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ECOLOGICAL STUDIES OF MORRO MANZANITA

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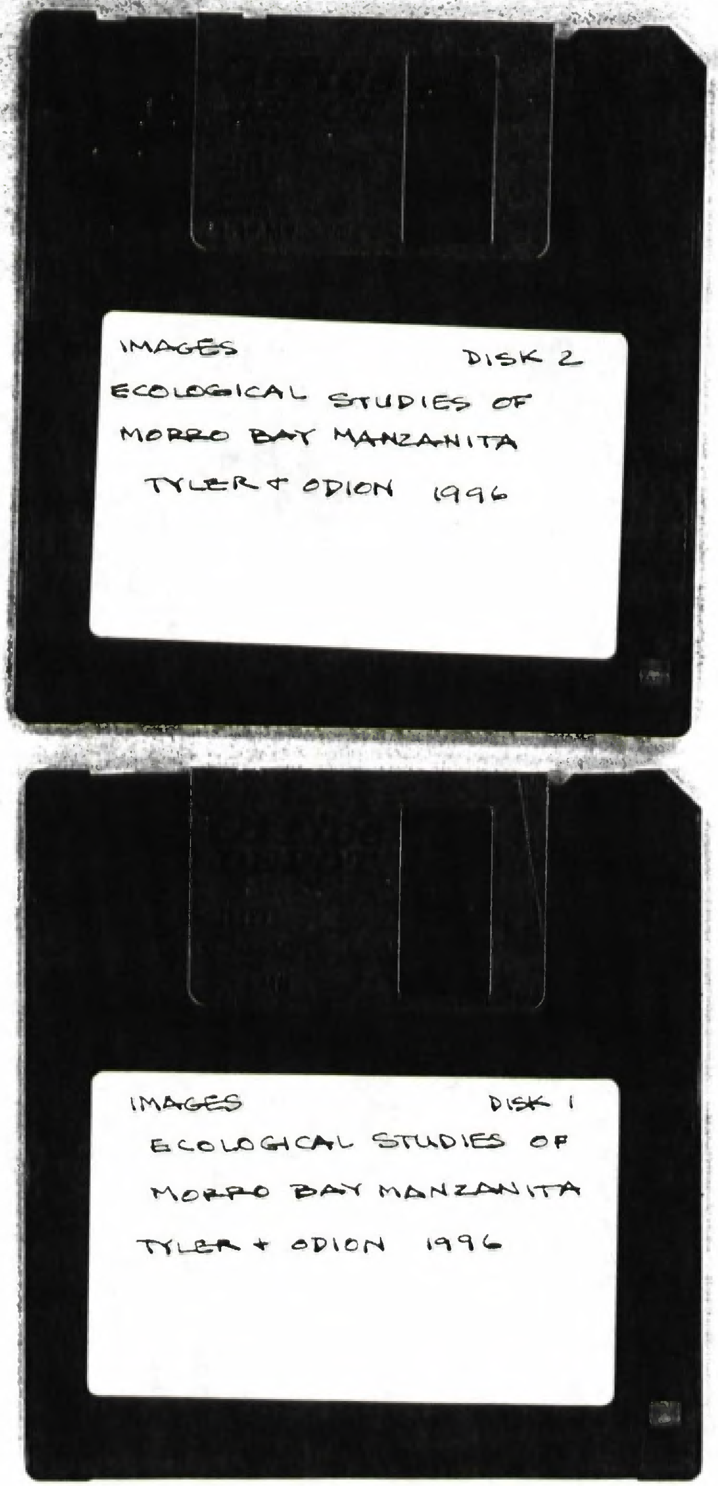
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ECOLOGICAL STUDIES OF MORRO MANZANITA (*ARCTOSTAPHYLOS MORROENSIS*)

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I) Abstract

Arctostaphylos morroensis is a shrub endemic to the coastal area of San Luis Obispo County, California. Its distribution is currently limited to approximately 890 acres of maritime chaparral and coastal dune scrub. In order to gain information about the ecology of this species, we conducted a literature review of the genus *Arctostaphylos*, as well as field and laboratory studies of *A. morroensis* and the plant communities in which it occurs.

To determine the characteristics of the plant assemblages in which *A. morroensis* is found, we collected data on the percent cover of associated species in 69 100 m^2 quadrats. Using multivariate analyses that group samples based on indicator species, we detected five distinct species associations: 1) maritime chaparral, 2) coastal scrub, 3) pure stands of *A. morroensis*, 4) *Quercus* dominated stands, and 5) associations under dead *A. morroensis*.

We estimated stand ages using historical aerial photographs from 1949 - 1992, and cross-sections from shrubs that establish after disturbance. We identified one large area (Montaña de Oro, west of Pecho Valley Road) that was 37 years old, and another area that was approximately 47 years old. All other stands were determined to be greater than 47 years old.

We collected soil seed bank cores from 20 different locations, within 4 different sites. The following were the primary results of our seed bank analysis: 1) there were significantly more seeds in the top 5 cm of soil than in the next lower 5 cm; 2) there were very low densities of seed adjacent to manzanitas (1.5 m away from the canopy edge) compared to underneath the shrub canopy; 3) the estimated seedbank size ranged from 12,491 to nearly 37,000 seeds per m^2; 4) percent viability was low at all sites, on average 4.8%; 5) the estimated number of viable seeds per m^2 ranged from 390 to 2,876.

We provide recommendations for management and future research, including using estimates of the current abundance of *A. morroenis* (rather than acreage of total habitat), and developing a fire managment plan. We also discuss threats to the Morro manzanita, and restoration of Morro Bay maritime chaparral.

II) Introduction

Arctostaphylos morroensis is a narrowly endemic species restricted to a portion of coastal area in San Luis Obispo County (Fig. 1). It is an erect shrub (family Ericaceae) which becomes arborescent with old age; it can be distinguished from other species of co-occurring manzanitas by its persistent shreddy bark and densely hairy lower leaf surfaces.

The distribution of this manzanita is highly correlated with Baywood soils (Soil Conservation Service 1984). These are very deep, somewhat excessively drained soils on stabilized sand dunes near the coast. The permeability is rapid and the available water capacity is low. The three categories of this soil series are separated based on slope: Baywood fine sand, 2-9 % slopes; Baywood fine sand, 9-15 % slopes; and Baywood fine sand, 15-30 % slopes (Fig. 2). The areas of highest cover of *A. morroensis* are found on the 9-15% and 15-30% slopes.

The major threat to *A. morroensis* is urban development. This species has been listed by the California Native Plant Society as a plant that is "rare, threatened or endangered in California." The current distribution of *A. morroensis* has been estimated to be approximately 890 acres. This estimate is for the total acreage of habitats in which *A. morroensis* is present. However, since this species occurs in low cover abundances in most places where it is present, estimates of the acreage of this species alone are much lower, probably less than 353 acres (see management recommendations).

The objective of this study was to gather information on several aspects of the ecology of Morro manzanita (*Arctostaphylos morroensis*) that may be useful in preparing recommendations for the management of this species. This report includes: 1) a review of literature on the ecology of the genus *Arctostaphylos*, and the stand dynamics of coastal maritime plant communities; 2) qualitative and quantitative descriptions of the plant communities in which Morro manzanita occurs; 3) estimates of stand ages; 4) estimates of the density of viable seeds in the soil seed banks; and 5) recommendations for the management of *Arctostaphylos morroensis*.

III) Literature review on the ecology of the genus *Arctostaphylos*

Modes of regeneration

The genus *Arctostaphylos* contains about 100 taxa (Hickman 1993). Their distribution is strongly centered in California. Many types of manzanita are recently evolved (Wells 1969). The nature of their variability and distinctiveness, as well as hybridization among types makes classification difficult. Accordingly, there have been several taxonomic treatments of the genus, and a new treatment is forthcoming from Tom Parker and Mike Vasey of San Francisco State University.

There is an unambiguous difference in a basic life history trait that segregates *Arctostaphylos* into two functional groups. One group resprouts from a specialized woody burl following canopy removal by fire or mechanical means. Sprouters also recruit new branches into the canopy from these lignotubers regularly in between fires (Keeley 1992). Other manzanitas are obligate seeders (OS). They have, through evolution, lost the ability to resprout. Instead, maintenance and regeneration is dependent upon mass germination triggered by fire (Wells 1969). This is facilitated by rapid seedling growth and relatively low mortality levels (Horton and Kraebel 1955, Odion 1995). Low mortality in part results from particularly efficient water use (Schlesinger and Gill 1978, Frazer and Davis 1988). Thus, stands of obligate seeders may be completely consumed by combustion, but, eventually return to the same abundance as in a prior fire cycle.

Seeds of obligate seeders are refractory (Sweeney 1956, Keeley 1992); that is, germination is completely inhibited until primary dormancy is released by a specific mechanism. Moisture and temperature stratification is required to overcome secondary dormancy (Berg 1974). Refractory seeds are long-lived. The dormancy mechanism allows shrubs to build up a seed bank that is persistent (Parker and Kelly 1989).

The obligate seeding mode of regeneration is considered to be an example of evolution of extreme specialization to fire (Keeley and Zedler 1978). Seedlings of obligate seeders are encountered infrequently in the absence of fire, usually where mechanical disturbance of soil occurs (Keeley and Keeley 1988). Presumably this can scarify seeds and allow them to germinate. *Arctostaphylos morroensis* is an obligate seeder. Stands are even-aged, dating to the most recent fire at each site. There are some young Morro manzanita saplings and seedlings in areas where soils have been disturbed, but only a handful.

The occurrence of both resprouting and obligate seeding shrubs within such dominant genera as *Arctostaphylos* and *Ceanothus* provides an example of how mode of regeneration may influence allocation of resources to sexual reproduction, and the ecological significance of this regeneration strategy. Obligate seeders produce more flowers, fruit, and seeds compared to resprouting congeners (Keeley and Zedler 1978, Fulton and Carpenter 1979). It has been suggested that the obligate seeding mode evolved based on selection for sexual reproduction, which would permit greater rates of evolution and allow taxa to change with the highly dynamic (over geologic time) California environment (Wells 1969). More recently, authors have speculated that the obligate seeding mode of regeneration is a response to a regime of relatively infrequent fire (perhaps 70-100 years) (Keeley and Zedler 1978), or a regime of intermediate fire intervals (ca. 50 years). Odion (1995) provides evidence indicating that obligate seeders appear quite resilient to varying fire interval. There is much variation in shrub longevity, growth rate, seed production and seed bank dynamics (Parker and Kelly 1989, Odion 1995). Different obligate seeders may be favored with different fire regimes, as opposed to obligate seeders and sprouters each being favored by a particular fire regime.

The few known cases of poor seedling establishment by obligate seeders can all be attributed to out of season burning (Horton and Kraebel 1955, Parker 1987, Moreno and Oechel 1992), or an extremely short interval between fires (Zedler, Gautier and McMaster 1983, Haidinger and Keeley 1993). Luxuriant post-fire seedling growth following typical dry season fires is commonplace in chaparral (Brandegee 1891, Sampson 1944, Horton and Kraebel 1955, McMinn 1964, Frazer and Davis 1988), including maritime chaparral (Davis, Borchert, and Odion 1989, Tyler 1995, Odion 1995, Tyler 1996).

It should be noted that prescribed burning of Morro manzanita stands, except select small parcels, would not be feasible under the wildfire conditions such as have occurred in relation to the sites observed in the aforementioned studies. Burning small parcels would require construction of fuel breaks and would further reduce the occurrence of even-aged populations.

Flowering and fruiting

Reproductive growth in manzanita is initiated in summer, when a nascent inflorescence develops. This inflorescence becomes active with the onset of seasonal rains in fall. Flowering follows soon after in most species, including *Arctostaphylos morroensis*, which blooms in winter. Flower and subsequent fruit production in *Arctostaphylos* may be determined largely by rainfall during the previous year because buds are set at that time (Keeley 1977). Keeley (1987a) found that fruit production for *Arctostaphylos glauca* (OS), *and A. glandulosa* (sprouter) varied over a ten year period from near zero to 1100 seeds/m^2.

Arctostaphylos seeds are contained in a fleshy or mealy drupe. From 4 to 11 seeds are variously coalesced, or are sometimes separate (Berg 1974). Seeds of *Arctostaphylos morroensis* are rather strongly coalesced. There are typically 8 to 10 per fruit.

Manzanita fruits are dispersed from summer to fall (Berg 1974). These fruits are not specialized to attract animals, and dispersal is apparently strongly confined to underneath the shrub canopy (Kelly 1986). Animals such as black bears and coyotes, which are known to eat manzanita seeds are not considered to have a quantitative predatory impact on the overall production of seed (Keeley 1992). Rates of *Arctostaphylos* seed predation have been found to be as high as 60 percent of the entire seed bank within a 6 month period (Keeley 1977). Rodents are known to be attracted to the fruit and/or seeds (Horton and Wright 1944, Keeley and Hays 1976). Seed predation is greater for species with larger seeds (Keeley 1992).

Seed banks

While *Arctostaphylos* nutlets are most frequently encountered individually in the soil seed bank, it is common to find 2 or more nutlets remaining together, and this is true for *Arctostaphylos morroensis* (see section on results of seed bank studies).

The depth at which seeds occur in the soil seed bank may have significant effects on seed mortality during a fire. In maritime chaparral near Lompoc, California, Odion (1995) found that species with more deeply buried seed suffered lower seed mortality than species with shallowly buried seed. For example seed mortality was not as great in *Arctostaphylos purissima* (83% mortality) because a greater proportion of seed occurred at depth (~50% below 2.5 cm) compared to *Adenostoma fasciculatum* (10% of seed below 2.5 cm, 97% mortality). Only 5% of the annual *Navarettia attractyloides* seed was below 2.5 cm in depth, and only 10% survived fire in the areas of even the lowest soil heating, the pre-burn gaps. Considering the extreme temperature gradients that develop in the upper soil layers during fire, depth of seed burial will be paramount in determining survival. This may be particularly germane for *Arctostaphylos morroensis* as well as the maritime species from the Monterey Bay area because they occur on similar Pleistocene sands. In the present study, we found that approximately 80% of *Arctostaphylos morroensis* seed was in the upper 2.5 cm of soil (see section on results of seed bank studies).

