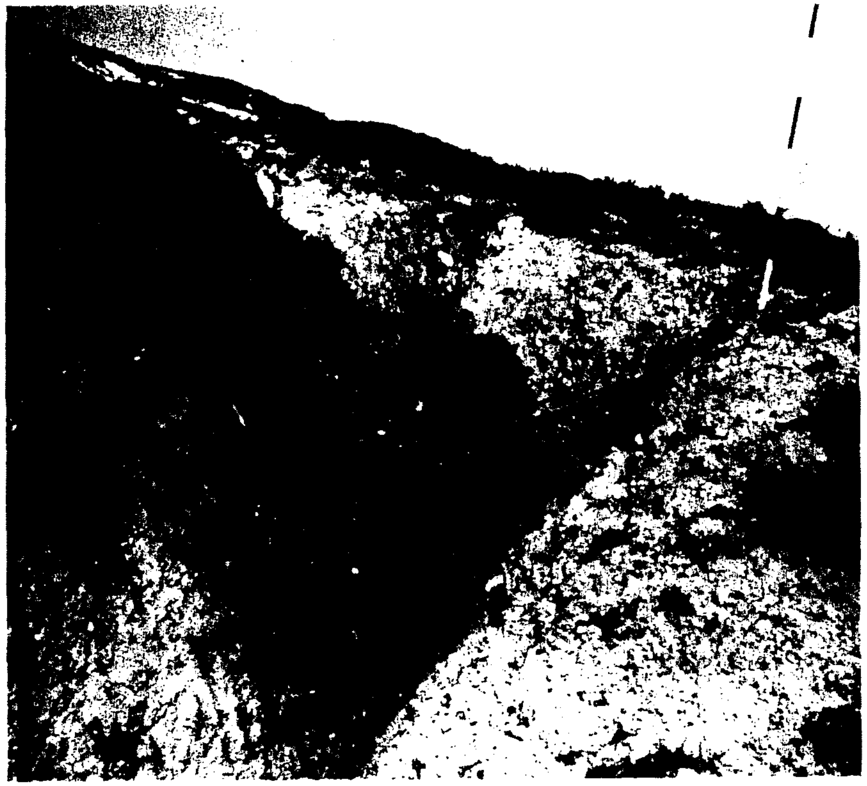

FIGURE 8. *Exposed roots of prostrate* Quercus dumosa. *Gully is cut 4 m into San Onofre Breccia on a south-facing slope along Cañada Cebada.*

scarcity of food induced by want of rain."

Finally, man may have had a direct role in the vegetal destruction. There is a record that timber was taken off Santa Cruz Island for building in Santa Barbara on at least one occasion in 1817 (Spaulding 1964). In addition, woodcutting for use on the island ranch may have taken a significant toll on the wooded mountain slopes. Vegetal change on the island must be examined, then, in the light of these various dynamic forces; that is, the coincidence of extreme drought conditions with the introduction of sheep, along with additional direct modification by man in the form of possible brush burning and woodcutting.

Geomorphology

Nineteenth-century landscape change is evident in the intense hillslope gully development characteristic of many drainages on Santa Cruz Island. This accelerated erosion may be a recent expression of sheep-related geomorphic processes, rather than a continuing process pre-dating the introduction of sheep. Many of the hillslope gullies post-date the sometimes sparse vegetation growing on the slopes. Frequent root exposure on the entire individual gully span is characteristic of several incised hillslopes. On the west end of the island, exposed roots of prostrate *Quercus dumosa* often span gullies (Fig. 8), as do *Pinus muricata* roots (Fig. 9). In many cases the plant is still alive and the roots maintain their biological functions.

