Effects of Vegetation Change on Shallow Landsliding: Santa Cruz Island, California[1]

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Abstract: Santa Cruz Island has been grazed by sheep for over 100 years. During this time large areas of coastal sage scrub and pine and oak woodland have been reduced to grass or barren ground and the resulting soil erosion has been severe. In 1978 an intense series of storms caused more extensive landsliding than has occurred in the last half century. Triggering mechanisms, slide morphology, and denudation rates are related to soil and vegetation characteristics. The most extensive landsliding is temporally associated with intense rainfall which occurred decades after vegetation conversion.

In many Mediterranean-type zones with rugged terrain, particularly southern California, mass movements include dry sliding, deep seated failures, and shallow soil slips. This paper will concentrate on the latter. Several studies have examined the relations of shallow landsliding to vegetation type in Mediterranean lands. Rice and others (1969) and Rice and Foggin (1971) have shown that conversion of chaparral vegetation to grasses resulted in a 180 to 640 percent increase in slip erosion (depending on storm size) in the San Gabriel Mountains, southern California. This is attributed to the decrease of root strength in the soil. On Santa Cruz Island, reduction in vegetal cover by grazing during the last 130 years has caused a considerable increase in erosion (Brumbaugh) 1980). It is yet unclear to what extent this increase is attributable to landsliding as opposed to fluvial erosion. In early 1978 a series of heavy rains caused very extensive shallow landsliding on the island, and this recent activity is the subject of the present study.

Santa Cruz Island lies 40 km south of Santa Barbara, a approximately 34°N, 119°45W (fig. 1). The 249-km^2 island has very rugged topography as a result of rapid stream downcuttinq, and slopes in excess of 40° are common. The diverse bedrock geology includes volcanic, plutonic, and diverse

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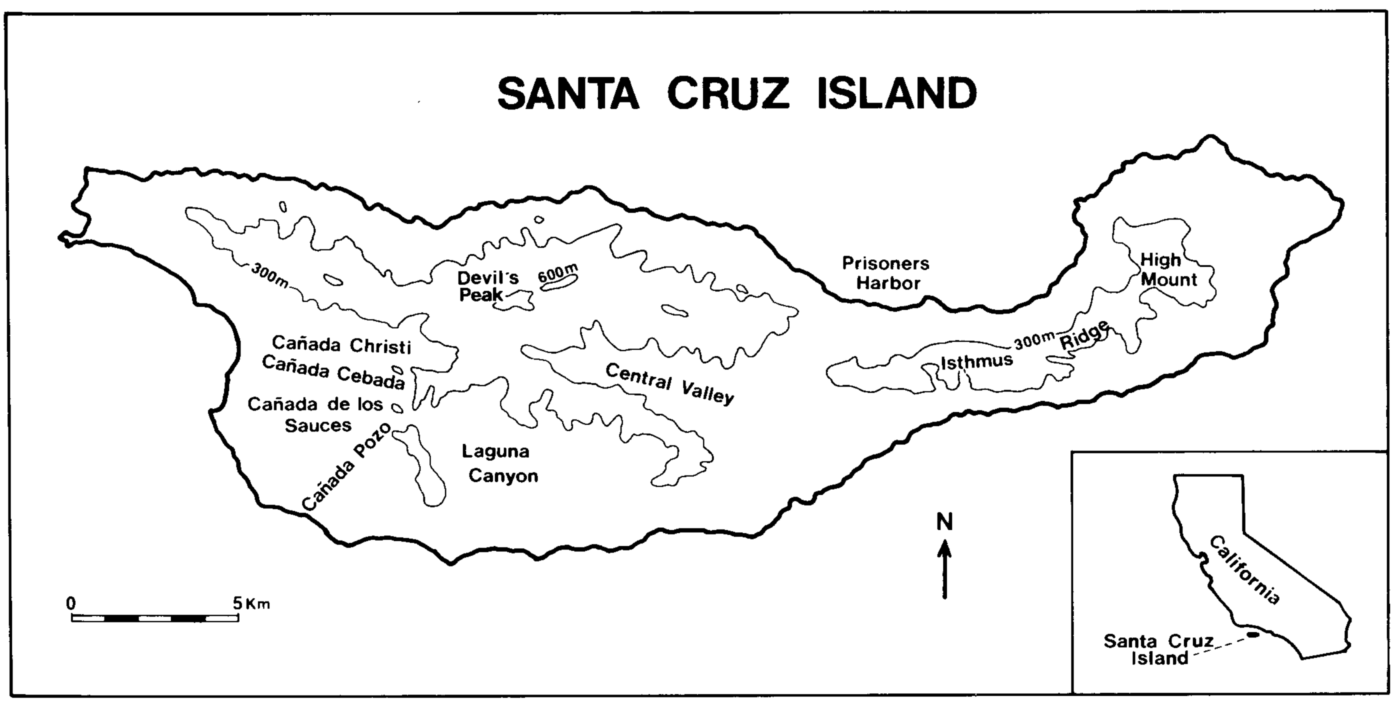