Parker and Kelly (1989) report that among *Arctostaphylos* there is an inverse relationship between seed size and seed bank size. Small-seeded *Arctostaphylos viscida* may accumulate 22,177 seeds/m^2, while larger seeded species, such as *A. mewukka* and *A. crustacea* accumulate considerably fewer (6463 and 978 seeds/m^2, respectively).

We could find no data addressing how long manzanita seeds can live in the soil seed bank. Seeds of chaparral shrubs have been found in duff under conifer vegetation lacking shrub understory (Quick 1962). This indicates that seeds can live for at least the length of time required for chaparral to be replaced by mixed conifer vegetation, which could take 200 years. It is of obvious ecological necessity that seeds of obligate seeders have fairly long lived seed.

Seed viability

Keeley (1977, 1987a) examined embryos of *Arctostaphylos glauca* (OS), and found 50 percent viability. Work on other species by Victoria Kelly and Tom Parker (1990) has revealed much lower viability, ranging from 4 percent for *Arctostaphylos mewukka* (sprouter) to 13 percent for *Arctostaphylos crustacea* (sprouter). Kelly and

Parker found viability of obligate seeders *Arctostaphylos canescens* and *A. pechoensis* to be 10 and 6 percent, respectively.

Seed germination

Seeds of *Arctostaphylos* have hard seedcoats and dormant embryos (Berg 1974). When the seed germinates, the hypocotyl is forced through a channel at the basal end (Berg 1974). The tissue plugging this channel is softer than the surrounding endocarp wall. Germination can proceed if the softer tissue is dissolved artificially using acid, or if the endocarp is cracked by heat or mechanical means. Thus, immersion in sulfuric acid, or application of dry heat are standard methods of propagating manzanitas from seeds (Emery 1988).

Sampson (1944) studied germination of manzanita seeds subjected to various levels of heating, and found that germination rates were greatly enhanced with heat up to a threshold beyond which mortality occurred. Even with heating, however, germination percentages were found to be low (11 percent for common manzanita *A. glauca* and 9 percent for *A. parryi*, both obligate seeders). Berg (1974) found that germination following immersion in sulfuric acid was 3 - 5 percent for *A. glauca* (OS), 3 - 8 percent for *A. glandulosa* (sprouter), and 20 percent for *A. patula* (sprouter). All of these results are apparently from seed that was freshly collected, dried, and stored following standard procedures.

In recent years, researchers have been experimenting with the effects of charred wood and smoke on germination of chaparral seeds. Both are byproducts of combustion and overlap to some degree in their chemical composition. They have been found to significantly enhance germination of some chaparral species. In a review of chaparral seed germination, Keeley (1992) did not include *Arctostaphylos* among species requiring heat for germination, but indicated that cold stratification is necessary, and that charred wood eliminated dormancy in some species. (Keeley et al. 1985, Keeley 1987b). Parker (1987) obtained 14 percent germination for *A. canescens* (OS) seeds extracted from the soil and then incubated with an aqueous leachate of charred wood. Interestingly, charred wood did not release fresh seed of this species from dormancy, so the effects of charred wood/smoke on release from dormancy apparently can change as seeds age in the seed bank.

Odion (1995) found that charate significantly enhanced germination of soil stored seed in the maritime chaparral endemic *Arctostaphylos purissima*. Seed bank samples that were collected prior to burn and were treated with heat and charate had much greater total germination than controls, heat-treated samples, and samples collected from the same locations immediately following a high intensity dry season fire.

Seedling regeneration following fire

Thomas and Davis (1989) compared survival of obligate seeding and seeder/sprouter species of *Ceanothus* and obtained results consistent with the hypothesis that lack of resprouting ability among obligate seeders is offset by an enhanced ability to establish seedlings after wildfire. In contrast, Sampson (1944), observed higher mortality and lower establishment in an obligate seeding species compared to a seeder/sprouter species of manzanita, in a burned chaparral site in northern California; at a site dominated by Eastwood manzanita (sprouter/seeder), there were approximately 25/m^2 Eastwood manzanita seedlings, and about 9/m^2 of *Arctostaphylos glauca* (OS). After five years, survivorship of Eastwood manzanita was 72%, compared to 38% for *A. glauca*. Horton and Kraebel (1955) also found no evidence for enhanced establishment for obligate seedling species of manzanita. They studied vegetation development after fire in southern California. At a site described as dominated by *Adenostoma fasciculatum* and *Arctostaphylos glandulosa,* they found about 5 seedlings/m^2 of *A. glandulosa* (seeder/sprouter), and about 6 seedlings/m^2 of *A. glauca (*OS) following a fire. Fifteen years after burning all of the manzanita seedlings in this study had died.

Odion (1995) studied postfire establishment of *Arctostaphylos purissima* in maritime chaparral and found highest densities of seedlings in vegetation gaps where soil heating during the fire was lowest. An average of 14 seedlings/m^2 were found where gaps in the chaparral cover occurred prior to burning, compared to an average of 8.7/m^2 in the same area where there was a shrub canopy prior to the fire (in paired understory plots). Along a transect where pre-burn shrub cover was high, only 3.3/m^2 were found, with seedlings strongly concentrated in areas of lower soil heating during fire. In gap areas, where seedlings of all species were much more abundant, survival after 5 years varied between 11 and 15 percent

Based on this literature, it appears that seedling establishment and long-term survival for obligate seeding manzanita may vary from fire to fire depending on soil heating, seed populations, factors affecting seedling survival, etc. Such variability has important repercussions for conservation in narrowly restricted species. If a fire occurs over their existing range with suboptimal conditions for germination and establishment, a significant reduction in population densities could occur. This could be exacerbated by the occurrence of exotic pest plants in the area, such as *Eucalyptus* or iceplant, or animals, such as feral pigs, which could disturb soil at critical periods of seedling establishment (Odion 1995).

Stand dynamics of coastal maritime chaparral communities

Sampson (1944), Horton and Kraebel (1955), and Keeley and Zedler (1978), among others, have documented that the highest mortality of chaparral seedlings occurs during the first year following fire. It is likely that water stress due to drought is the predominant cause of this high mortality (Frazer and Davis 1988). Mortality may also result from herbivory (Mills 1983, Tyler 1994). It has been hypothesized that selection for traits maximizing seedling survival has occurred to a greater extent among obligate seeders because they are completely dependent upon seedling establishment for their maintenance (Frazer and Davis 1988, Moreno and Oechel 1992). Seedlings of obligate seeding *Ceanothus* have been shown to be more tolerant of water stress during summer drought compared to *Adenostoma* (Jacks 1984, Frazer and Davis 1988). Thus, it is surprising that Odion (1995) found the overall survival of the maritime chaparral obligate seeder *Arctostaphylos purissima* (10.7%) was lower than for *Adenostoma* (13.3%). These survival percentages for *Arctostaphylos purissima* were somewhat lower than the 5th year survival measures obtained by Sampson (1944), and Horton and Kraebel (1955) for the obligate seeding *Arctostaphylos manzanita* and *A. glauca.* Tyler (1994) found that *A. purissima* survival at the same site studied by Odion was 46 percent from the 2nd to the fourth growing season. Thus, as expected, mortality for *A. purissima* is concentrated in the first year following germination. The same would likely be true for *A. morroensis*.

Odion (1995) found that *Arctostaphylos purissima* survival varied significantly among locations in a burned area. The most important factor affecting this variation in survivorship was the presence of shrub canopy before the fire. After 5 years, survival was 15-16 percent where *Adenostoma* canopy was present prior to fire. This was significantly greater, than the 11 percent survival found where there had been pre-burn canopy gaps. Using caging experiments to exclude mammalian herbivores, Odion (1995) found that over a three year period, significant *Arctostaphylos* mortality occurred even in the absence of herbivory.

While the presence of *Adenostoma* canopy had positive effects on recruitment of *Arctostaphylos* seedlings in the first several years after a burn, Odion (1995) found that after five years there appeared to be a negative influence of resprouting *Adenostoma* on *Arctostaphylos* survival; there was also much mortality apparently unrelated to the presence of *Adenostoma*. These results suggest that following a high intensity fire, where mortality of *Adenstoma* occurs, obligate seeding *Artostaphylos* may be able to establish in locations previously occupied by chamise and vie for long term occupation of those locations. In fact, seedling densities of *Arctostaphylos* were the highest of all shrub species after fire at the site studied by Odion (1995) and Tyler (1994), even though the shrub was only scattered in the stand prior to fire, and seedlings of *Adenostoma fasciculatum, Ceanothus cuneatus*, and *Ceanothus impressus* were also abundant. Even with its poor survival, densities of the manzanita after 5 years were sufficient to ensure that its population was maintained. In fact, a long-term increase in *Arctostaphylos purissima* abundance appears to have resulted following the high intensity fire. Along a 47 m transect observed by Odion (1995), three living and two dead *Arctostaphylos* were found prior to the burn. Five years later there were 23 established shrubs.

Davis, Hickson, and Odion (1988) studied vegetation composition in 27 stands of varying age (1 to 50+ years) in maritime chaparral on Burton Mesa. They found that the obligate seeding purisima manzanita (*Arctostaphylos purissima*) increased in cover as a function of stand age. Their sites did not include the 75+ year old stand studied by Tyler (1994, 1996) and Odion (1995). At this site, there was considerable recent mortality of *A. purissima*, perhaps due to senescence. Live *A. purissima* were still abundant at the site, but it appears that the trend for this older stand was toward an overall reduction in cover of *A. purissima*.

In the present study, we observed that mortality of *A. morroensis* has occurred in recent years in the Elfin forest area, where we observed over 10 dead individuals (all large). For some obligate seeders, longevity appears to be, at least in part, genetically controlled. For example, the short lifespan of *Ceanothus* species is well known in both wild and garden grown plants (Hickson 1987, Davis, Hickson, and Odion 1988, Sunset Western Garden Book 1988). Further research is needed to determine the longevity of obligate seeding manzanitas.

IV) Species associated with Morro manzanita

One goal of this project was to characterize the plant communities in which Morro manzanita occurs. Using the diagrams that map the distribution and percent cover of Morro manzanita, prepared by the Department. of Fish and Game (and thesis by M. Mullany 1990), we surveyed the polygons, or areas, in which manzanita was shown to occur (Fig. 3, Table 1). At each location we recorded the dominant plant species present.

To quantify our description of the plant communities, we selected a subset of the polygons for more intensive sampling. Over the range of manzanita cover classes, we sampled the vegetation using the following relevé technique. A representative stand or manzanita shrub was selected haphazardly. We recorded the percent cover of all species present within three 100 m^2 circular quadrats: one under the shrub canopy, and two in randomly selected directions adjacent to the manzanita. At locations where the manzanita formed a dense stand, we were unable to sample adjacent plots. We sampled 24 different locations, yielding a total of 24 samples under manzanita shrub canopy, and 41 samples of adjacent vegetation. In addition, we recorded the percent cover of all species present within 100 m^2 quadrats in the understory of four dead manzanitas found in the Elfin forest (Fig.3, polygon 1).

The data from relevé sampling was analyzed using multivariate techniques to detect associations or characteristic groupings of species within communities where Morro manzanita occurs. For this analysis, we used two way indicator species analyis, or TWINSPAN (Hill 1979), which is a program that was developed to classify phytosociological data, that is, data on the occurrences of a set of species in a set of samples. Samples are grouped together (classified) in a hierarchical arrangement based on the occurrence of indicator species which are used identify each group in the classification. Abundance is important in the identification of indicator species, for example, high cover of *Arctostaphylos morroensis* can be an indicator of an association even though this species is present in other associations. The program treats high cover values of a species in a plot and low cover values of the same species in another plot as separate "species" (psuedospecies) in order to separate plots that may have the same species composition, but with different relative abundances. The data matrix which is produced approximates the traditional Braun-Blanquet tablework, which was a manual, cut and paste approach for grouping plots based on floristic composition. The goal of this type of classification is to identify associations of species that can be named. The named objects are then used to provide a parsimonious description of vegetation including all of its floristic elements. The table also succinctly expresses the species' synecological relations, in other words, how they are associated.

Two way indicator species analysis of relevé data from within and adjacent to stands of Morro manzanita revealed 4 general species associations (Table 2). The first division in the plot data separates plots sampled underneath live *Arctostaphylos morroensis* canopy (plots grouped at the right side of the table) from those sampled immediately adjacent and from under dead *Arctostaphylos morroensis*.

The environment under live *Arctostaphylos morroensis* canopy is one of low light and deep leaf litter. *Arctostaphylos morroensis* may also be allelopathic, as is *A. glandulosa* var. *zacaensis* (Chou and Muller 1972). These factors, along with herbivory, combine to create an environment that supports little understory plant growth. Old *Ceanothus cuneatus* that dated back to the previous fire within stands were occasionally found. Generally these were shaded out and most were dead. *Marah fabaceous* and *Mimulus aurantiacus* were also fairly common under *Arctostaphylos morroensis*, but generally these plants were small compared to their counterparts elsewhere. Because of the infrequency of consistent associates, the vegetation under the canopy of *Arctostaphylos morroensis* can be described as the *Arctostaphylos morroensis* association. It is likely that after fire, and for the decade or two that it takes for the manzanita canopy to reform, there would be a host of other species associated with *Arctostaphylos morroensis* in the same locations that are eventually overtopped by it. There were no relatively young stands present to sample at the time of our field work. The *Arctostaphylos morroensis* association occurs in patch sizes ranging from the size of individual shrubs (often quite large), to nearly continuous pure stands covering many acres. Small patches occur in areas mapped by Mullany (1990) as having less than 25 percent cover. These are mostly on level terrain. Continuous *Arctostaphylos* cover occurs in polygons having greater than 25 percent cover. These occur at the south end of the study area on sloping terrain. Density of manzanitas and fuel loading in these areas is remarkably high compared to what we have seen in other chaparral areas.