FIGURE 9. *Exposed roots of* Pinus muricata. *Gully is incised 1 m into Willows Diorite in northwestern portion of Laguna drainage, southwest Santa Cruz Island.*

The response of valley bottoms to changes in the adjacent upland landscape can be distinguished in the simple stratigraphic sequence found in valley fills of several small watersheds. This sequence, consisting of fine alluvium underlying mostly coarser alluvium and colluvium, is evident in a drainage in the "No Man's Land" pasture. This drainage, located on the southeastern side of the isthmus, is still subject to extreme grazing by feral sheep. Much of the surface is completely barren, with only scattered shrubs (*e.g.*, *Quercus dumosa*) at higher elevations in the watershed. This drainage is cut into diatomaceous Monterey Shale that dips to the west, orthogonally to the direction of drainage. Thus, the western canyon side is very steep and a large section of basal Monterey strata is exposed, while the eastern canyon side lies along the dip plane and, indeed, is marked by massive, deep-seated slope failure and severe contortion of the shale strata. The main channel bed of the drainage is characterized by incising

FIGURE 10. *Site of UCLA-2075, "No Man's Land." Recent rilling and mini-debris scars mark the slope. Bottom 50 cm is fine alluvium; arrow points to UCLA-2075 site.*

of alluvial and colluvial debris deposited along a very narrow canyon bottom (varying from 5 to 15 m wide). Large debris flow levees (up to 1.5 m in height) frequently lie on the channel bed. Sections of relatively coarse debris overlying finer alluvium are exposed along several long reaches where the valley fill is incised (up to 15 m of channel fill are exposed). Grain size, particle sorting, and the fabric of clastic sediments provide a measure of the energy of the depositing medium. Variation in the channel fill thus represents different geomorphic processes. The underlying alluvium (generally the bottom 50 cm of the exposed section) consists of moderately sorted clays and silts with occasional sand and pebble lenses. Generally, these characteristics are found in water-laid sediments or fluid mudflow deposits (Bull 1964). Coarser clasts overlie the fine alluvium. These deposits are poorly sorted and pebbles are irregularly arranged and are without preferred orientation—characteristics of viscous debris flow deposits (Bull 1964, 1972). Thus, the coarse debris probably represents either colluvial debris, debris-flow matrices, or, occasionally, coarse alluvium. This channel wall stratigraphy is shown in Figure 10. At no place are fine clays or silts deposited at the top of a section to any great extent. Charcoal taken from the top 10 cm of the fine alluvium in a channel bank (Fig. 10) was radiocarbon dated at 1,550 ±80 years B.P. (UCLA-2075). The fine alluvium was, therefore, probably deposited before the introduction of sheep to the island. A similar sequence is found in Cañada Cebada. Several long reaches expose charcoal-laden, fine-textured, floodplain deposits underlying coarser alluvium. The drainage, cut predominantly into dioritic and volcaniclastic rocks, has a fairly narrow floodplain (less than 70 m) along most of the canyon bottom. A radiocarbon date of 1,555 ±80 years B.P. (UCLA-2089) was obtained from charcoal from the top 2 cm of a dark clay-silt, organic-rich alluvium exposed on a channel bank. Above this

fine alluvium (50 cm exposed above the channel bed) is a coarser unit of pebble and sand lens within a light-colored, fine-textured matrix (100 cm).

The coarser alluvium and colluvium may represent a byproduct of grazed hillslopes, rather than just lateral changes in stream channels that can result in varying types of clastic deposition. The slopes, overgrazed and made barren by sheep, may have become dominated by rilling and mass wasting processes as a result of the much reduced cover of both shrubby and herbaceous vegetation. The fine alluvium appears to represent a different geomorphic regime which may have existed at the time intensive sheep grazing commenced in the 1850s. This geomorphic regime is characteristic of a more vegetated landscape, where mass wasting processes would probably be inhibited to a greater extent, and a channel fill would represent either sheet wash, stream deposition, or very fluid mudflow deposits. Vegetated (especially brush covered) hillslopes would be likely to experience less debris avalanching and individual rockfall than hillslopes completely denuded of vegetation (Rice *et al.* 1969, Rice and Foggin 1971).