Figure 1--Map of Santa Cruz Island, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

sedimentary rocks (fig. 2). Soils developed on these rocks range from deep (1 to 1½ m) vertisols on some volcanic areas, to mollisols on some shales, and poorly developed entisols on all lithologies. Major vegetation zones include chaparral woodland (Quercus dumosa, Arctostaphylos spp.), pine woodland (Pinus muricata), coastal sage scrub (Artemisia californica), annual grasslands, and areas of essentially barren ground (fig. 3).

Grazing by feral sheep during the last 130 years has been the major cause of the substantial reduction of vegetation on Santa Cruz Island. Sheep were introduced to the island during the early 1850's (Brumbaugh 1980). By 1857, there were some 7000 or 8000 head of sheep on the island (Greenwell 1858), and by 1870, the sheep population had increased to at least 45,000 (U.S. Census of Agriculture 1870). Other estimates of sheep during the last half of the 19th century range between 60,000 and 100,000 head (Cromise 1868, Carman and others 1893, Towne and Wentworth 1945). Some control of the sheep during the last few decades has been attempted by fencing the open range and curtailing grazing over large areas of the island. Today, most of the feral sheep are confined to the more rugged and less accessible coastlands and mountains of the northeast and northwest portions of the island. A much smaller population with fluctuating numbers of sheep remains on the steepest slopes of the southern portion of the island.

Changes in vegetation since the 1850's (the onset of sheep grazing) are indicated by historical accounts and old photographs. Comparisons of U.S. Coast Survey accounts with present-day landscape indicates reduction of brush cover on various island locales (Brumbaugh 1980). Comparison of photographs taken in 1869 of the Central Valley with present-day photographs (Brumbaugh 1980) shows significant reduction of coastal sage scrub on south-facing slopes north of the Central Valley, in addition to depletion of several chaparral shrubs, especially chamise (Adenostema fasciculatum). Exposed root platforms on now-barren slopes also indicate widespread reduction of scrub woodland cover.

Shrubs and trees in areas still grazed by sheep appear to have experienced only gradual reduction over the last 50 years (comparison of 1929, 1940, 1964, and 1970 photographs in Brumbaugh 1980). Hobbs (1978, 1980) reports an absence of regeneration and an accelerated deterioration of Pinus muricata in sheep-grazed areas, and Leishman (1981) reports reduced health and vigor of chaparral shrubs in heavily grazed areas north of the Central Valley. Reduction of chaparral shrubs by grazing is species selective; for example, chamise is especially susceptible (Brumbaugh 1980, Minnich 1980).