The remaining plots were separated into two main types. The first of these is characterized by high relative abundances of three understory species, *Marah fabaceous, Ribes speciosum*, and the exotic pest plant *Conocosia elongata*. This type is further subdivided into two associations because these understory species were common in two rather different situations, the *Marah* and *Ribes* were common under and near *Quercus agrifolia*, and *Conocosia* was comomon under and near dead *Arctostaphylos morroensis*. These associations are best referred to as *Quercus-Marah* and *Conocosia*-dead *Arctostaphylos* respectively. *Conocosia* is a rather recent arrival that appears to be rapidly increasing in abundance. Death of *Arctostaphylos morroensis* provides a high light environment into which this iceplant invades. Elsewhere in the chaparral, this iceplant invades mostly in artificially disturbed places, such as trailsides, dozer scrapes, etc. Both of these associations are most common in polygons 1-5. As described above, all the dead manzanita individuals we observed were in the Elfin forest area. The *Quercus-Marah* association that is found intermixed with chaparral differs from the *Quercus* forests found on steep north facing slopes in the area (e.g. on the north facing slope just north of the Elfin forest). Patch size of these associations is at the scale of individual *Quercus* and manzanitas.

The remaining group of plots were all sampled adjacent to *Arctostaphylos morroensis* and are representative of the mixed coastal chaparral of the region. In addition to the manzanita, the dominant and indicator species of this vegetation are *Ericameria ericoides*, *Adenostoma fasciculatum*, *Ceanothus cuneatus*, *Mimulus aurantiacus*, and the subshrub *Lotus scoparius*. Although these plants occur among and immediately adjacent to *Arctostaphylos morroensis*, they usually do not occur underneath its canopy. Areas adjacent to the manzanita are also characterized by bare ground, generally 30-50 percent. Because this association is dominated by a host of species, and some of these, such as *Arctostaphylos morroensis*, may be absent from some chaparral areas, it is probably best to refer to the type as simply Morro Bay maritime chaparral, rather than using the convention naming by the genera of plants that distinguish it. Having openings and bare sand between shrubs, Morro Bay maritime chaparral is characterized by a considerable herbaceous flora that varies significantly from year to year depending on rainfall. Species such as *Camissonia micrantha* and *Chorizanthe diffusa*, which were not common during our sampling season, may be common in certain years, along with a host of other annuals. Both fire and mechanical disturbance will greatly increase the abundance of these species. In the case of mechanical disturbance, Morro Bay Maritime chaparral is converted to a weedy coastal scrub vegetation that may retain chaparral elements, or may not. This coastal scrub vegetation was not sampled quantitatively, but areas found to have been previously cleared or type converted based on analysis of air photos (e.g., polygon 14) were described, and species lists made. In addition to isolated individuals of the aforementioned chaparral shrubs, this vegetation is characterized by shrubs with wind-dispersed readily germinable seed, such as *Artemisia californica* and *Baccharis pilularis*. Exotic grass and iceplant invasion is also common in the coastal scrub. Species not found in plots adjacent to *Arctostaphylos morroensis*, but found in coastal scrub vegetation in the vicinity of the manzanita include *Lupinus chamissonis*, *Lupinus arboreus*, *Eriastrum densifolium*, *Pholisma* sp., and *Prunus fasciculata*. Prior to introduction of mechanical disturbances or other type conversion in the study area, the predominant vegetation was probably Morro Bay maritime chaparral with abundant Morro manzanita. Coastal scrub was probably limited to select few loose, open south facing slopes, and along the immediate coast. Mechanical disturbance has converted most of the area in polygons mapped by Mullany (1990) as having less than 25 percent *Arctostaphylos morroensis* cover to coastal scrub.

Coastal sage scrub vegetation is not expected to develop back into maritime chaparral. At La Purissima Mission State Historic Park, where disturbance history has been well documented, Ferren *et al.* (1984) observed that previously cleared maritime chaparral areas on eolian sand have remained as coastal sage scrub for decades. This is true even in previously cleared areas that have since burned. Some establishment of *Ceanothus cuneatus* var. *ramulosus* has occurred in these areas from seed that remained in the soil following scraping. It is possible that this species as well as *A. morroensis* could have limited regeneration following fire in coastal sage scrub in the Morro Bay area. The amount of soil loss that occurred during previous type conversion would likely determine the extent of this. Clearing to remove chamise (*Adenostoma fasciculatum*) involves considerable soil loss or redistribution because the lignotubers must be excavated; chamise often occurs with *A. morroensis*. Type conversion using the method of burning, establishing a grass crop to create fuel, then burning again the following year (Hedrick 1951), would result in complete loss of the seed bank of refractory species like Morro manzanita. Seed is either killed by the initial fire, or it germinates. Seedlings are killed by the subsequent fire. Seed input will only occur in the immediate vicinity of adult *A. morroensis*, so there would be little or no seed returned. Knowledge of the disturbance history of coastal sage scrub sites in the Morro Bay area would be helpful for predicting the response of this vegetation to burning. Coastal sage scrub areas could be restored to maritime chaparral by adding seed bank material from chaparral areas prior to burning (see management recommendations), however, this technique is untested, and results are uncertain.

Being floristically-derived, species associations are not as suited to mapping as are structurally-derived vegetation formations. Nonetheless, the associations described here can be effectively mapped. The *Quercus-Marah*, dead *Arctostaphylos* and pure *Arctostaphylos* associations are defined by their overstory, and are discrete features. However, these occur in patch sizes too small to resolve at typical map scales, for example when individual *Quercus* or *Arctostaphylos* are scattered amid maritime chaparral or coastal scrub, such as at the Elfin forest. Under these circumstances, these features can be effectively depicted by mapping the general vegetation of the area, and showing the oaks and manzanitas as point features. The map legend and accompanying text can explain that these are discrete entities too small to resolve as individual polygons (i.e., below the minimum mapping unit). The pure *Arctostaphylos* association also occurs as large patches, which can be delineated. The legend should explain that these features and the point features of *Arctostaphylos* are the same, except for their size. The remaining association, coastal sage scrub is easily distinguished from the others, but may be confused with dune scrub vegetation.

Odion, Hickson, and D'Antonio (1992) mapped Central Coast Maritime Chaparral on Vandenberg Air Force Base for management purposes. This mapping depicted the threat of iceplant invasion for each polygon. The amount of iceplant within each polygon as well as the seed source in the vicinity were criteria used to determine this threat. Polygons were delineated in part based on this information. It would be desirable from a management standpoint for maps of Morro manzanita and surrounding vegetation to similarly indicate potential for exotic species invasion as well as stand age and perhaps other features.

In summary, the vegetation in areas where *A. morroensis* occurs consists of five easily recognizable types: 1) maritime chaparral, 2) coastal scrub, 3) pure stands *of A. morroensis*, 4) *Quercus* dominated stands, and 5) dead *A. morroensis*. Much of the landscape is dominated by Morro Bay maritime chaparral, a relatively rich assemblage of maritime chaparral shrubs, subshrubs, and herbaceous plants, with considerable bare ground. Where this community has been mechanically disturbed, chaparral species abundance is much lower, and coastal scrub species, a host of annual and perennial herbs, and exotics are dominant in a coastal scrub assemblage that we did not sample, but observed in our survey of polygons. Embedded within these associations are patches of pure *Arctostaphylos morroensis*, pure *Quercus agrifolia*, and large, dead *Arctostaphylos morroensis*, each having distinct species composition. On level sites such as the Elfin forest area, the patches of live *Arctostaphylos* and *Quercus* are relatively small, consisting of one to a few usually large individuals. *Marah* is a consistent associate of *Quercus*. *Conocosia* has invaded all locations where manzanitas have died in recent years. Both live and dead manzanita individuals in the Elfin forest area are large, with diameters of up to about three feet, and canopy diameters up to about 10 m. The sloping landscapes to the south and southwest support large patches of *Arctostaphlos morroensis*. Large or small, patches of pure manzanita are characterized by a paucity of associated species.

V) Estimation of stand ages

Ages based on historical aerial photos

To determine minimum stand age, and to provide information about the disturbance history of Morro manzanita stands, we studied aerial photographs of the Baywood Park - Los Osos area from the photo collection in the Map and Imagery Library at the University of California, Santa Barbara. Images from 1949 to 1992 were examined and areas of disturbance were traced onto current photographs using a zoom transfer scope.

Ages based on cross sections of *Ceanothus cuneatus*

To provide additional information about stand age, we collected cross-sections of *Ceanothus cuneatus* near five different stands of Morro manzanita, in summer 1995. *C. cuneatus* is an obligate seeder, similar to the Morro manzanita, which germinates following fire. Thus, the age of *C. cuneatus* should indicate the age of the manzanita stands. In two locations where there were dense stands of *A. morroensis*, we also collected one cross-section of manzanita. Shrubs were cut with a hand saw, as close to the level of the soil as possible. The cross sections were then finely sanded, and the rings counted using a high resolution dissecting scope.

Results

The earliest aerial photographs of the Morro Bay area available in the Map and Imagery Library at U.C.S.B. were taken on June 4, 1949. They show a large area south of Highland Drive that was cleared and/or burned (Photo 1). While, this disturbance may have occurred several years prior, it is likely that it had taken place close to 1949, because there was very little vegetation present in the patch. We hypothesize that the stand age of this area is approximately 47 years (as of 1996). This area includes polygons # 18,19, and 20 (Table 1, Fig. 3).

The aerial photograph taken on July 28, 1954 (Photo 2) is noteworthy for two reasons: 1) it shows the regrowth of vegetation in the area disturbed near 1949; and 2) it shows that the vegetation in the dunes area west of Pecho Valley Road was intact at this date.

The dunes area mentioned above was cleared and/or burned between 1956 and 1959. The aerial photograph taken on November 6, 1959 (Photo 3) shows a large area west of Pecho Valley Road from which vegetation was removed and/or burned. Visible are dark striations that were likely caused by bulldozer tracks and ash. A report prepared by the U.S. Army Corps of Engineers (1994) describes historical ordnance removal operations in this area, formerly called the Baywood Park Training Area. It reports a search and surface clearance of unexploded ordnances conducted in the area on July 1958. The report recommends that "further clearance of subject land be accomplished by the following method: clearing of surface by bulldozing, windrowing and burning not to include large active sand dune area." There is no description of this recommended clearing and burning, but photographs from the year following this report suggest that this operation was conducted between 1958 and 1959. This area includes polygons # 29-35, and #37. This area apparently contains the youngest stands of intact *A. morroensis*, at about 37 years old.

Also evident in the 1959 photograph, is the disturbance of a small patch near the Los Osos Oaks Preserve (Photo 3). This disturbance was first visible on a photograph taken in 1956. This area corresponds to polygon # 14. The stand age of this area is 41 years.

A photograph taken in August 1988, shows most of the vegetation cleared in polygon #22; this vegetation was intact in the photo from the year previous - August 1987. The only vegetation in this polygon that was evident in 1988 were several patches of shrubs. Visual surveys of this polygon conducted in 1996 indicate that there were saplings of *A. morroensis* scattered among the coastal scrub vegetation. We estimate that those saplings are approximately 8 years old. The adult shrubs present in this polygon are > 47 years old.

The counts of annual rings from shrub cross-sections generally confirm the minimum stand ages determined from aerial photos. The ring counts put stand ages below that indicated from disturbance history, but used in conjunction with information from historical photos, helps to accurately age some of the stands. The number of rings counted from *C. cuneatus* cross-sections varied from 29-47. In the dune area west of Pecho Valley Road, where the stand age was determined to be 37 years old from aerial photographs, we cut an *A. morroensis* from a dense stand (Fig.3, Table 1 - polygon 33), and counted 32 rings in the cross-section. All other cross-sections were taken from stands that had not been disturbed since before 1949. The greatest number of rings counted from these areas was 47, suggesting that the stands are >48 years old. Although this study did not confirm differences in ages between the dense stands of *A. morroensis* in Montana de Oro State Park near the rim trail (polygon #28), and the shrubs in the Elfin forest, we hypothesize that the large, tree-like individuals in the Elfin forest are the oldest *A. morroensis* in the species natural range.

In summary, we believe the youngest stands of *A. morroensis* (37 years old) are those in Montana de Oro State Park in the dune area west of Pecho Valley Road. The next youngest (47 years old) are the scattered shrubs west of Bayview Heights Drive, south of Highland Drive. The other stands, including those in the Elfin forest and Montana de Oro State Park, south of Cabrillo Estates, are all older than 47 years old, and we suggest that the individuals in the Elfin forest are the oldest.

VI) Estimates of the density of viable seeds in the soil seed bank

We collected seed bank cores from four different sites that reflect a range of manzanita cover classes. The first was the dunes area west of Pecho Valley road in Montaña de Oro State Park where the stand age was estimated at 37 years. This site was a mix of maritime chaparral and coastal scrub. The percent cover of *A. morroensis* in this site (according to Mullany 1990) ranged from 25-50% to 75-100%.

The second and third sites were north of Hazard Canyon. These sites were a mix of chaparral and *Quercus*, and dense stands of *A. morroensis*. The percent cover of *A. morroensis* ranged from 50-75% to 75-100%. These stands of manzanita are intermediate in age between sites 1 and 2.