The presence of moderate amounts of charcoal in many of the channel banks of small drainages on Santa Cruz Island reinforces the possibility that the contact between silt-clay deposits and colluvium represents the time of arrival of sheep on the island. In each drainage I examined, the overlying coarse alluvium and/or colluvial matrix contained little or no charcoal. This absence is significant; wildfires have not been reported on the island in this century, except for a fire in the stands of *Pinus muricata* on the north side of the island near Pelican Bay (Hobbs 1980) and very localized fires, mostly grassfires (Dr. Carey Stanton, pers. comm.). Ubiquitous charcoal deposits in the underlying fine, and often indurated, alluvium thus provide reasonable evidence that the fine material represents at least pre-twentieth-century processes.

Similar valley-fill sequences have been reported elsewhere, although generally in broader basins than the "No Man's Land" drainage. In the broad cienegas of southeastern Arizona, Melton (1965) reported a sequence of coarse clasts burying pre-European settlement deposits of fine alluvium, following nineteenth-century grazing disturbance; the sequence was then incised because of steepened transverse gradients. Many instances of this "culturally" accelerated erosion in the southeast, central, and western United States are cited by Happ *et al.* (1940). In the cases cited, floodplain silts are often covered with mud and some boulders after disturbance of nearby slopes by either mining, agriculture, or urbanization. In some of the island drainages large enough to have small floodplains, the charcoal-laden fine deposits are indurated floodplain deposits—stable for some period of time—that are now so rapidly aggrading as to prohibit development of an A_1 soil horizon on the floodplain surface (for example Cañada Cebada). Not all drainages on Santa Cruz Island are characterized by a "pre-sheep/post-sheep" stratigraphic sequence. For example, the Loma Pelona drainage adjacent to "No Man's Land" does not have fine alluvium lying beneath coarse alluvium and colluvium. Instead, the deeply incised (up to 6 m) terrace deposits along the narrow canyon bottoms consist of beds, each of different-sized clasts, ranging in size from small pebbles to large cobbles (Fig. 11). Some beds may represent sieve deposits (Bull 1972). The distinctly identifiable beds probably represent individual events and debris flow processes. The Loma Pelona drainage thus provides evidence that, indeed, some degree of catastrophic mass wasting was prevalent and dominant on some portions of the island before the introduction of sheep.

While slope failures are definitely part of the island geomorphic system under natural vegetation conditions, as they are on the mainland (Campbell 1975), it can be argued from the evidence present in the "No Man's Land" drainage, along with several other watersheds, that for *at least* the time immediately preceding sheep introduction on the island many drainages were not experiencing the kind of catastrophic debris avalanche and debris torrent events that disrupt the valley fills today. Rather, these drainages were characterized more or less by landscape "stability." It must be recognized, however, that historic landscape stability in

FIGURE 11. *Coarse deposits in Loma Pelona terraces.*

southern California is always suspect in view of the forces of wildfires, tectonic uplift and earthquakes, and erodability and instability of many coastal sediments. Processes on the hillslopes and adjacent valley bottoms are necessarily related to these forces and characteristics. I do not intend to imply complete, long-term geomorphic stability before sheep introduction, but rather a short-term, and perhaps localized, landscape stability, especially with respect to geomorphic processes.

PRESENT-DAY LANDSCAPE PROCESSES

Geomorphology

Sheep grazing has been progressively curtailed in large areas of Santa Cruz Island over recent years. Removal of the feral sheep has had a marked effect on hillslope gully processes in some areas. While some firmly established hillslope gullies continue to function as debris chutes, many of the gullies are aggrading, thus demonstrating the reversability of these accelerated erosion processes on steep watershed. Evidence of hillslope gully aggradation includes the