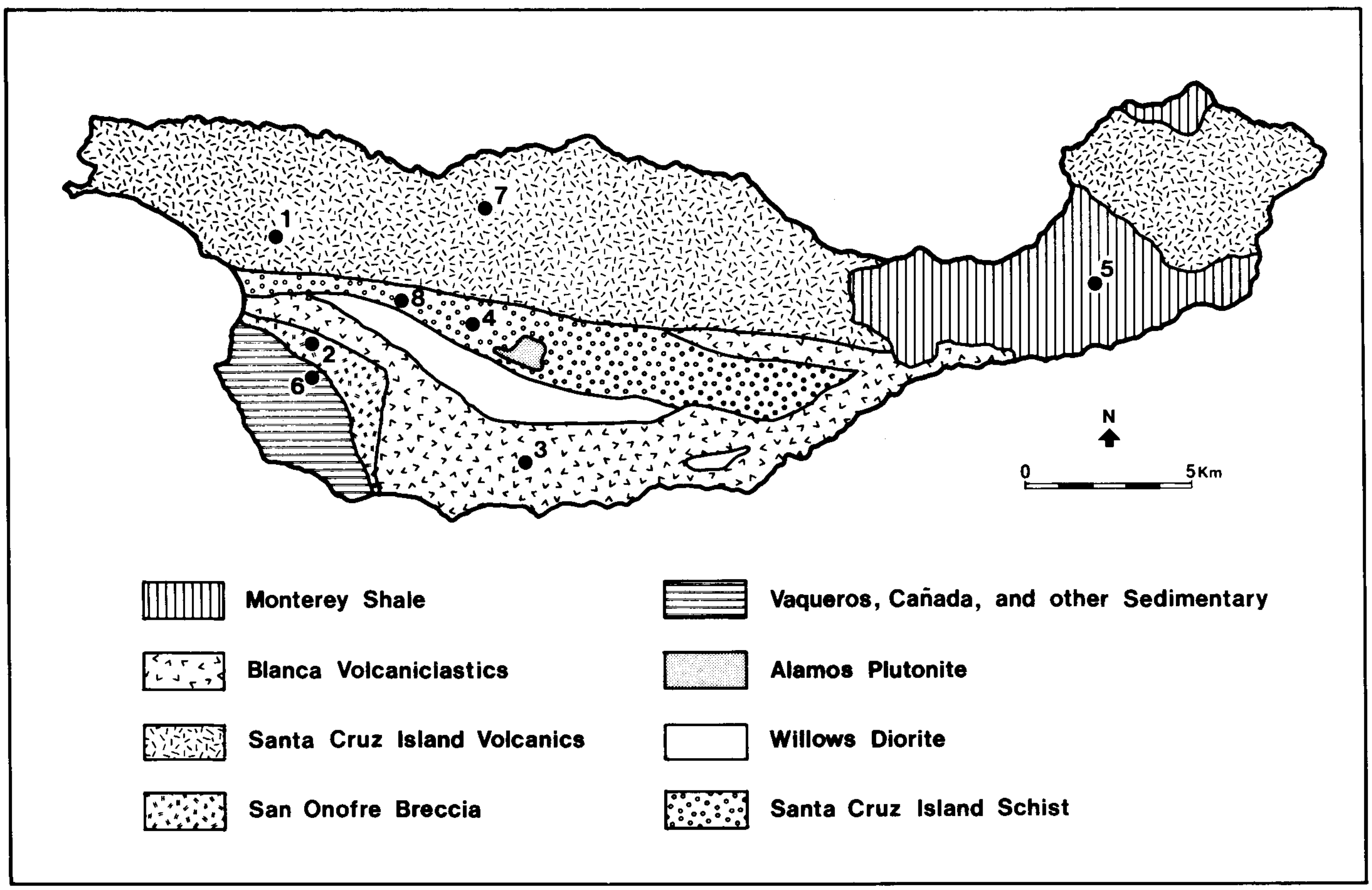

Figure 2--Generalized geologic map of Santa Cruz Island (simplified from Weaver and others 1969 and Howell and others 1976). Major rock units are listed in sequence from youngest to oldest.