The fourth site was in the Elfin forest, north of Santa Ysabel Ave. and west of South Bay Blvd. This area is a mix of maritime chaparral, coastal scrub, and oaks. The percent cover of *A. morroensis* is low, ranging from <1% to 5-25%. The vegetation at this site is older than 47 years, and some individual manzanitas appear to be very old.

Odion (1995) has documented that there is considerable variation in maritime chaparral soil seed densities at several spatial scales. To assess the variability over the range in distribution of *A. morroensis*, we sampled at 4 different sites, described above. To assess this variability within a site, at each site we sampled the seedbank at 5 different locations; we selected five *A. morroensis* shrubs or groups of shrubs (in most cases, the same locations that we sampled associated species vegetation.).

High variability in the densities of seeds in the soil are evident even at the microscale level; under a single shrub, densities can vary significantly in samples collected within a single meter (Odion 1995). For this reason, at each location we collected 6 different soil cores which were then consolidated.

The cylindrical soil corer was 7.1 cm in diameter, and 10.3 cm deep (area per core = 39.6 cm^2). For each sample, the depth of the litter was recorded, and litter removed and collected, then the soil cored to 10.3 cm. Seeds present in the litter were not counted because these would be incinerated during a fire. We were interested in the density of seeds that could potentially germinate following fire. Each soil core was separated into two sections - the top 5.1 cm and the bottom 5.1 cm. The total area of soil sampled per location (6 cores) was 237 cm^2, the total volume was 2437 cm^3 (top and bottom = 1219 cm^3 each)

To determine the distance at which seeds were dispersed, we also collected soil cores 1.5 m away from the edge of the shrub canopy (n = 6 per location). At some locations (particularly sites with dense manzanita stands) we were unable to collect adjacent soil samples.

In the lab, we homogenized each soil sample, and removed the seeds by passing the sandy soil through a No. 12 USA Standard Testing Sieve (mesh size - 1.70 mm), and then hand sorted the seeds from litter, pebbles, and other small debris. We sorted the entire sample in this way for 5 samples; for all others, we extracted half the sample, and doubled the resulting seed counts.

After the seeds were separated from the soil, for each sample we counted the number of intact seeds, and examined all seeds for viable embryos. To assess viability, we cut open each seed and examined it under a dissecting microscope. Embryos that were white and fleshy were counted as viable. This visual technique of assessing seed embryo viability has been shown to yield results consistent with tetrazolium testing (Parker, pers comm.).

Some of the seeds we examined were intact, but completely lacking any embryo. We scored these seeds as infertile. In addition, we found that in many samples, there were 2 or more nutlets remaining together. In one sample we examined 150 of these groups, and recorded the number of seeds per cluster.

Results of seedbank study

There were significantly more seeds (total) per sample in the top 5 cm of the soil compared to the lower 5 cm for all sites (Table 3; paired samples t-test: $t = 8.051$, $df = 19$, $P < 0.001$). On average, 80% of the seeds collected were in the upper 5 cm of the sample. We also found that there were significantly more viable seeds in the top of the sample, at all sites (Table 3, paired samples t-test: $t = 5.247$, $df = 19$, $P < 0.001$). There was only a small proportion of seeds that were viable at all sites. There was no significant difference in percent viability between the top and bottom samples (paired samples t-test: $t = -1.287$, $df = 19$, $P = 0.178$). The depth at which seeds occur in the soil seed bank will have important effects on seed survivorship and germination following fire. As discussed in the literature review, there may be high seed mortality in the upper several cm of soil during a high intensity burn. In addition, the seed that is deeply buried may not be sufficiently heated to germinate (Auld 1986). The ecologically relevant seedbank is probably a portion of the soil between 5-10 cm below the surface. The upper portion is important as the source of seed that eventually enters this lower seedbank.

Analysis of soil samples collected away from the manzanita canopy reveal that there are relatively low densities of seed in soil nearby *A. morroensis* (Table 4). We found that soil that was adjacent to manzanita shrubs (1.5 m away) had significantly fewer seeds per sample (paired samples t-test: $t = -5.524$, $P < 0.001$), and fewer viable seeds per sample (paired samples t-test: $t = -3.951$, $P = 0.003$). There was no significant difference in percent viability (paired samples t-test: $t = -0.565$, $P = 0.586$). Thus, on average, there were 10 times more seeds under the shrub canopy compared to soil less than 2 m away. This result suggests that re-establishment of *A. morroensis* following disturbance will primarily occur in locations where they occurred prior to the burn. Given the observed pattern of low seed densities away from existing aduls, it is likely that replacement, rather than expansion of this species would result after a fire, unless manipulation of seed was undertaken.

We found no significant relationship between maximum shrub canopy height and total number of seeds per location (linear regression: $n = 15$, $P = 0.259$, $R^2 = 0.097$), although the trend was toward a positive relationship. We also found no significant difference in litter depth among sites (ANOVA: $n = 20$, $P = 0.55$); the average litter depth for all locations was 2.5 cm, the loweset recorded depth was at the youngest site (1.3 cm) and the greatest litter depth (4.0 cm) was recorded at the site north of Hazard Canyon (#3).

Examining the total seedbank samples collected under *A. morroensis*, we found there were an average of 733 total seeds per sample and 35 viable seeds per sample, for all sites combined (Table 5), but there was considerable variation among sites Analysis of variance (ANOVA) revealed that there was a significant difference among sites in numbers of seeds, and number of viable seeds ($P = 0.001$, and $P < 0.001$, respectively). Post hoc comparisons (Tukey) show that the Dune area and the Elfin forest had significantly lower seed densities than the other two sites. Percent viability for all sites combined ($n = 20$) was relatively low, 4.8%, compared to other manzanita species. Parker and Kelly (1989) list the range of viability for *Arctostaphylos* species as 3% (*A. glandulosa*) to 54% (*A. glauca*).

In addition, we found that percent viability was exceptionally low at the Elfin forest (1.7%); although the difference between the Elfin forest and the other sites was not statistically significant at the 0.05 level (ANOVA: $P = 0.076$), this is a noteworthy pattern. More extensive sampling might reveal depressed seed viability in Elfin forest populations of Morro manzanita. Low seed viability could be a manifestation of inbreeding problems in small populations (i.e. Allee effect). The percentage of seeds that were infertile (lacking an embryo) was high, on average 45% over all sites; % infertility did not differ significantly among sites (ANOVA: $P = 0.679$).

Estimated seedbank size per m^2, and estimated number of viable seeds per m^2, are given in Table 5. There is a large seedbank of *A. morroensis* under adult shrubs; estimated number of seeds per m^2 ranged from 12,491 to nearly 37,000. The estimated number of viable seeds per m^2 ranged from 390 to 2876. Depending on the location, *A. morroensis* can have an extremely high or low seed density compared to other manzanita species. Other published studies on *Arctostaphylos* seedbank sizes (listed in Parker and Kelly 1989) show a range of 346 (*A. glauca*) to 28,177 (*A. viscida*) seeds per m^2. The average number of viable seeds per m^2, reported for other *Arctostaphylos* species ranges from 160 to 2536 (Parker and Kelly 1989).

VII) Recommendations for management and future research

The Morro manzanita is a plant whose future existence may be more tenuous than heretofore realized for two basic reasons: it is less abundant than recent mapping efforts indicate, and it appears in jeopardy due to a host of factors that began affecting it relatively recently.

Current distribution and abundance of Morro Manzanita.

Within the range of Morro manzanita, field surveys using the cover classes and polygons mapped by Mullany (1990) showed that this species is less abundant than concluded in earlier reports. In several large polygons drawn by Mullany (Fig. 3, polygons 2, 6, 18, 19, 34), *A. morroensis* is present as a few scattered individuals, or in one or two small dense patches. In contrast, Morro manzanita is abundant only on the ridge to the north of Hazard Canyon. There it forms almost monospecific stands.

Current estimates of the acreage of the Morro manzanita (approximately 890 acres), weigh the areas of very low cover and the dense stands equally (Table 6). While this estimate is accurate in describing the total acreage of habitats in which *A. morroensis* is present, the acreage of Morro manzanita cover alone is far less. Using Mullany's (1990) cover classes and the estimated acreage of the polygons she drew (McGuire and Morey 1992), we calculated the maximum extent of *A. morroensis* for each cover class (Table 7). For example, in the cover class 5 - 25%, we calculated acreage *of A. morroensis* on private and public land as follows: 93 acres (total habitat) x 25% = 23 acres. This method yields a maximum of 353 acres of Morro manzanita, 84 on public land. Most large intact areas of Morro manzanita (cover between 50 - 100%) occur on land not managed for biological resource protection (240 private vs. 60 public acres). Efforts by the Department of Fish and Game, and the Land Conservancy of San Luis Obispo County working with private landowners will be imperative to preventing Morro manzanita from becoming extinct as a naturally occurring species.

The 353 acres of Morro manzanita is an exceptionally small range for any organism, and especially for such a distinctive, recently-evolved species. The range of Morro manzanita is limited by its confinement to one soil type - Baywood fine sandy loam. This means the area defined by this substratum is the only place where the shrub can occur naturally. Much Morro manzanita habitat (57-69% of historical) has been replaced by residential development over this small area, eliminating the potential for the manzanita to approach its former abundance (McGuire and Morey 1992). There is, in fact, limited potential for any demonstrable increase, and substantial likelihood for decrease. Naturally occurring stands of Morro manzanita should not be subject to artificial treatments such as plantings to increase densities where it is already present.

These treatments should be limited to degraded areas or areas of manzanita die-off that are deemed severe enough to warrant agricultural treatments.

The ~265 acres of Morro manzanita on private land have considerable real estate value. Even if development pressure leads to no further habitat loss on these lands, the manzanita may experience decline in abundance as well as population fragmentation as a result of private land use, fire suppression, disease, exotic species, etc. In addition, considerable resources may be required to protect the species from such threats as described below. Continued development of private lands where Morro manzanita occurs, could significantly endanger the viability of this species.

It is uncertain whether the populations of Morro manzanita on public lands could alone be sufficient to maintain the species because lack of genetic variability could make them less resistant to disease and less successful in producing viable seed. Also, disease and exotic species invasion will occur on public lands and these and perhaps unforeseeable threats may not be possible to thwart.

Threats to Morro manzanita

a) Exotic species

Iceplant. The most pernicious exotic species problem in maritime chaparral is the invasion of iceplant (*Carpobrotus* spp. and *Conocosia pugioniformis*). This phenomenon currently threatens to convert maritime chaparral on eolian sands, like Baywood fine sandy loam near Lompoc, into an artificial vegetation dominated by South African succulents. The mechanism by which *Carpobrotus edulis* invades maritime chaparral has been elucidated (D'Antonio, Odion, and Tyler 1993). Seed of this iceplant is spread in the feces of deer and rabbits. This seed germinates and iceplant becomes established in openings in the canopy of maritime chaparral on eolian sand. Iceplant recruits abundantly in burned or mechanically disturbed areas if a source of seed is present in the general vicinity. The present distribution of iceplant is critical to determining present distribution of seed, and thus, the areas of manzanita habitat that would be susceptible to invasion. *Carpobrotus* seed is mostly destroyed by fire, but it will return to a burned area when deer come to forage on resprouting chamise and other post-fire vegetation. This post-fire growth is a preferred and nutritionally superior browse (Davis 1967), so use of burned areas by deer is expected to be high. Germination and initial growth of *Carpobrotus* is much faster than that of manzanitas, perhaps because of lack of biological control. When these species are establishing and initially vying for space, iceplant is likely to be more successful. Unchecked, mats of iceplant will become established in abundance proportional to the amount of seed that arrives onsite. When fire reoccurs in the area, the existing iceplant will not completely burn. The unburned mats will serve as sources of abundant seed for the area. Thus, after two fire cycles, iceplant displacement of maritime chaparral can be virtually complete.

Probably because of the lack of fire and mechanical disturbance in the maritime chaparral around Morro Bay, iceplant has not dominated the plant communty. Fire in chaparral is inevitable, so iceplant invasion will occur unless counter measures are undertaken. In addition, another iceplant that is a relatively new arrival, *Conocosia pugioniformis*, is presently invading gaps throughout Morro Bay maritime chaparral. This includes gaps formed by death of *A. morroensis*. This iceplant has wind dispersed seed, and it has become common in the Morro Bay area fairly recently.

Schmalzer and Hinkle (1987) review methods of iceplant control. Biological control of *Carpobrotus* will not be an option for the foreseeable future. A scale insect that preys on iceplant was introduced to control the plant; however, the success of this biocontrol agent has been thwarted by Cal Trans, who spent $190,000 between 1978 and 1981 to suppress the scale insect using predatory wasps. Herbicide use in burned areas is risky because of the difficulty in limiting the effects to target pest plants amid chaparral seedlings. Fortunately, iceplant seedlings are easy to remove by hand. Any burned areas will therefore need to be hand weeded to prevent iceplant invasion. This must be done with a minimum of trampling damage to establishing *A. morroensis* plants. A preventative measure that can be undertaken as part of comprehensive conservation efforts would be to remove iceplant from roadsides and other landscapes where it presently occurs in the Morro Bay area.

Eucalyptus. *E. globulus* and *E. camuldulensis* may also invade following fire. *Eucalyptus* seedlings can outgrow and displace maritime chaparral dominated by *Arctostaphylos*. This occurred following 1981 and 1984 burns along 13th St. on Vandenberg Air Force Base. It should be anticipated that some *Eucalyptus* seedling regeneration would occur in the chaparral around Hazard Canyon following fire, expanding the range of these trees. The solution to this problem is a careful monitoring and hand-weeding program early in the post-fire regeneration period in areas near *Eucalyptus* when they burn. *Eucalyptus* has the most extreme fire behavior of any vegetation type in the world (McArthur 1967). Of particular concern is downwind propagation of fires during wildfire. This occurs extensively with vigorous combustion of *Eucalyptus* because it produces firebrands at a remarkable rate. This may cause spot fires as much as 20 km downwind. As described below, reduction of fire hazard from wildland fuels in the vicinity of Baywood Park and Cuesta by the Sea is important to the conservation of Morro manzanita.