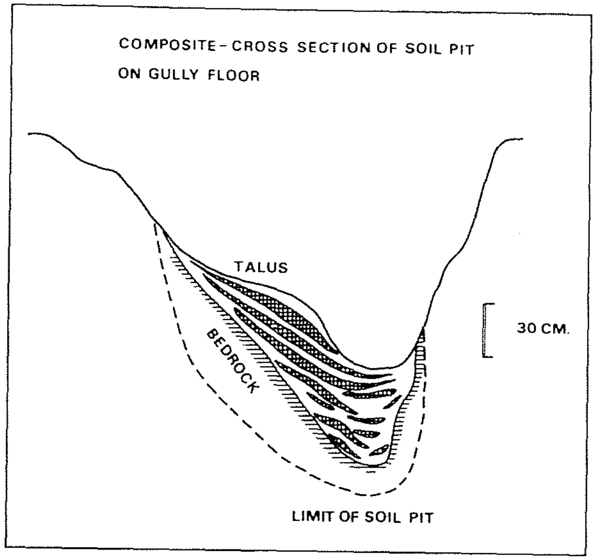

FIGURE 12. *Representative cross sections of hillslope gully-fill; cross hatching represents organic lenses.*

recent burial of the root crowns of small shrubs on the gully floors, and gully-fill stratigraphy (Fig. 12). Many gully floors are now revegetated with grasses, at least; also, bank caving and scouring to bedrock by infrequent heavy storm runoff and debris flows are either greatly reduced or have ceased. Indeed, there has been no appreciable expansion of hillslope gully networks on Santa Cruz Island since 1929, as evidenced by aerial photographs taken in that year (1929 [Fairchild], 1954 [Mark Hurd], and 1970 [color infrared photos from Orme *et al.* 1971, on file at Geography Dept., Univ. California, Los Angeles]). This apparent cessation of hillslope gully enlargement may be partially explained by either the previously mentioned revegetation of some of the drainages and consequent gully healing, or by the fact that gully processes are presently weathering-limited. Indeed, many of the gullies incised into the steep drainages are cut to bedrock. The phenomenon of hillslope gully aggradation is documented in the South Carolina piedmont upland (Ireland *et al.* 1939) and in the loessial uplands of Iowa (Daniels and Jordan 1966). However, these researchers related gully stabilization not only to the revegetation process itself, but to expected stages of gully development.

Vegetation

Some portions of Santa Cruz Island are undergoing revegetation as a result of the reduction and restriction of sheep begun in the 1950s. Comparison of 1929, 1954, and 1970 aerial photographs indicates slow attrition of shrubs and trees in those areas still grazed by sheep. Hobbs (1980) has documented the lack of regeneration of *Pinus Muricata* on the heavily grazed slopes on the north side of the island near Pelican Bay, whereas the pine forests above Chinese Harbor and on the western portion of the island are undergoing regeneration in response to removal of sheep in those areas (Linhart *et al.* 1967, Hobbs 1980). Figure 13 shows present densities of *Pinus muricata* on Sierra Blanca ridge on the southwest portion of the island. The different densities of *Pinus muricata* on opposite sides of the fence line are probably, in part, a result of slope aspect and related fog drip. Aerial photographs of Sierra Blanca ridge can be compared for 1929 and 1970 (Fig. 14). Several of the slopes which, except

Figure 13. *Looking south along Sierra Blanca ridge. Fence line separates distinct* Pinus muricata *stands. Note youthful stature of* Pinus *to west (right) of fence line. Many dead stumps and fallen trees are found on the slope to east of fence line.*

for fallen trees, are now nearly barren supported small stands of *Pinus muricata* in 1929; slopes now experiencing pine regeneration were much more barren than at present. The slow attrition of *Pinus muricata* is aided by their relatively short life span of approximately 65 years (Linhart *et al.* 1967). In general, however, chaparral and woodland trees and shrubs (especially *Quercus dumosa*) show little change in extent or densities since 1929. Indeed, examination of the 1929 and 1970 aerial photographs reveals that, over most of Santa Cruz Island, shrubs and trees now present on the landscape were present in 1929. Likewise, little attrition has occurred since 1929, even on the slopes on the northern portion of the island which are still heavily grazed by sheep. There are exceptions, however, besides the previously mentioned *Pinus muricata*. For example, some shrubs on the heavily grazed upper east drainage of Twin Harbors on the north side of the island have been thinned (Minnich 1980). While *Quercus dumosa* has suffered no significant attrition since 1929, other shrubs (*e.g.*, *Adenostoma fasciculatum*) have suffered up to 30 per cent localized decreases in cover in scattered stands. At present, I am undertaking a more complete evaluation of these changes over the period 1929 to 1970.