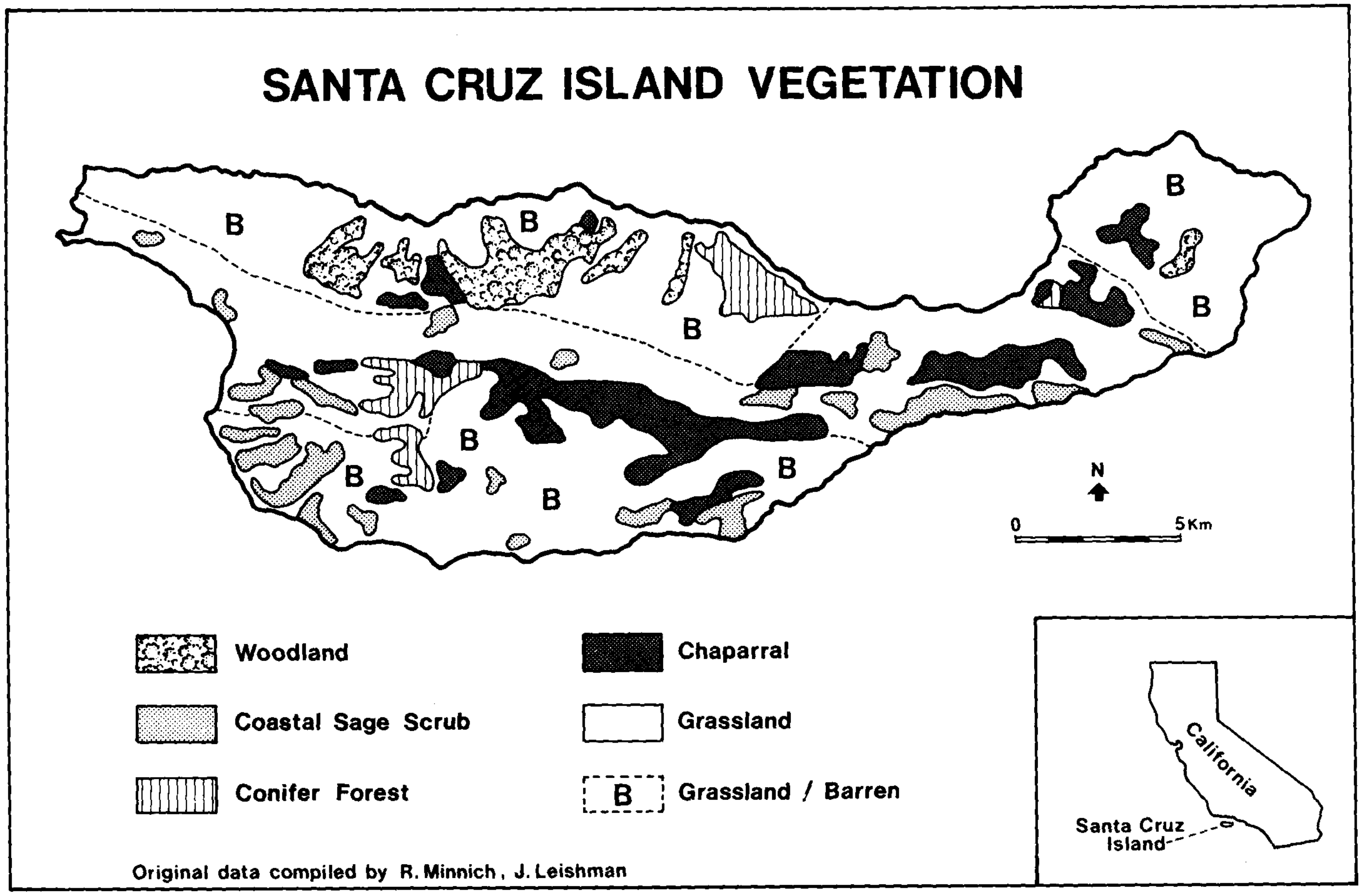

Figure 3--Generalized vegetation map of Santa Cruz Island, California.

Vegetation has recovered wherever sheep have been successfully excluded during the last 25 years. Regeneration of coastal sage is occurring on some portions of the island (Brumbaugh 1980, Minnich 1980), most notably, the steep southern slopes of the Isthmus and Canada Pozo, and Pinus muricata is regenerating in "sheep-free" areas (Brumbaugh 1980, Hobbs 1978,1980).

In addition, Brumbaugh (1980) reports that a small sheep exclosure located in the Central Valley experienced rapid vegetation recovery; post-sheep removal vegetation response included basal sprouting of toyon (Heteromeles arbutifolia) and scrub oak (Quercus dumosa) and return of native bunch grasses.

LANDSLIDING PRIOR TO 1978

Extensive aerial photographic coverage is available for the island. This includes black and white photos at a scale of approximately 1:20,000 flown in 1929, 1940, 1954, and 1964; color infrared at a scale of 1:20,000 flown in 1970 and 1980; and oblique color and color infrared photos flown by the authors in 1978.[3] The aerial photographs have been supplemented by the authors with extensive ground level photography. The quality of the above coverage ranges from fair to excellent. Resolution is poorest on the 1929 photos, allowing identification of features only as small 5 m. In most of the later photos, however, features 2 m in size are clearly distinguishable. Most of the shallow failures on the island are from 5 to 15 m in horizontal dimensions and are easily discernible on the photographs.

Daily precipitation has been measured on the island since the 1936-37 season (monthly data is available back to 1904-05), and the mean annual rainfall is about 500mm.[4] The daily data were

[3]1929 photographs from the Fairchild Collection; 1940 photographs from the Soil Conservation Service, U.S.D.A.; 1954 and 1964 photographs from Mark Hurd; 1970 imagery from Orme and others (1971); and the 1980 imagery from the National Park Service.

[4] Data on file, Stanton Ranch, Santa Cruz Island, California.

Table 1--Extreme precipitation events (in mm) on Santa Cruz Island, 1937-1978.

Month/yr	maximum 1-day	maximum 2-day	maximum storm[1]	maximum 1-day + 30-day antecedent
2/37	99	208	218	362
3/38	163	163	252	412
1/41	164	204	248	530
3/58	86	139	123	297
2/62	161	221	394	253
1/69	61	115	230	364
3/78	140	161	258	507

[1]a storm is defined here as a period of time in which every day has here as measurable precipitation.

analyzed to determine which storms were likely to have caused extensive landsliding.

