Endangered Habitats for Insects: California Coastal Sand Dunes*

Jerry A. Powell

Division of Entomology and Parasitology, Department of Entomology, University of California, Berkeley, California 94720, USA

Abstract

Coastal sand dunes of California represent natural habitats which support unique plant and insect communities and occur in such limited geographic areas that destruction of whole populations is likely. Habitat alteration/destruction comes from the invasion of agressive non-native plants, urban and industrial growth, and off-road vehicle (ORV) use. A brief review of the status of three dune systems of special interest: Antioch, San Francisco and Santa Maria is made.

Eighteen of the 32 identified coastal dune systems in the state were surveyed for microlepidoptera. The results seem to indicate higher species diversity in larger dune systems, although several problems exist in interpreting these data. On the basis of distribution, three general groupings of species can be made. Only a few of the surveyed species represent narrow endemics, restricted to one or two adjacent dune systems.

Introduction

The preceding contributors have discussed political and theoretical aspects of extinction and the endangered species problem. Examples of conservation programs in progress, including management projects, have been given. In contrast, my topic is the description of a natural habitat that supports unique plant and insect communities and occurs in such limited geographic areas that destruction of whole populations is likely. The coastal sand dune systems of California provide a relevant example since in the western United States we have the dilemma of an incomplete knowledge of insect fauna, coupled with continued population growth and the associated decimation of habitats.

I know of no documented cases where widespread species of North American insects are being uniformly eliminated by the effects of man, as is the case with predatory mammals and birds. In general insects can persist in smaller areas, can tolerate higher levels of foreign substances such as insecticides, and are lower on the food chain. Insofar as insects are concerned, "endangered" refers to local situations where populations are confined to naturally subscribed habitats. It is the destruction of these habitats with which we are concerned.

The only difference between the extinction of a local population and of a species is one of degree. Whether local populations are or were potentially interbreeding with other similar populations is a matter of conjecture; the degree and duration of isolation indicated by slight morphological distinctions exhibited in insects considered to be locally occurring species, such as in the extinct San Francisco butterfly *Glaucopsyche xerces* (Bdv.), are unknown. Indeed, the degree of isolation is not important; rather it is the elimination of communities which unique insects represent that is the central issue.

Preservation of habitats, not species, will have to be the aim of any conservation efforts directed to insects, and Lepidoptera may play a key role since butterflies are so much better known than other insects. In the United States, most conservation proponents have focused their attention on vertebrates or dominant plants as indicator species simply because invertebrates are too poorly known to document the plight of diminishing habitats. Yet in local situations like coastal dunes, a given site may have no endemic vertebrate colony and an insect population could play an important role in conservation.

Characteristics of Coastal Dune Communities

The coastal dune community develops wherever there is accumulated sand above high tide level, and it occurs like a chain of islands along the immediate ocean front of the Pacific Coast of North America. The active foredunes and inner, stabilized dunes support a simple, yet unique plant and animal community. The overall diversity is low, with only a few dominant plant species at any given locality, and there is a little horizontal zonation in the vegetation. In California these areas are characterized by annual rainfall ranging from 175 cm in the north to less than 30 cm in the south. There is considerable fog and wind, particularly during summer, which is the dry season for other low elevation communities in the region. The growing season is 12 months, with 360-365 frost-free days. The climate is thus moderate with small seasonal and diel fluctuations in temperature; the summer maxima range 16-22 degrees C and the minima in winter 4-8 degrees C.

The vegetation is low or prostrate, often succulent and late flowering relative to nearby communities. There are three primary zones or land forms, although not all occur at each locality: (1) The *foredunes*, the line of dunes paralleling the beach behind high tide level. These are characterized by unstabilized sand, partially covered with a simple community of 3 to 6 low-growing invader plant species; (2) The *deflation plain* immediately back of the foredunes, which is at or near the water table, and is characterized by a mixture of water tolerant plants and invader dune species; (3) The inner zone consisting of

*Based on a presentation in the symposium "Endangered Insects of the World," 31 August 1976, at the International Congress of Entomology, Washington, D.C. Some aspects of the data presented here, however, are the result of research during 1977.