The capability of rapid vegetation recovery following removal of sheep is shown by examination of a small sheep exclosure located in the Valle del Medio (Fig. 15). At the time of construction (fall 1976), the 10 × 14 × 14-m exclosure contained one individual each of *Heteromeles arbutifolia*, *Quercus dumosa*, and *Opuntia littoralis*. No herbaceous cover was

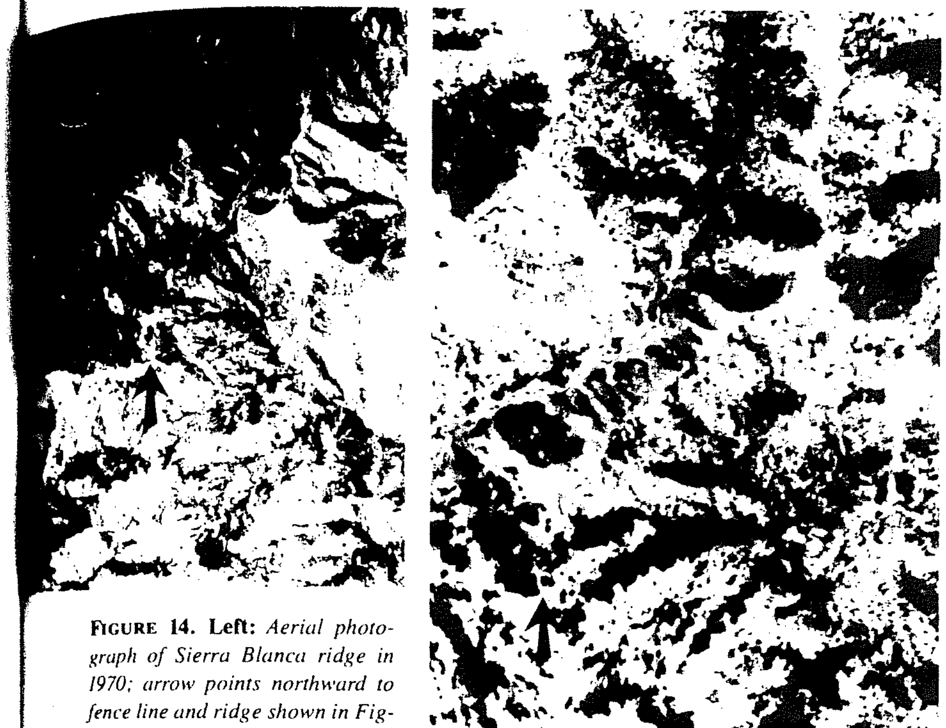

Figure 14. Left: *Aerial photograph of Sierra Blanca ridge in 1970; arrow points northward to fence line and ridge shown in Figure 13. Area to west of ridge crest is free of sheep; area to east has reduced, but fluctuating, numbers of sheep.* **Right:** *Aerial photograph of Sierra Blanca ridge in 1929; arrow points north. Several small clusters of* Pinus muricata *present in 1929 to east and northeast of arrow are absent by 1970 with no replacement.*

present at that time. Upon sheep exclusion, the *Heteromeles arbutifolia* and *Quercus dumosa* began sprouting vigorously from the base. The pre-exclosure pruned appearance is rapidly disappearing. In addition, *Artemisia californica*, a component of coastal sage scrub, is also now established within the exclosure; no *Artemisia californica* plants are present outside the exclosure where sheep can graze. The regeneration of coastal sage is evident on some portions of the island. Comparison of 1929 and 1970 aerial photographs shows a slight increase in sage density, especially on the steep southern slopes of the isthmus to the east of Valley Anchorage. The susceptibility of coastal sage to sheep grazing is also evident in the comparison of 1869 photographs with present-day photographs (Figs. 4, 5, and 6). Coastal sage, very prevalent in 1869 on the northern slopes of the Valle del Medio, is virtually absent today in areas heavily grazed by sheep.