Monterey Cypress. This native California plant (*Cupressus macrocarpa*), which is rare in the wild (only 2 natural populations), produced massive seedling regeneration following the 1977 fire in the vicinity of three windrows on South Vandenberg in maritime chaparral on eolian sand. Cypress trees have come to displace chaparral at this site. *Cupressus macrocarpa* is serotinous (Munz and Keck 1968); seed does not accumulate in the soil seed bank, but is released from cones immediately following fire. Invasion by cypress can easily be controlled by removing the trees in and adjacent to maritime chaparral areas. We did not map the distribution of Monterey cypress in the vicinity of the chaparral around Morro Bay.

Pines. *Pinus radiata, P. torreyana,* and *P. muricata* may also invade maritime chaparral. This occurred in the absence of fire at the La Purissima State historic Park near Lompoc. It is anticipated that invasion would occur with fire. As with Monterey cypress, these pines are serotinous, or largely serotinous, so invasion can be controlled by removing trees in and adjacent to chaparral areas.

Erhrharta calycina. Another exotic plant that is a potential threat to *A. morroensis* is the South African veldt grass. This perennial grass is most common in relatively open dune scrub vegetation, mostly to the west of Pecho Valley Road. Invasion by *Erhrharta* into mature chaparral does not appear to be a threat. We have not observed significant *Erhrharta* invasion after fire in Vandenberg, however, the grass was not particularly common in the vicinity of the burns we studied. *Erhrharta* is abundant upwind of virtually the entire range of *A. morroensis*. Stands that burn may be subject to invasion via wind blown seed. Burn areas will need to be monitored for *Erhrharta*, and hand weeded of the grass where it is found. Removing *Erhrharta* from the vicinity of chaparral areas around Morro Bay may not be feasible with present technology. The development of control techniques for this pest plant should be closely monitored.

b) Population fragmentation

A more subtle threat to the future of *A. morroensis* may be the fragmentation of populations into small stands. Viabilities of plant and animal populations may be reduced disproportionately with a decline in their size. This phenomenon has come to be known as the Allee effect. Plants in smaller populations are not as effectively pollinated, so seed set may be low. Further, pollen transfer will increasingly be between siblings and other more genetically similar individuals as patch or population size declines. Fragmentation has been found to educe seed production in an Australian shrub *Banksia goodii* (Lamont, Klinkhamer, and Witkowski, 1993). This plant shares similarities with *A. morroensis*--it is a rare obligate seeder found in fire prone, sclerophyll shrub vegetation on sand. Lamont et al. (1993) found that there was no viable seed produced in small populations (7.8 +/- 6.7 plants). According to the authors, "the sobering message for land managers and population modelers is that a series of small populations may not have the same conservation value as a larger one with the same total population size, while there may be a threshold below which local extinction is inevitable."

Data we obtained on seed viability and seed populations suggest that the Allee effect may be occurring in isolated populations of *A. morroensis*. Even though *A. morroensis* in the Elfin forest are older than those in other populations, and therefore would be expected to have deposited more seed on the soil, their seed populations were lower than elsewhere. Viability was also low. Differences were not statistically significant, but this could be because of our sample sizes. Our research was not designed to test differences among populations, but to sample the range of variation in *A. morroensis* stands. Further research is needed to determine if reproductive distress occurs in fragmented populations. In addition to lower seed densities and viability, it is possible that lower rates of germination among viable seed may occur if there is an Allee effect. Should future research detect an Allee effect, it may be desirable to augment fragmented populations, such as those at the Elfin forest, by planting manzanitas in their vicinity, perhaps trying to connect these populations with the larger populations to the south. This could be facilitated by a program of Morro manzanita planting in residential Baywood Park.

Importance of developing a fire management plan

Arctostaphylos morroensis maintains itself by mass regeneration from seed following fire. Fire will therefore be essential to its viability.

The fire regime in the Morro Bay area is and has for centuries been controlled by humans. Fire regimes in the central coast differed in pre-historic times, during aboriginal occupation of the area, and since the beginning of European/American occupation of the area (Greenlee and Langenhiem 1990). Fire suppression in recent decades has introduced a new fire regime, but it is unknown whether the current stand ages for Morro manzanita are old based on the species' evolutionary history. Prior to the introduction of purposeful burning by humans, the fire interval was almost certainly rather long, perhaps 80-100 years, as has been estimated for the Monterey Bay region (Greenlee and Langenheim 1990). Lightning is infrequent in both areas. Thus, *A. morroensis* is presumably well-adapted to long fire intervals. Conversely, it is unclear how the species would fare with a fire regime of short intervals (ca. 20-30 years). Odion (1995) reviews the literature and provides empirical evidence suggesting that obligate seeders are likely to be resilient to a range of fire intervals as long as they are not extremely short (< 5-10 years); such short fire intervals can only come about in chaparral by seeding with annual grasses to introduce high fuel levels (Zedler, Gautier, and McMaster 1983).

With one exception, we observed no areas where burning would be justified on the basis that the stands were old and "unhealthy". The exception is the Elfin forest, where death of Morro manzanita is occurring. Another coastal maritime site that was comparatively old (~ 75 years old), studied by Odion (1995) and Tyler (1994, 1996), had a positive response to prescribed burning conducted in the dry season. There was successful recruitment of chaparral species, even shrubs (such as *Ceanothus impressus*) that had been absent from the site before the fire. It should be noted that burning in the wet season has strong negative effects on regeneration of chaparral regardless of stand age (Horton and Kraebel 1955, Parker 1987, Davis et al. 1989, Moreno and Oechel 1991).

Before proceeding with a program of prescribed burning for the management of Morro manzanita, it will be important to determine that there will be a good response - e.g., that there will be adequate seed germination of *A. morroensis* and that there will be minimal invasion by exotic species. The present study provides some information about the potential for seed germination following fire. Our results indicate that there is a dense seed bank with many viable seeds in most locations, although there are a few sites, like the Elfin forest that have fairly low viable seed densities. Our seed bank studies also show that most seeds are present directly under the mature shrub canopy, so burning would likely not lead to significant expansion of the population unless preburn manipulations of seed distributions were done. Most of the seed is in the upper several cm of soil. Moderate to considerable seed mortality would occur during fire depending on how much canopy material collapses and combusts slowly on the soil surface (Odion 1995), and how much heat is generated by the considerable amounts of litter that will also burn by smoldering combustion. Within a stand, some areas will have substantial seed mortality, while others will have little. Presence of seed at depth is critical to seedling regeneration in areas of high soil heating.

We recommend that a primary goal for the conservation and management of the Morro manzanita is to develop an appropriate fire management plan, and that the following information be obtained to help in developing such a plan: 1) determine the response of *A. morroensis* seed to heating; 2) in the Elfin forest site, determine the densities of viable seed under dead manzanitas to predict the likely postfire composition of patches formerly occupied by *A. morroensis*; 3) within a small controlled burn, determine a) the relationship between pre and postfire distribution of *A. morroensis*, b) the response of *A. morroensis* seeds that have been moved from under the shrub canopy to open patches away from shrubs, c) the invasion by exotics and their effects on *A. morroensis* seedling establishment; d) effects of herbivores on seedling survivorship (small prescribed burns may have unnaturally high seedling mortality due to herbivory), and e) the effects of high levels of soil heating on seedling regeneration of Morro manzanita. The fuel load in dense stands of Morro manzanita is exceptional. Much of this fuel is large size class material, and it is uncertain how much of this would be consumed by fire, but it is possible that soil heating during a fire in such stands could lead to seed mortality that is excessive for optimal seedling regeneration. Soil heating, fire intensity and chaparral regeneration have been reviewed recently by Borchert and Odion (1995).

The fire management plan must also include a strategy for wildfire suppression that will have minimal impacts on the manzanita (see description of fuelbreaks adjacent to future preserves below). Wildland fuel and fire hazard must be reduced and maintained in an arrangement that will allow suppression activities to be limited to the perimeter of stands of Morro manzanita. This will require comprehensive planning that evaluates such factors as how to make structures themselves more fire safe, creating and maintaining adequate defensible space around structures, reducing fuel hazards such as *Eucalyptus*, etc. It will be necessary to work with the California Department of Forestry as well as City and County officials to develop a plan for fire suppression that is consistent among agencies and most consistent with protection of *A. morroensis* habitat Burn rehabilitation efforts must also be addressed. The plan should explicitly state that artificial seeding with grass following fire shall not be allowed. The deleterious effects of such practices on chaparral seedlings have long been known (Shultz, Launchbaugh, and Biswell 1955, Nadkarni and Odion 1985), and have recently been thoroughly reviewed (Keeler-Wolf 1995).

Restoration of Morro Bay maritime chaparral

There are areas of Baywood fine sandy loam that support little or no *A. morroensis* presently and which formerly were almost certainly vegetated with Morro Bay maritime chaparral. These areas, which were probably mechanically cleared, now support mostly coastal sage scrub vegetation and/or grassland as well as some scattered chaparral plants. The areas include polygons 2, 6, 7, 8, 9, 18, 22, 23, and 29.

The best way to revegetate degraded chaparral areas is to utilize the soil resource, as described in Odion, Bornstein, and Carroll (1987). The procedure calls for adding soil from under chaparral to degraded areas, and subjecting it to the fire-related cues that will initiate growth of the propagules. Soil should be collected from chaparral immediately adjacent to the area being restored so that foreign genotypes are not introduced. About 90 percent of seed will be in the top 3 cm of soil. Bulbs, corms, and tubers may be buried as deep as 25 cm. Seed is concentrated in canopy gaps (Davis, Borchert, and Odion 1989, Odion 1995), but Morro manzanita seed occurs primarily under shrubs. Soil should be collected from both areas. The soil should be collected in late summer or fall when it is completely dry. If the soil is to be stockpiled, it should be kept in a dry dark place. Soil should not be stockpiled for more than 2-3 months.

Because of the abundance of seed in the soil, only a thin layer needs to be spread over the target area. This soil should be gently raked in. Bulbs encountered should be buried 10-25 cm in depth. Seeds of many plants from maritime chaparral, including the dominant shrubs are released from dormancy by heat and/or chemicals washed from charred wood (Keeley 1987, Emery 1988, Keeley 1991), or from smoke (Keeley, personal communication). The best way to supply these factors is to burn the site. In order for sufficient heat and charred wood to be produced by the fire in open areas, fuel will have to be added. Native shrubs should be collected from sites adjacent to structures and facilities where fuel reduction is needed. Other shrubby vegetation may work equally well. Shrubs can be scattered intact at a density that will produce a fuel load that amounts to about 25-75 percent of what is found in the chaparral adjacent to the area being restored. Shrubs should not be piled on top of each other. Because the cut fuel will become desiccated, it will burn more completely and release greater heat than live fuel. It would be best to minimize the desiccation of fuels. Once the fuel has been added, the site can be burned, which should be done during the dry season. Such restoration should involve entire parcels so that the perimeter of the burn can be determined by existing roads and other fuel breaks.

Following winter rains, these procedures will result in the rapid growth of the flora native to the site (Sweeney 1956), nourished by the nutrient-rich ash-bed (Christensen 1973). Unfortunately, iceplant will also grow in the restoration site, and iceplant removal as described previously must be part of the restoration program. If burning the site is not feasible, the soil will need to be heated elsewhere. Soil can be spread out in an open area, such as a parking lot, and fuel dispersed on top of it as described above, and this can be burned. Soil could also be heated in an oven, however, it is difficult to heat amounts that would be required in a restoration project because the soil needs to be spread into a thin, even layer and then heated. Heating for 5-7 minutes at 100°C has proved successful when soils were spread to a thickness of about 3 mm. Ground *Adenostoma* charcoal, or charate, (see Keeley 1987) will need to be added to oven-heated soil. Based on studies by Keeley and Pizzorno (1986), charate is effective in tiny amounts. One gram per ten thousand grams of soil should suffice. Charate should be spread evenly on top of oven-heated soil after it has been raked in at the restoration site. Oven-heated soil will lack the rich source of nutrients in the ash-bed, and it would probably be beneficial to add a time release fertilizer. Experiments are needed to see what effect this would have, and determine what amount of fertilizer would be optimal. Successful use of the soil seed reserve in revegetation should result in the same type of temporal vegetation dynamics that naturally follow fire in the chaparral, but, there is much to be learned about optimizing this experimental procedure.

Monitoring. A regular program of monitoring *A. morroensis* needs to be established. This can be set up by means of a conservation agreement on State Park lands. Monitoring should be designed to detect sudden disease outbreaks, changes in exotic species occurrences, etc. Following wildfires, monitoring should be intensive.

Morro Manzanita Preserve Management

The need for Morro manzanita preservation on private land will probably lead to the establishment of biological preserves in return for allowing some development. The chief management considerations for preserve sites are fire and the fuelbreak it necessitates. Structures will require protection from fire, but preserve areas must not be subjected to artificial alteration to ensure protection. Preserve areas should be separated from existing structures by a zone that fire will not spread across. Roofing material, building construction and design, as well as landscaping and topography can greatly influence whether fire spreads from wildlands to structures, and therefore the size of fuelbreak needed to safeguard the structures.

In calculating preserve areas to be credited as mitigation, the fuelbreak should not be considered preserve acreage. Fuelbreaks may have to be 30m or more wide, but do not have to be completely devoid of vegetation. Scattered mature specimens of chaparral vegetation can remain, but they should be freed of dead and some live fuel. The fuelbreak area shall be kept free of the invasive exotics described previously, and any new invasive species that appear in the future.