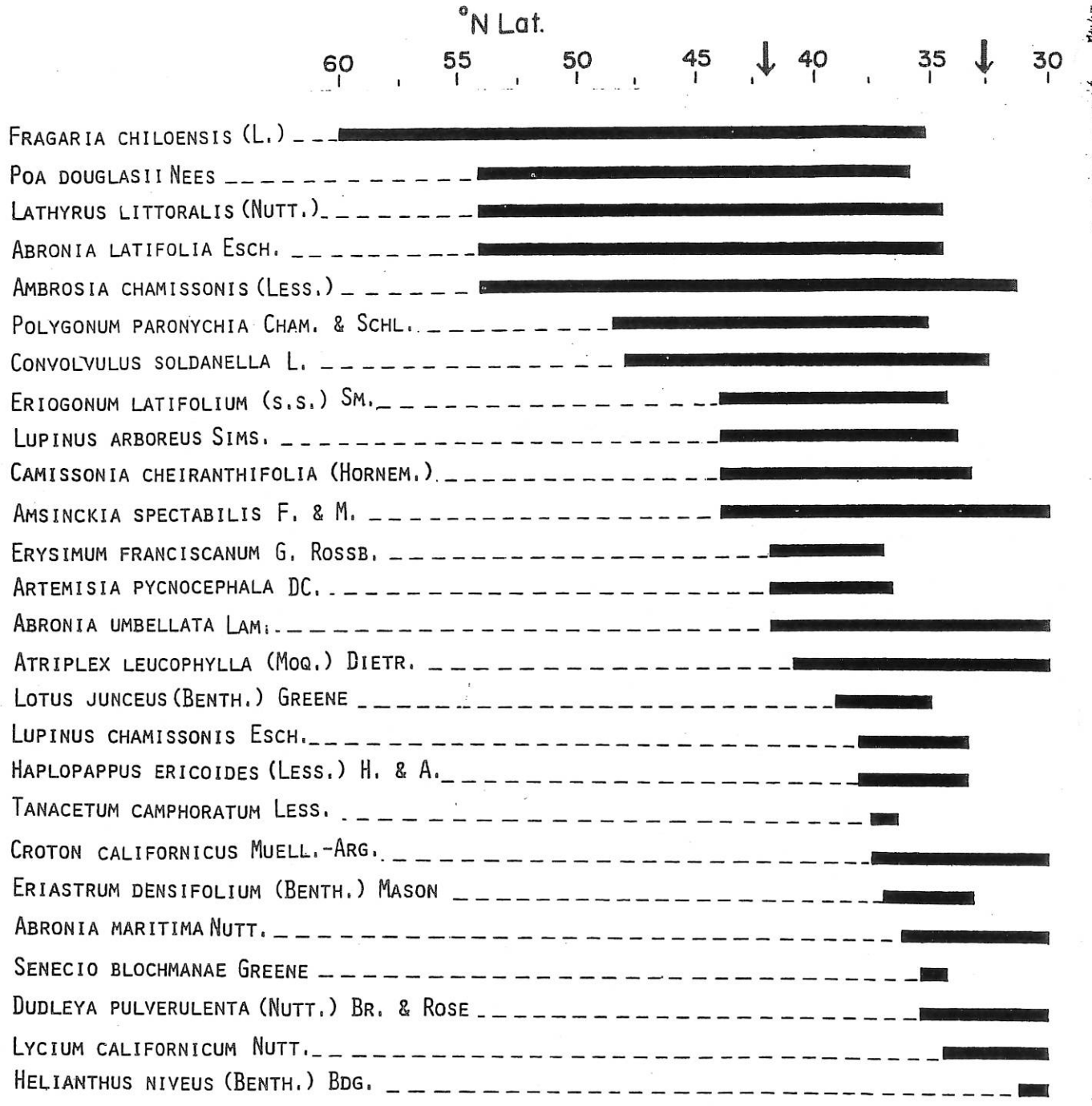


Figure 1: Latitudinal distribution of 26 characteristic coastal dune plants. Arrows indicate northern and southern boundaries of California.

stabilized dunes, situated adjacent to the deflation plain or in large dune systems still farther inland, behind high dunes of open active sand. The stabilized dunes, which are dominated by woody perennial plants, may be dissected by parabolas of secondarily invading, unstabilized sand.

The characteristic unstabilized foredune habitat occurs at even the smallest coastal dune areas. Invader plant species include *Cakile maritima* Scop., *Eriogonum latifolium* Sm., *Abronia maritima* Nutt., *A. latifolia* Esch., and *Ambrosia (Franseria) chamissonis* (Less.) Greene. There are interspersed areas of active sand, and the association supports a rich insect community of phytophagous species and sand-burrowing scavengers and predators and their associates. The unstabilized habitat gives way, often abruptly, to stabilized dunes, characterized in northern California and northward by conifers and shrubs such as *Arctostaphylos* sp. and *Vaccinium* spp. In central and southern California the stabilized flora consists of chaparral dominated by summer- and fall-blooming woody shrubs such as *Haplopappus ericoides* (Less.) H. & A., *Eriogonum parvifolium* Sm., and *Baccharis pilularis* DC.

Despite superficial uniformity of this community, the species constitution varies considerably from north to south. Some species extend the length of the state and beyond, but others reach their distributional limits in either northern, central, or southern California. The plant community therefore gradually changes in species composition and in formation from a more mesic one in the north to a less diverse, more xeric one in the south. As a result, most phytophagous insect species do not occur throughout the coastal strand even within California. Fig. 1 illustrates latitudinal distribution of some of the most characteristic plant species of the Pacific Coastal dunes (data from Munz & Keck, 1959, 1968; Breckon & Barbour, 1974). The 26 plants are listed in descending order of their northernmost occurrence. Species range differently in terms of latitude, with northern species tending to be more widespread. Within the shift in flora, the greatest diversity occurs in central California, with 13-15 species in northern California communities, 20-22 in the central coast and only 8-10 in the more xeric, southern California dune system.