Exclusion of sheep for two winter and spring seasons (November 1976 to May 1978) also demonstrated some recovery of valley grassland-herbaceous vegetation. Herbaceous cover within and without the exclosure (examined May 1978) is dominated by introduced European grasses and forbs. *Avena barbata*, *Bromus mollis*, *Centaurea melitensis*, *Medicago polymorpha*, and *Silene gallica* are the most prevalent herbaceous species in the vicinity of and within the exclosure. Native *Hemizonia fasciculata* is also present. In May 1978, the native

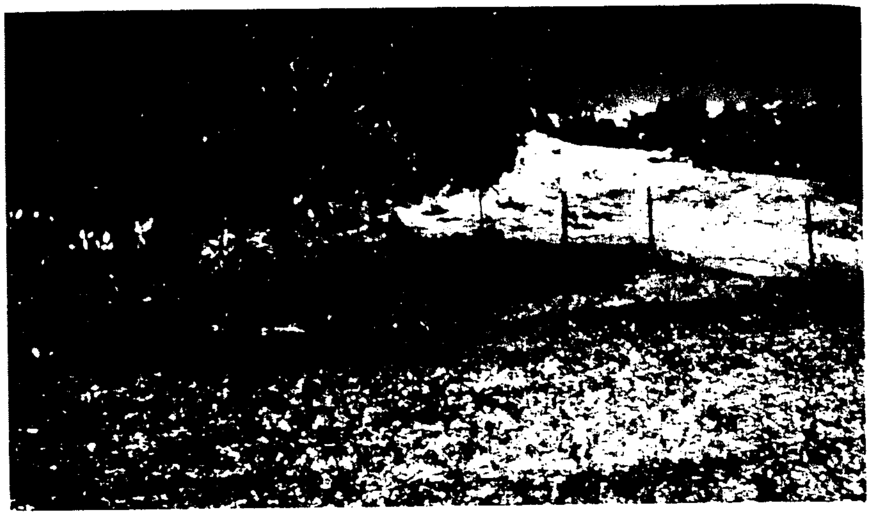

FIGURE 15. *Sheep exclosure constructed on 22° south-facing slope in the Valle del Medio. Bedrock under shallow soil is volcanic.*

bunch grass *Stipa lepida* was present in 60 per cent of one-meter quadrats located along a belt transect within the exclosure. *Stipa lepida* was completely absent outside the exclosure. However, in the late spring of 1979, following a second consecutive wet winter, *Stipa lepida* was present outside the exclosure, probably due to the production of herbaceous vegetation in excess of consumption by feral sheep. In general, *Stipa* is present in the island grasslands, although it is not nearly as extensive or abundant as the introduced annual grasses (Philbrick and Haller 1977).

In addition to vegetal recovery following sheep exclusion, previously sheep-trampled soils (moderately fine-textured loams) within the exclosure have also demonstrated a regained resiliency. Penetration resistance, both within and without the exclosure, was measured in November 1976—at the time of exclosure construction—on a relatively dry soil; penetration resistance was measured again in February 1977 on a moist soil, and in December 1977 on a relatively dry soil (Table 1). Penetration resistance is a measure of near-surface soil compaction only, not of compaction of the entire soil column. A Student's *t*-test showed statistically significant differences in soil compaction (at the 0.05 probability level) inside and outside the exclosure in February 1977 and December 1977. Soils within the exclosure were substantially less compacted than soils still exposed to trampling by sheep. The soils within the exclosure exhibited a rapid recovery from the trampling effect of sheep. However, a sheep trail located within the exclosure did not show significant change in near-surface soil compaction. Penetration resistance measurements on these trampled soils showed no significant difference between November 1976 (4.09 kg/cm^2) and December 1977 (3.87 kg/cm^2). Intensive use of the trails by sheep evidently results in deeper compaction of soils than can be easily mitigated.