The area between chaparral specimens should be disked or otherwise maintained free of groundcover vegetation. Costs of design, construction, maintenance, and monitoring of fuelbreaks should be born by the property owner(s) benefiting from fire safety. If a new development is located adjacent to a preserve, the development shall provide its own fuelbreak. A paved road should be part of the fuelbreak to facilitate access by fire suppression resources.

The existence of appropriate fuelbreaks adjacent to developments should allow for fire to occur in any season in the preserve without threatening structures. Therefore fire suppression efforts can focus on stopping fires at the breaks. Bulldozers, fire trucks, and other heavy equipment should stay in the fuelbreak. No new fuelbreaks should be created within the preserve during fire suppression. Prescribed burning shall be allowed only during summer or fall . Prescribed burns or wildfires must be followed by the previously described exotic species removal. Any burn areas should be carefully monitored. This may determine that additional management procedures are needed.

The fire management plan to be developed for Morro manzanita should direct any prescribed burning. This plan should be developed after the effects of the small burn proposed along Pecho Valley road have been determined. Morro manzanita presumably evolved with fairly infrequent fires that burned the entire population at once. Burning should probably not be done more frequently than every 30 years, and it may be desirable to maintain stand ages much greater than this. Burning small areas would also be unnatural, and could result in excessive herbivory.

Preserving the genetic integrity of *Arctostaphylos morroensis*

Manzanitas are known for free and frequent hybridization. Manzanitas are popular drought-resistant landscaping plants. The planting and occurrence of manzanitas other than *A. morroensis* in the vicinity of stands of *A. morroensis* has the potential to introduce genetic material from foreign manzanitas into the seeds produced by *A.*

morroensis. Foreign genetic material could gradually infiltrate populations of Morro manzanita. Conservation planning efforts should therefore work towards the elimination of foreign manzanitas from the vicinity of Morro manzanita populations, and discourage or prohibit their future planting.

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Table 1. Description of polygons shown in Figure 1. Cover class values for *A. morroensis* are from Mullany (1990).

Polygon #	Cover class	Age from photos (years)	Location
1	5-25%	>47	Elfin forest
2	<1%	>47	Elfin forest
3	1-5%	>47	E. of S. Bay Blvd, N of Santa Ysabel Ave
4	50-75%	>47	E. of S. Bay Blvd, N of Santa Ysabel Ave
5	5-25%	>47	E. of S. Bay Blvd, N of Santa Ysabel Ave
6	1-5%	>47	E. of S. Bay Blvd, S of Santa Ysabel Ave
7	<1%	>47	W. of S. Bay Blvd, S of Santa Ysabel Ave
8	1-5%	>47	W. of S. Bay Blvd, S of Santa Ysabel Ave
9	<1%	>47	W. of S. Bay Blvd, S of Santa Ysabel Ave
10	5-25%	>47	E. of S. Bay Blvd, S of Santa Ysabel Ave
11	1-5%	>47	W. of S. Bay Blvd, S of San Luis Ave.
12	<1%	>47	E. of S. Bay Blvd, S of Hollister Ln
13	1-5%	>47	Los Osos Oaks Preserve (N)
14	1-5%	41	Los Osos Oaks Preserve (S)
15	<1%	>47	W of Los Osos Oaks Preserve, N of Bayview Heights Dr.
16	5-25%	>47	W of Los Osos Oaks Preserve, S of Bayview Heights Dr.
17	1-5%	>47	W. of Los Osos Oaks Preserve, E of Bayview Heights Dr.
18	<1%	47	S. of Highland Dr., btwn Roders Ave. & Bayview Hts. Dr
19	1-5%	47	S. of Highland Dr., btwn Roders Ave. & Bayview Hts. Dr.
20	50-75%	47	S. of Highland Dr., btwn Roders Ave. & Bayview Hts. Dr.
21	50-75%	>47	S. of Highland Dr., btwn Roders Ave. & Bayview Hts. Dr.
22	<1%	8; >47	Cabrillo Estates; at Rodman Dr. & Travis Dr.
23	<1%	>47	Cabrillo Estates; on Travis Dr.
24	50-75%	>47	Cabrillo Estates; on Travis Dr.
25	25-50%	>47	Cabrillo Estates; near Travis Dr.
26	50-75%	>47	Cabrillo Estates; near Travis Dr.
27	5-25%	>47	Cabrillo Estates; at Rodman Dr.
28	75-100%	>47	Montana de Oro State Park, and S. of Cabrillo Estates
29	<1%	37	E. of Pecho Valley Road
30	1-5%	37	E. of Pecho Valley Road
31	5-25%	37	W. of Pecho Valley Rd., DFG Ecol. Reserve
32	25-50%	37	W. of Pecho Valley Rd., Montana de Oro State Park
33	75-100%	37	W. of Pecho Valley Rd., Montana de Oro State Park
34	1-5%	37	W. of Pecho Valley Rd., Montana de Oro State Park
35	5-25%	37	W. of Pecho Valley Rd., Montana de Oro State Park
36	5-25%	>47	E. of Pecho Valley Rd.
37	75-100%	37	E. of Pecho Valley Rd.
38	<1%	>47	W. of Pecho Valley Rd., Montana de Oro State Park

Table 2. Two-way table of species and plot data produced by TWINSPAN. Plots are numbered across the top. D indicates dead manzanita plot, a = plot adjacent to manzanita, and u = under *Arctostaphylos morroensis*. Species abundances listed in columns. - = species absent, 1 = 0-4 percent cover, 2 = 2-4 percent cover, 3 = 5-10 percent cover, 4 = 10-20 percent cover, and 5 is greater than 20 percent cover.