No single measure of precipitation accurately predicts landsliding. High soil moisture content and hence, high pore water pressures associated with landsliding are a function of both precipitation intensity and antecedent rainfall. Campbell (1975) found most slides occurring during intense periods of less than 6 hours duration. Although daily data mask these intensities there is a strong correlation between high hourly intensities and high daily totals. Daily totals and three other precipitation parameters for the seven heaviest rainfall years since 1937 are shown in table 1. The data indicate that 1941, 1978, and 1938 were the most severe. A high 1-day total occurred in 1962, but antecedent precipitation was low.

In view of the precipitation data there is surprisingly little evidence of any widespread shallow landsliding in any of the photos prior to 1978. Although quantitative estimates are difficult, the percent of land area in slides is at least an order of magnitude greater in the 1978 imagery than in any of the earlier years. Many slopes which show one or two scars in 1954 and 1964 have several tens of scars today. The most severe dap in photo coverage is that immediately after the 1941 storms, and it is quite possible that scars caused in that year had time to heal and were therefore not visible in the 1954 photos. Revegetation of scars may take up to a decade or more. Slips that occurred in 1978 are still quite visible in 1981, but scars shown in the 1954 photos are absent in 1970. The 1969 storms were intense and caused much landsliding on the mainland, but intensities were lower on the island and little landsliding is visible in the 1970 imagery.

SHALLOW LANDSLIDING IN 1978

Failures in 1978 were generally similar to those commonly described elsewhere (Campbell 1975, Rice and others 1969, Rice and Foggin 1971). Shapes vary considerably, from rounded and smoothly concave to highly irregular. Length/width ratios generally range from 1 to 5. Although there is some tendency for more irregularly shaped scars to be found in grasslands, there are many exceptions. Slides in woodlands and on barren areas are larger, having average surface areas of about 600 m^2 as opposed to an average of about 50 m^2 in grasslands. Individual slide volumes range from 3 to 3000 m^3. In most cases the debris flowed rapidly downslope and was delivered directly to stream channels.

The failure mechanism on areas of shale, volcaniclastic, and schist bedrock is presumed to be that described by Campbell (1975), in which infiltration in excess of deep percolation causes the formation of a perched water table in the soil, with resultant high pore water pressures and a reduction of shear strength. In areas of well developed vertisols on volcanic rocks, failure appears to occur as a result of water seepage from upslope or from permeable bedrock strata (fig. 4). The clay-rich A horizon confines soil water, and high pore water pressures result. Subsurface seepage may also contribute to failures in areas of permeable surface horizons. This would suggest that different precipitation parameters would be important in generating this type of failure, although there is no evidence that they occurred at a different time than the rest of the failures on the island.

Percent of surface area in shallow landslides was measured from oblique air photos and ground level photos at several locations on the island (table 2). There is a large range in landslide occurrence: from 0.002 to 3.5 percent of area on sampled areas of 14.5 to 455 hectares.

Much of this variability can be explained by spatial variation in precipitation intensity. Table 3 shows storm precipitation for locations in the central (Main Ranch, in the Central Valley), western (Christi, near the mouth of Canada Christi), and the eastern part (isthmus ridge) of the island.

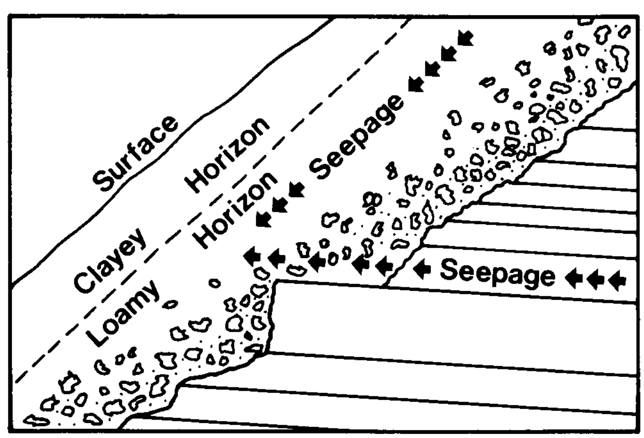

Figure 4--Diagram of subsurface water flow in vertisols resulting from bedrock configuration and convergent flow.