SUMMARY

Landscape change on Santa Cruz Island in the mid-nineteenth century can be related to the interaction of introduced animals, direct modification by man, and environmental constraints

TABLE 1. Changes in penetration resistance (compressive strength) for areas inside and outside sheep exclosure. Measured by a pocket penetrometer CL-700, in kg/cm^2 $\pm s.e.$

	Inside exclosure	Outside exclosure	Probability level
Nov. 1976	4.62 ±0.46 n = 20	3.37 ±0.87 n = 20	0.20
Feb. 1977	1.95 ±0.30 n = 20	3.91 ±0.81 n = 20	0.01
Dec. 1977	2.14 ±0.37 n = 20	3.81 =0.72 n = 20	0.02

and phenomena. The introduction of sheep coincides with significant modification of the island vegetation. Coastal sage scrub appears to have been especially reduced in extent, while *Pinus* and chaparral woodlands have suffered slow attrition. Geomorphic phenomena also point to recent changes in the landscape. Changes in upland erosion and subsequent modifications of adjacent valley bottom deposits roughly concur with the vegetal changes. There is some evidence for reversal of accelerated erosion because of revegetation enhanced by sheep removal. Sheep exclosure evidence also indicates the possibility of rapid vegetal and soil recovery if soils are not completely eroded away to bedrock. Thus, direct and indirect modifications of the landscape by man are, in some cases, temporary.

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Effects of Grazing on the Northern Population of *Pinus muricata* on Santa Cruz Island, California

Elizabeth Hobbs

Department of Geography, University of California, Los Angeles, California 90024

INTRODUCTION

The effects of grazing on the vegetation of Santa Cruz Island have been apparent since 1875 (Wheeler 1876), only 22 years after the earliest documented introduction of sheep to the island (Shaw 1857). Although grazing damage has been mentioned in the literature since that time (Dunkle 1950, Linhart, Burr, and Conkle 1967), it is difficult to determine the extent or degree of damage from these descriptions.

Of the three main populations of *Pinus muricata* on Santa Cruz Island (Fig. 1), the western (Cañada Cervada) and eastern (Chinese Harbor) populations have been protected from grazing since about 1958 (C. Stanton, pers. comm.). The northern (Pelican Bay) population, however, has been subjected to continuous grazing pressure which, combined with the effects of an extensive fire that occurred sometime between 1929 and 1932 (C. Stanton and M. Daily, pers. comm.), has had a dramatic effect on the pines and associated species.

METHODS

Study areas were defined for each of the three pine populations on the island (Figs. 2 to 4). The sizes of the northern and western study areas were approximately equal (120 hectares) and each contained 14 systematically placed 25 m × 25 m sample sites. The eastern study area was much smaller (30 hectares) due to the much less extensive pine population in that area. Only four 25 m × 25 m sites were sampled in this study area. The proportion of the area sampled to the total study area was held constant for all three populations.

The vegetation of the sites was sampled by line transects to measure foliar cover of pines and other woody species; percentage cover for each site was estimated. Since overlapping individuals of different species were measured separately, it is possible to have greater than 100 per cent foliar cover. However, it should be noted that overlapping individuals of the same species were measured as one individual, so that some dominant species may be underestimated in relation to the rarer species.

Height was estimated visually; diameter at breast height (dbh) was measured for each pine intercepted by a line transect. Increment cores were taken from trees in several different size classes within each population. These data allowed estimation of the age structures of the three populations. In addition, seedling censuses were taken within the sample sites in each population to assess the regeneration potential of each population under present conditions. Seedlings were defined as any trees less than 3 m high.

RESULTS

Comparison of Populations

For the purposes of this study, it was assumed that the vegetation of the three closed-cone pine forests on the island was similar prior to disturbance and that gross differences could be attributed to disturbance, particularly grazing. However, the following environmental differences among the three populations should be noted as possibly sufficient to account for some differences in species composition and vegetation density.