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                             ddd d    12211   111 1  12  111     11122211111   11   1111 2  22211 112
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                             dddad aaaaaaaa aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa uuuuuuuuuuuuuuuuuuuuuuuu
Claytonia perfoliata         --12- -2------ 11------1--11------------------- 1----------1------------  000
Marah fabaceous              32332 232----- 21---2-52----1------------------ 11--221------1------1---  000
Toxicodendron diversilobum   ---13 --223--- ---2------------1--------------- ---------------1--------  001000
Achillea millefolium         ---1- 21------ -----------1-------------------- ------------------------  001001
Amsinkia spectabilis         -1-1- -1------ -------2------------------------ ------------------------  001001
Asparagas aspargioides       ----1 -------- -------------------------------- ------------------------  001001
Bromus diandrus              -1--- -1------ -1------------------------------ ------------------------  001001
Chenopodium ambrosiodes      ----- -1------ 1------------------------------- ------------------------  001001
Conocosia elongata           25522 2------- --1----22--1-------------------- 21---------1------------  001001
Cryptantha clevelandii       ----- -1------ -------------------------------- ------------------------  001001
Eucrypta chrysanthemifolia   ---1- 12------ ---1-1--1----------------------- ------------------------  001001
Galium aparine               ----- -1------ -------------------------------- ------------------------  001001
Gnaphalium californicum      -1-1- ------1- 1--1-1-1----------------1------- 1-----------------------  001001
Hespericnide tenella         -12-1 -1------ 1------1------------------------ 1-----------------------  001001
Quercus agrifolia            ---52 55555555 -3-5-55------4----------------5- -2--------------------1-  001001
Ribes speciosum              -412- 222----- 22-1---------------------------- ------------------------  001001
Rubus ursinus                -1--- 2------- -------------------------------- ------------------------  001001
Salvia spathecea             ----- ---2--1- -------------------------------- ------------------------  001001
Sambucus mexicana            ---1- -------- -------------------------------- ------------------------  001001
Senecio mikanoides           ---2- -------- -------------------------------- ------------------------  001001
Solanum douglasii            ----- -------- -------------------------------- 1-----------------------  001001
Solanum umbelliferum         -3-1- -------- ----1---1-----------------1----- ------------------------  001001
Stachys ajugoides            ----1 2--1---- 21------------------------------ ------------------------  001001
Stellaria media              ----- -1------ -------------------------------- ------------------------  001001
Symphoricarpos mollis        ----- -------- -------------------------------- -1----------------------  001001
Unknown grass                ----- 1------- -------------------------------- ------------------------  001001
Unknown wood. per.           ----- -------1 -------------------------------- ------------------------  001001
Cirsium vulgare              ---1- -------- ---1---------------------------- ------------------------  001010
Melica imperfecta            ---1- -------- -----2-1----1------------------- ------------------------  001010
Paeonia californica          ----- -------- 2------------------------------- -1----------------------  001010
Pteridium aquilinum          ----- -------- 41------------------------------ -2----------------------  001010
Rhamnus californicus         ---2- -1------ 22-33--------------------------- -2----------------------  001010
Sanicula arguta              --1-- -------- -1------------------------------ ------------------------  001010
Sonchus oleraceous           -1--- -------- -1------------------------------ ------------------------  001010
Baccharis pilularis          -222- -------- 22-----------------------55----- ------------------------  001011
Bromus laevipes              ---2- -------- ------------------------------2- ------------------------  001011
Lessingia filaginifolia      ---2- 21------ -1-112---1-----111-1-1---1-12111 ------------------------  001011
Vulpia octoflora             --1-- -------- -------------------------------1 ------------------------  001011
Salvia mellifera(d)          --1-- -------- -------------------------------2 ------------------------  001011
Artemisia california         -12-- 2-----22 3322-32-2--2---2---------5-2212- 2------------------2----  0011
Galium nuttalli              -1-2- 122----- -1-----1---1111------------11-2- 1--------1--------------  0011
bare ground                  55555 5--4-2-5 55435554555554455554554555455545 22222-------------------  0011
Eriophyllum confertiflorum   ----- 11---1-- -1-1-------22--112-2-2--11-22222 ------------------------  010000
Arctostaphylos morroensis(s) ----- -------- -------------------------------1 ------------------------  010001
Camissonia cheiranthifolia   ----- -------- ---------------------------1---- ------------------------  010001
Carex globosa                ----- -------- -----------------11--1---------1 ------------------------  010001
Carpobrotus aequilaterus     ----- -------- ---------------------------2122- ------------------------  010001
Chorizanthe californica      ----- -------- ---------------------------1---- ------------------------  010001
Chorizanthe diffusa          ----- -------- ---------------------------1-11- ------------------------  010001
Croton californicus          ----- -------- --212----------121-112-111-232-2 ------------------------  010001
Dudleya lanceolata           ----- -------- -----------11--------2-----1111- ------------------------  010001
Erhrharta calycina           ----- -------- ----1----------------------115-- ------------------------  010001
Galium andrewsii             ----- -------- -----------------1---1---------1 ------------------------  010001
Gnaphalium bicolor           ----- -------- ---------------------------111-1 ------------------------  010001
Helianthemum scoparium       ----- -------- -----------1-1-----1---21--32-2- ------------------------  010001
Heteromeles arbutifolia      ----- -------- -2--------------5--------------- ------------------------  010001
Navarettia attractyloides    ----- -------- -------------------------------1 ------------------------  010001
Prunus illicifolia           ----- -------- ---------------52--------------- ------------------------  010001
Silene laciniata             ----- -------- ----1------------1---1-----1-111 ------------------------  010001
Unknown grass(1)             ----- -------- ----------------1--------------- ------------------------  010001
Lotus scoparius(d)           ----- -------- ------------------1------------- ------------------------  010001
Filago arizonica             ----- -------- -----------1-------------------1 ------------------------  010010