More shallow landslidinq occurred on the western portion of the island (northwest end, Canada de los Sauces, Canada Cebada, Canada Christi) than on the eastern portion (table 2). Correspondingly, greater 1-day rainfalls occurred in the central and western portions of the island than on the eastern portion of the island.

There is little evidence to demonstrate systematic variation in slide intensity with bedrock lithology. There are, however, significant variations in shallow sliding with soil and vegetation type. The most intense activity is associated with grassland areas underlain by vertisols (northwest portion and Canada de los Sauces). Measurement of percent area in failures suggests that grassland has higher slippage rates than coastal sage scrub, which in turn, has higher failure rates than oak or pine woodland (table 2). Chaparral species have deeper penetrating root systems than coastal sage, and coastal sage scrub slightly deeper than grassland mats (Hellmers and others 1955). However coastal sage scrub grows on slopes often characterized by shallow soils. The amount of shallow failures in coastal sage, therefore, may be as much dependent on soil character as on vegetation type. Although many fewer failures occur on woodlands than on grasslands, the failures are much larger in woodland areas. These failures are debris avalanches that clear off vegetation below the actual failure surface. Upon reaching the slope base, they mobilize channel-bed material resulting in debris torrents capable of completely disrupting the channel bottom and aggradinq the valley downstream. Thus, although less soil slip denudation may occur in the wooded areas than on grassland areas, watershed disruption is substantial -- disrupted surfaces downslope and along the adjacent channel, and often unwanted aggradation downvalley. Areas of little or no soil have few shallow failures; landslides are either absent or deep-seated.

MANAGEMENT IMPLICATIONS

The variation in failure rates in different vegetation types supports earlier work showing that shallow landsliding is more intense under grassland than under woodland vegetation, presumably due to the binding strength of woody roots. Although other studies have shown increases in landsliding following vegetation change, reduction of vegetation cover such as from woodland to grassland, has two contrasting effects on soil moisture which preclude simple recommendations. Evapotranspiration is reduced, which would tend to increase soil moisture, but at the same time, runoff is increased. Evapotranspiration is less significant during a storm, but will have important effects on antecedent moisture. On the other hand, devegetation generally causes a reduction in infiltration, which would tend to promote surface erosion at the expense of landsliding. Detailed site-specific hydrologic investigations are necessary to determine the relative importance of these two effects of vegetation cover change.

Table 2-- Shallow landslides, March 1978, on differing watershed types, Santa Cruz Island.

Location	Lithology/ soils	Vegetation	Area mapped (ha)	Number of slides	Average slide area(m^2)	Percent area in slides	Range of percent area in slides
Northwest end	volcanic/ vertisols	grassland	86.9	511	59	3.5	1.2 - 7.7
Canada de los Sauces	sedimentary: breccia, silt-stone, sandstone	grassland	86.6	555	54	3.4	3.2 - 3.6
Isthmus	shale	grassland	[1]455	179	61	0.2	0.1 - 0.7
Canadas Sauces-Cebada-Alegria	sedimentary: breccia, silt-stone, shale	coastal sage	14.5	13	42	0.4	0 - 1.2
East Central Valley	volcanic, volcaniclastic	coastal sage	21.1	3	63	0.1	0 - 0.5
Isthmus	shale	coastal sage	85	6	75	0.05	NA
Central Valley	schist	oak woodland	254	31	588	0.7	NA
Canada Christi	schist	pine forest	40.6	8	597	1.2	1.0 - 1.3
Isthmus	shale	woodland/ pine forest	71	1	15	0.002	NA

[1] sample includes large units of gently sloping surfaces.

Table 3--Variation in storm precipitation (in mm), March 1978 on Santa Cruz Island, California.[1]

	Main Ranch (62m elev)	Christi (33m elev)	Isthmus (460m
Storm precipitation (February 27-March5)	262	191	188
Pre-storm precipitation (30 day total)	315	223	326
One-day maximum	140	[2]145	69

[1]data courtesy of Dr. Carey Stanton, Santa Cruz Island Company.

[2]represents a 3-day total; however, it is probable that most precipitation fell within a 24-hour period.

The temporal patterns of landsliding suggest little direct association between vegetation removal and increased landsliding. Major vegetation changes occurred on the island in the late 19th and early 20th centuries, and accelerated erosion is very evident in the 1929 photographs. Vegetation has recovered locally in recent years, and yet the most severe landsliding in the last half century occurred in 1978. Several major storms occurred during this period, but apparently they were less intense than the 1978 storms. Precipitation characteristics are probably much more important than vegetation type in controlling landslide rates on Santa Cruz Island.

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