Astragalus                   ----- -------- -1------------------------------ ------------------------  010011
Calyptridium monandrum       ----- -------- ------------1------------------- ------------------------  010011
Camissonia micrantha         ----- -------- -----------1-------------------- ------------------------  010011
Crassula erecta              ----- -------- -----------1-------------------- ------------------------  010011
Satureja douglasii           ----- -------- --------1----------------------- ------------------------  010011
Ericameria ericoides         ---2- 41------ 5222343-443224422222213-5-233322 -------1----------------  0101
Eriogonum parvifolium        ---1- 21------ -2222212--2-21-------------2112- ---------------------1--  0101
Lotus scoparius              --1-- -------- 341-34-112-2322122-1233-3-42432  ----------------------2-  0101
Salvia mellifera             ----- ------2- 3-323434542455---2-23--1---222-2 -----------------22-----  0101
Adenostoma fasciculatum      ----- ------2- ------253-35555--5455555----2--- -----1--------------121-  0110
Ceanothus cuneatus           ----- -------- 235554-545444--5-5544452-3555552 2-2-221112--------------  0110
Horkelia cuneata             ----- -------- -2----1---3----22123221341-2-213 1------1--1-1-----------  0110
Ceanothus cuneatus(d)        ----- -------- -----2-----------3-------------3 2-----------------------  0110
Mimulus aurantiacus          --221 22--42-- 12112213212222211334333123421-12 1--1---1--111-----1-12--  0111
Cardionema ramosissima       ----- ---1---- ---------------------------1-112 -----------------------3  10
Pterostegia drymarioides     ----- ---4---- 1-----------11-----------4------ -----------------------3  10
Quercus agrifolia(s)         -1--- -------- ------------------1------------1 --------------------1---  10
Gnaphalium ramosissima       --1-- ------1- -------------------------------1 -----------------------2  10
Arctostaphylos morroensis    ----- 2---2--- -2-----3-2------242222-333345343 555555555555555555555555  11
                             00000 00000000 00000000000000000000000000000000 111111111111111111111111
                             00000 00000000 11111111111111111111111111111111 000000000000000000000001
                             00000 11111111 00000000000000011111111111111111 0000000000111111111111
                             00011 00011111 00000001111111100000000000011111 0000001111000000000111
                                      00011 00111110111111100000000001100001 000111    000000011
                 Conocosia-dead |Quercus- |  Morro Bay maritime chaparral | Arctostaphylos morroensis
            A. morroensis assoc.|Marah assoc.                             |       association
```

Table 3. Total number of seeds and number of viable seeds in the top 5cm of each sample versus the bottom 5 cm of each sample. Shown are the mean number of seeds and standard error for each of the four sites sampled. Each top and bottom soil sample was 237 cm^2 x 5.1 cm.

SITE	1		2		3		4	
	Dune area - Montaña de Oro		N. of Hazard Canyon				Elfin forest	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
n	5	5	5	5	5	5	5	5
# total seeds /sample	296.7	64.9	877.1	194.9	815.4	195.7	457.3	54.6
	(48.9)	(22.0)	(105.3)	(89.1)	(70.6)	(32.8)	(115.0)	(20.6)
# viable seeds /sample	12.7	4.4	39.4	8.9	53.7	14.6	39.4	8.9
	(2.5)	(1.6)	(6.8)	(2.7)	(9.5)	(5.8)	(6.8)	(2.7)

Table 4. Total number of seeds and number of viable seeds in the complete (top + bottom) samples under manzanita shrubs versus 1.5 m away from the edge of the shrub canopy. Shown are the mean number of seeds and standard error for three of the sites sampled. Each soil sample was 237 cm^2 x 10.3 cm

SITE	1		2		4	
	Dune area - Montaña de Oro (n=1)		N. of Hazard Canyon (n=4)		Elfin forest (n=5)	
	Under shrub	Adjacent	Under shrub	Adjacent	Under shrub	Adjacent
# total seeds /sample	353.8	26.8	1151.3	80.5	511.9	53.2
	-	-	(135.2)	(27.2)	(127.3)	(21.3)
# viable seeds /sample	9.8	2.4	43.4	3.7	9.3	0
	-	-	(4.0)	(2.3)	(3.1)	(0)

revised

TABLE 5. Mean and standard error of total number of seeds and number of viable seeds per sample ($237.6\ cm^2 \times 10.3\ cm$), percent viability, percent infertile seeds, and estimated seedbank size and number of viable seeds per m^2. P-values are results of one-way analysis of variance to determine differences among sites (df: site, error = 3, 16).

SITE	1	2	3	4		
	Dune area - Montaña de Oro	N. of Hazard Canyon		Elfin Forest	P	all sites combined
n	5	5	5	5		20
Total number of seeds per sample	362 (61)	1072 (131)	1011 (99)	512 (127)	< 0.001	739 (86)
Viable seeds per sample	17 (4)	48 (6)	68 (15)	9 (3)	< 0.001	36 (7)
% Viability	6 (2)	5 (1)	7 (1)	2 (1)	0.076	5 (1)
% Infertile	47 (2)	42 (4)	45 (4)	49 (5)	0.679	45 (2)
Estimated seedbank size (no. per m2)	15,224 (2552)	45,134 (5529)	42,569 (4181)	21,551 (5358)		31,119 (3636)
Estimated # viable seeds per m2	719 (152)	2017 (245)	2876 (631)	390 (132)		1501 (281)

Table 6. Estimated acreage of coastal maritime habitat in which *A. morroensis* is present, based on data from Mullany (1990). From McGuire and Morey (1992).

Percent cover	Private	Public	Total
<1%	107	5	112
1-5%	103	139	242
5-25%	46	47	93
25-50%	23	10	33
50-75%	97	0	97
75-100%	167	60	227
Totals	543	261	804

Table 7. Estimated acreage of *A. morroensis*, based on data from Mullany (1990).

Percent cover	Private	Public	Total
<1%	1	<0.1	1
1-5%	5	7	12
5-25%	11	12	23
25-50%	11	5	16
50-75%	73	0	73
75-100%	167	60	227
Totals	269	84	353

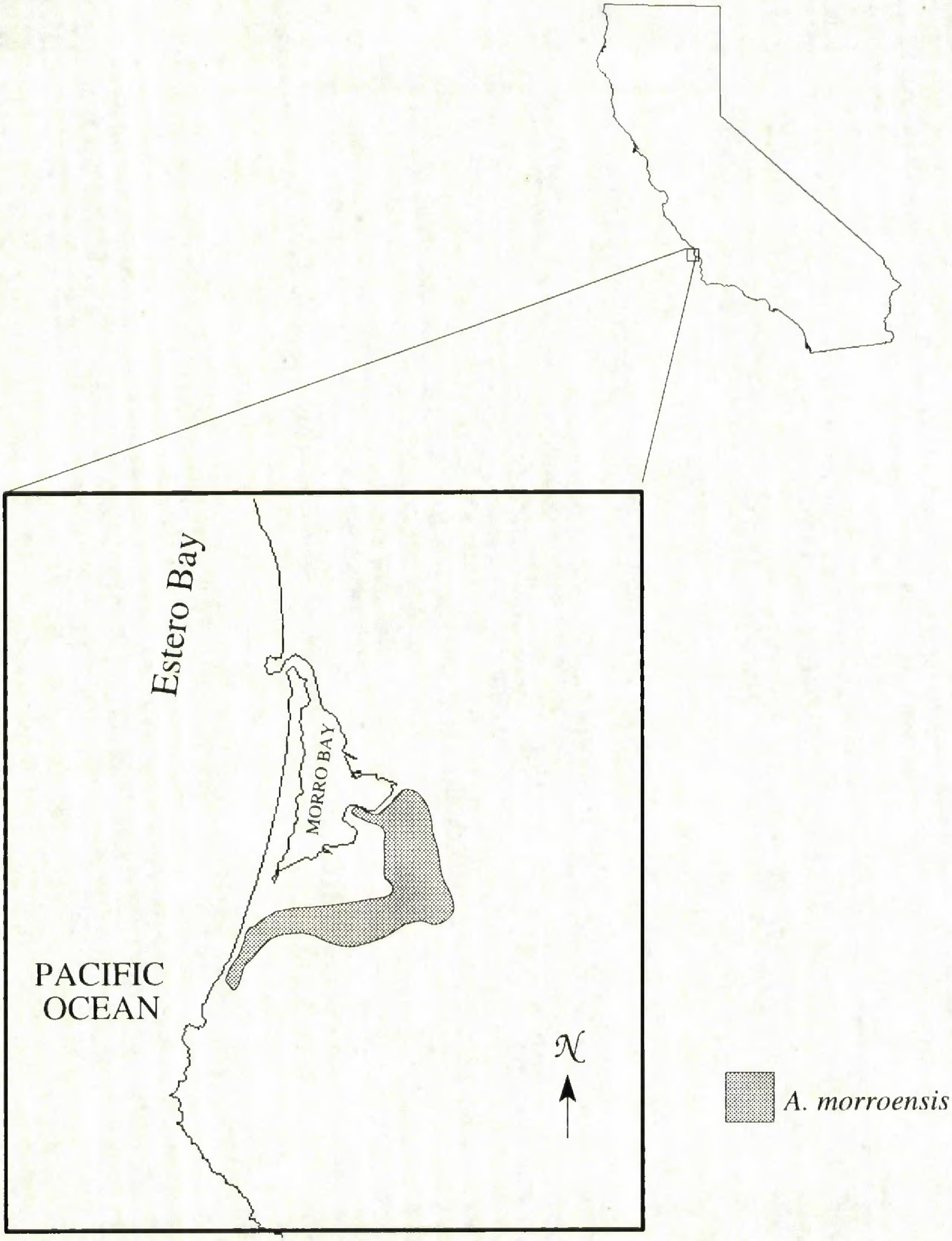


Figure 1. Distribution of *Arctostaphylos morroensis*

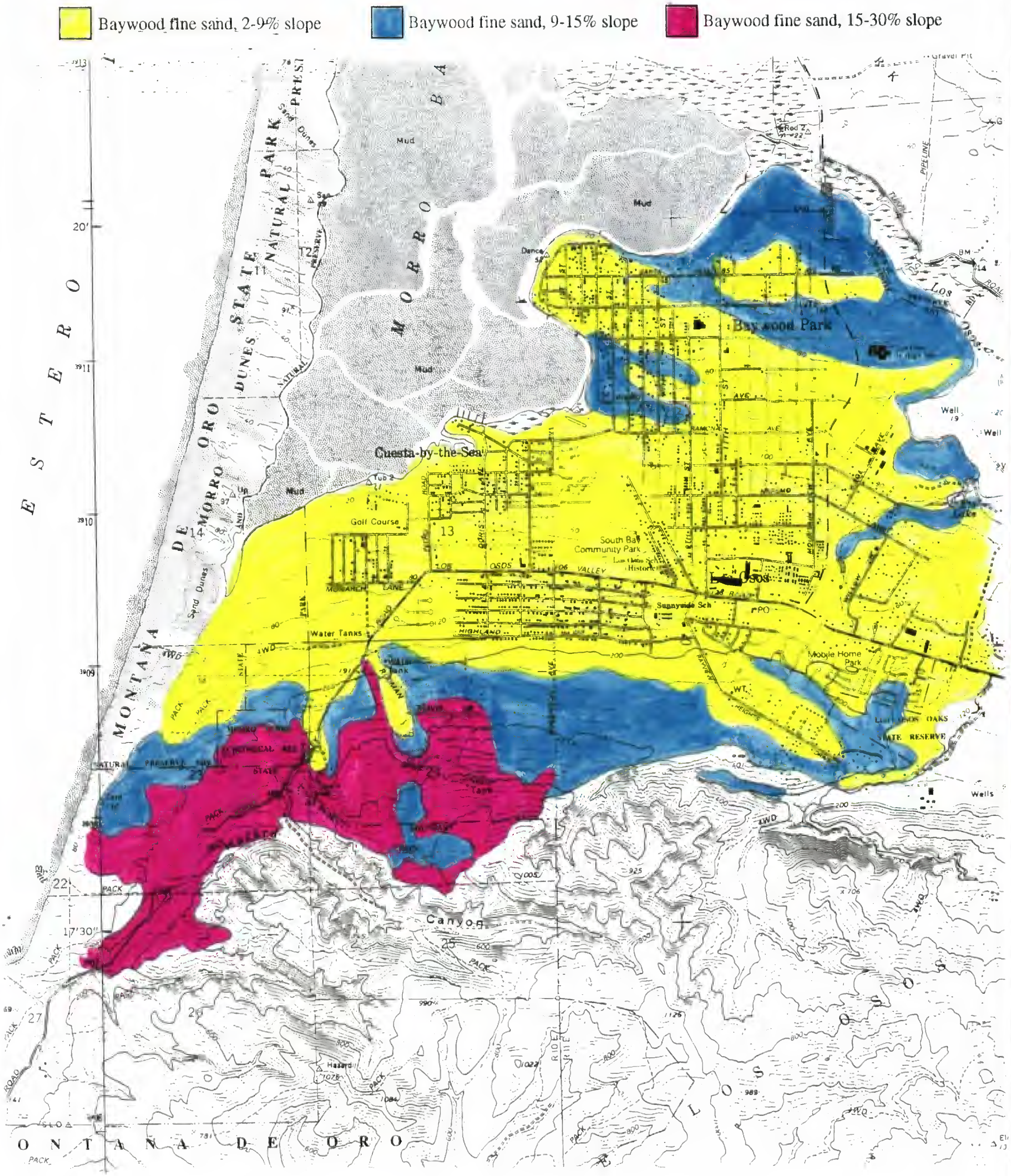


Figure 2. Distribution of Baywood soils. Adapted from U.S.D.A. Soil Survey of San Luis Obispo County, California.

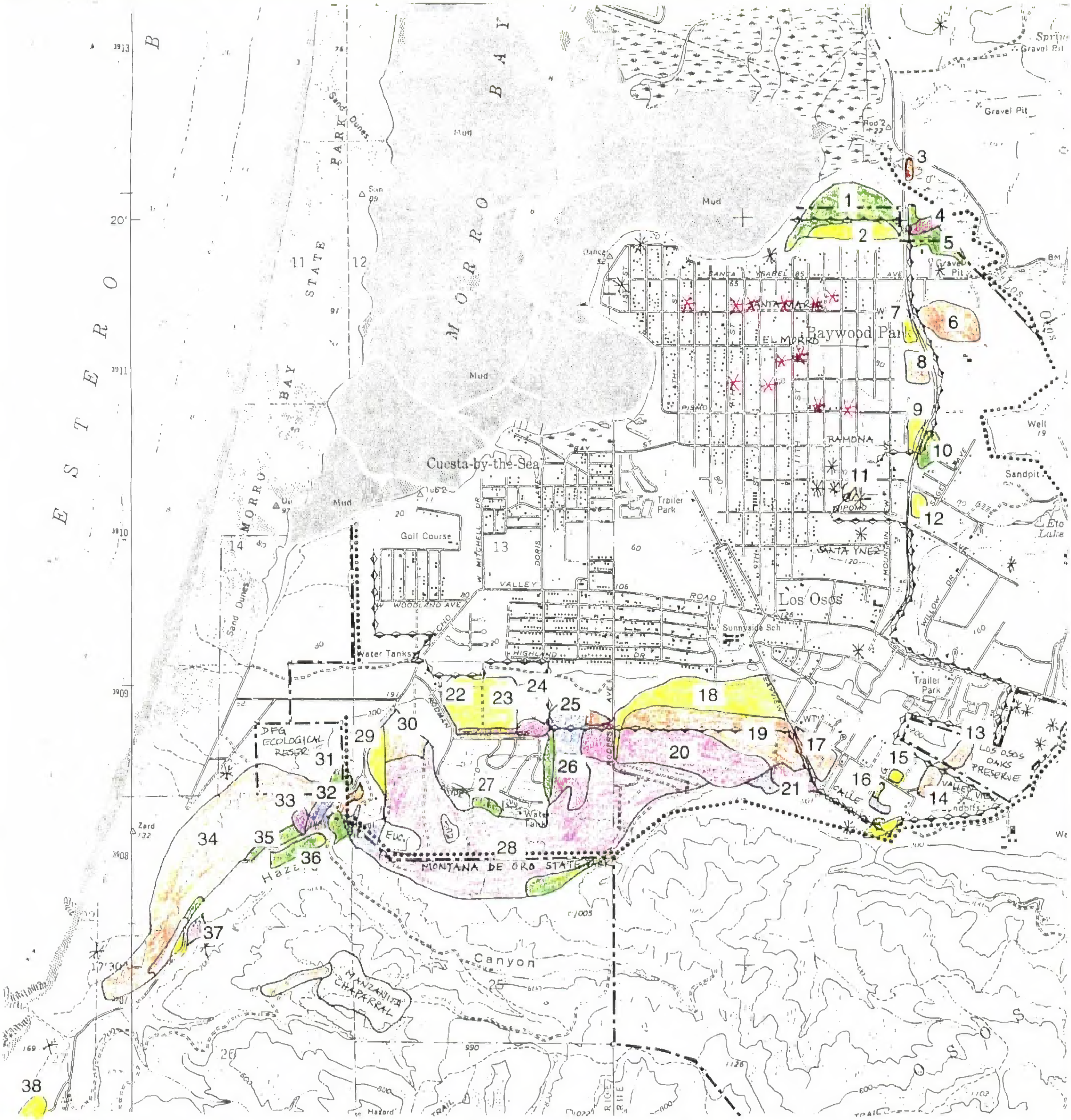


Figure 3. Percent Cover for *Arctostaphylos morroensis* From McGuire and Morey (1992).
(Sources: Mullany 1990, San Luis Obispo County Local Coastal Program, Regional Water Quality Control Board)
Morro Bay South $7\frac{1}{2}$' Quad

☐ 75 - 100%
🟪 50 - 75%
🟦 25 - 50%
🟩 5 - 25%
🟧 1 - 5 %
🟨 < 1%
* One or a few individuals (Mullany)
✳ One or a few individuals (Chipping)

— · — · — Public Lands
◇◇◇◇◇◇◇◇◇ Prohibition Area Boundary
••••••••••••••••••••• Urban Reserve Line (URL)

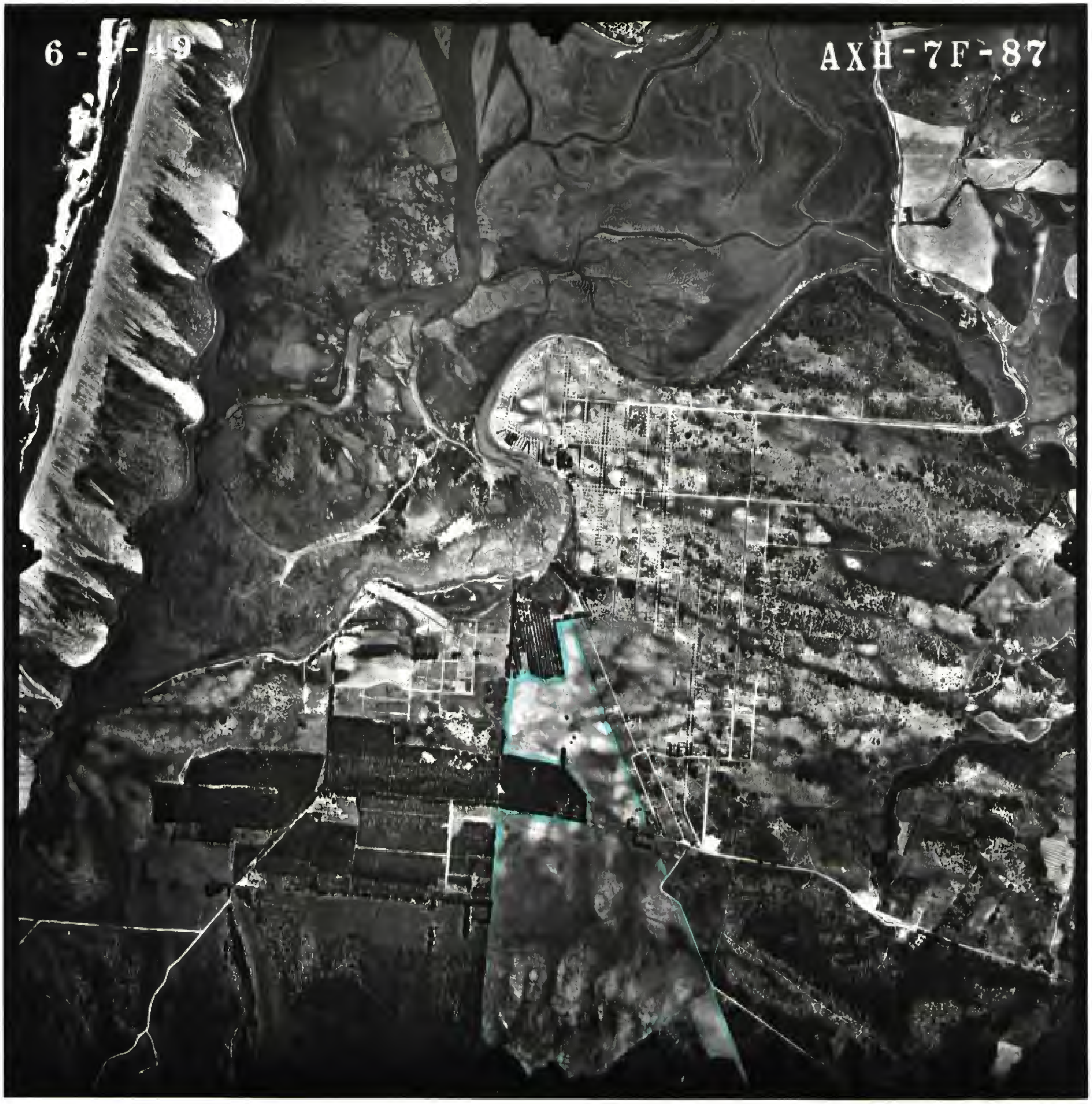
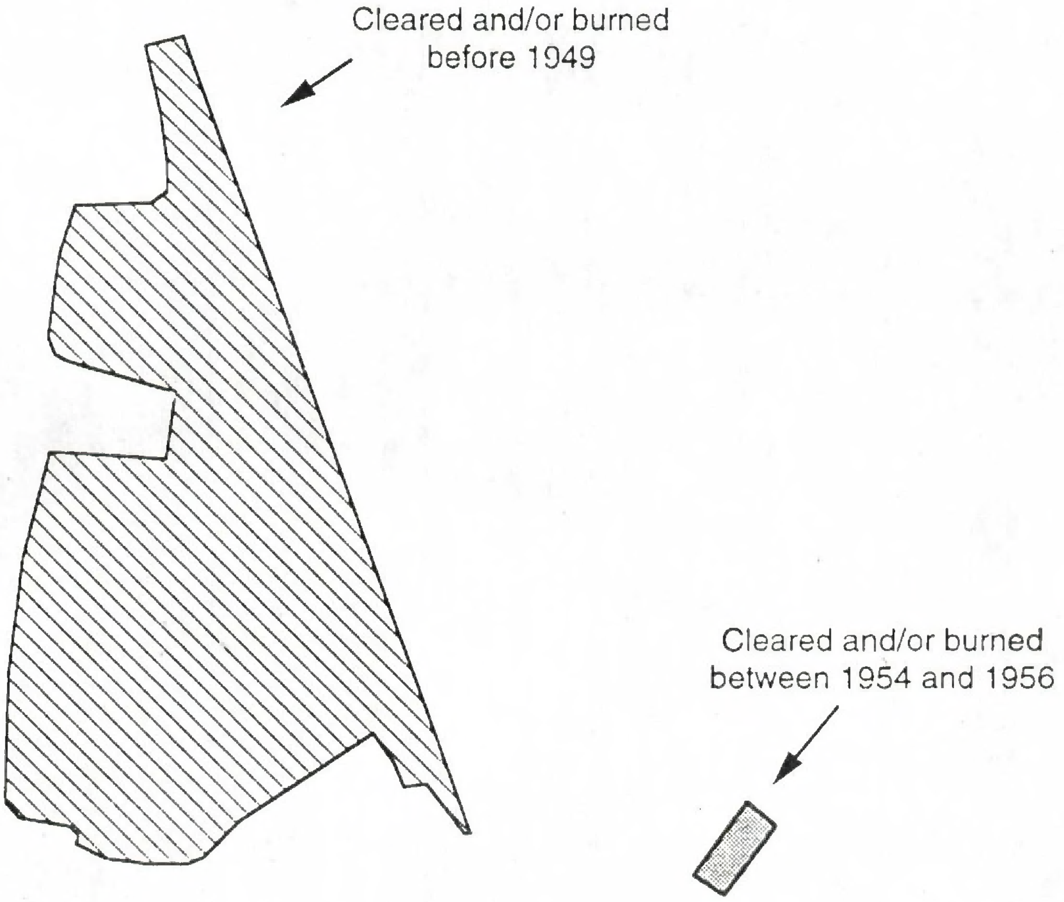


Photo 1. Baywood Park - Los Osos area, June 4, 1949. Note area in lower center that has been cleared and/or burned.

Photo 2. Los Osos area - Hazard Canyon, July 28, 1954. Note intact vegetation in dunes area west of Pecho Valley Road.

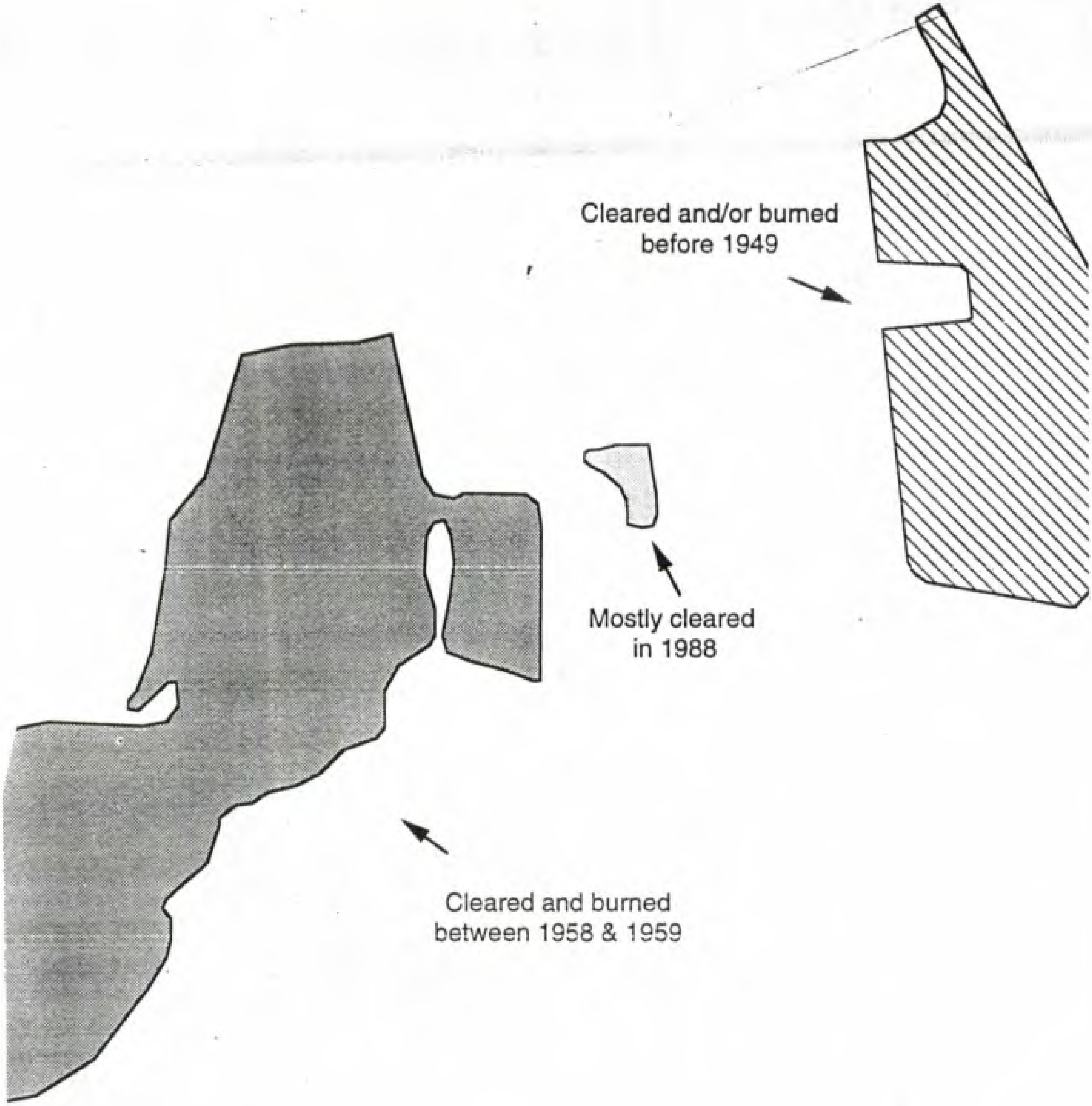
Photo 3. Montaña de Oro State Park - Hazard Canyon, November 6, 1959. Note cleared, burned area west of Pecho Valley Road. Striations may indicate bulldozer tracks. Also note small cleared patch in upper right corner (south of Los Osos Oaks Preserve).

Photo 4. Baywood Park - Los Osos area, December 2, 1992



Overlay 4.1. Disturbance documented from aerial photographs.

Photo 5. Montaña de Oro State Park - Hazard Canyon, December 2, 1992



Overlay 5.1. Disturbance documented from aerial photographs.