Effects of Human Population

The coastal strand and sand dune communities in general have survived a curious paradox in their relationship with humans. During early colonization in the 18th and 19th centuries in California, the dune systems were largely spared because they were undesirable for man's activities, especially agriculture. Thus, in most cases these habitats survived until they could be partially sampled by biologists (unlike certain communities such as natural grasslands, which were essentially gone before entomologists arrived on the scene). With accelerating population pressure in recent decades, however, the dune communities are being eliminated because they are considered wasteland of no practical value.

There are three primary kinds of decimation of dune habitats by man: (1) The extensive planting of alien plants for stabilization, especially Iceplant (*Mesembryanthemum* spp.) from South Africa and the European Marram Grass (*Ammophila arenaria* (L.) Link.). The latter outcompetes native floral elements and forms dense stands that are essentially devoid of insect life (SIobodchikoff & Doven, 1977). (2) Urban and industrial growth, including sand mining, where dune systems occur near metropolitan centers. (3) The recent, amazing popularity of off-road-vehicles (ORV), which has accelerated destruction of the fragile plant communities far beyond that of urban sprawl itself. Thus there are complicating factors in conservation of these habitats.

Fig. 2 depicts the distribution, size, and estimated condition of one riverine and 32 coastal dune systems in California (data mainly from Cooper, 1967, and personal observations 1974-1977). Each dune system is indicated in black (somewhat exaggerated in extent). The circles refer to relative size, computed by multiplying the greatest straight line length by the width of the unstabilized and stabilized portions of each dune system. This can be interpreted as an estimate of biological island size, not actual area. The black portion of the circular pie diagrams are estimates of the percent area that has been destroyed by human activities. The shaded areas are estimates of the proportion of the remainder that is held in some kind of "preserve" (state, county, University of California, etc.; designations of ownership indicated in the legend). About 75 percent of the systems are small, less than 10 square kilometers, and these include primarily unstabilized foredune habitat. In fact, about half of these are less than 2 square kilometers. Essentially all the southern California dune systems are destroyed, although fragments of the once extensive El Segundo dunes are held in preserves by Standard Oil Company and the City of Los Angeles.

Of special interest are the five largest systems. San Francisco and Los Angeles (El Segundo) are essentially gone, while the three in less populous, central California are the best large islands remaining: Monterey Bay and the vicinity of Purisima Point (both largely military) and the Santa Maria dunes system (state and private).

Status of Insect Survey

Sporadic collections of insects were made at coastal dune localities during the first half of this century [e.g. 1905-1920 at San Francisco; concerted survey efforts by Pierce and others at El Segundo in the late 1930's (Pierce & Pool, 1938 *et seq.*)], but no really systematic survey of any dune system in its pristine condition ever occurred. My special interest is in the microlepidoptera (small moths), although I carry out general insect survey during field work. I began studying coastal sand dune insects in the late 1950's in connection with a moth, *Argyrotaenia franciscana* (Walsingham, 1879), the first microlepidoptera described from the California coastal dunes (Powell, 1960, 1964, 1965). I continued sporadic sampling through the 1960's, and in 1972 began a more systematic survey of coastal dunes after I recognized the drastic effects of off-road vehicles (ORV's) on the Santa Maria dunes, our largest dune system. I have probably sampled this habitat more than any other entomologist and therefore am in the best position to appreciate the inadequacy of our knowledge.

Of the 32 dune systems (Fig. 2), 18 have been surveyed for microlepidoptera at least once. All the others are small, less than 10 square kilometers, except one, Purisima Point (now largely Vandenberg Air Force Base). However, not a single system has been sampled around the calendar and clock in a systematic fashion. This statement is probably true for all dune insects. One exception may be the sand-dwelling Coleoptera, which have been sampled for diversity, abundance, and seasonal succession at several dunes in California by J. T. Doyen of the University of California at Berkeley.

Distribution of Coastal Dunes Microlepidoptera

When studying microlepidoptera and other plant-feeding insects, there are three primary sources of problems in any attempt to assess endemism or other aspects of geographical distribution. First, definition of the habitat is difficult because many plants do not observe dune boundaries. At each locality, plant species characteristic of adjacent non-dune habitats also inhabit stabilized or even unstabilized dunes. Ideally we would need to know the host plant preferences of each insect in order to judge which are limited in occurrence to the dune community. Second, we have inconsistent sampling, both seasonal and geographical. For example, my surveys have ranged from 1 to 30 days per locality. Larger dune systems have received more attention, which of course is necessary to attempt coverage of the greater diversity of habitats. As might be predicted by island biogeography theory, the larger dune systems have more insect species, but to what extent the data reflect community

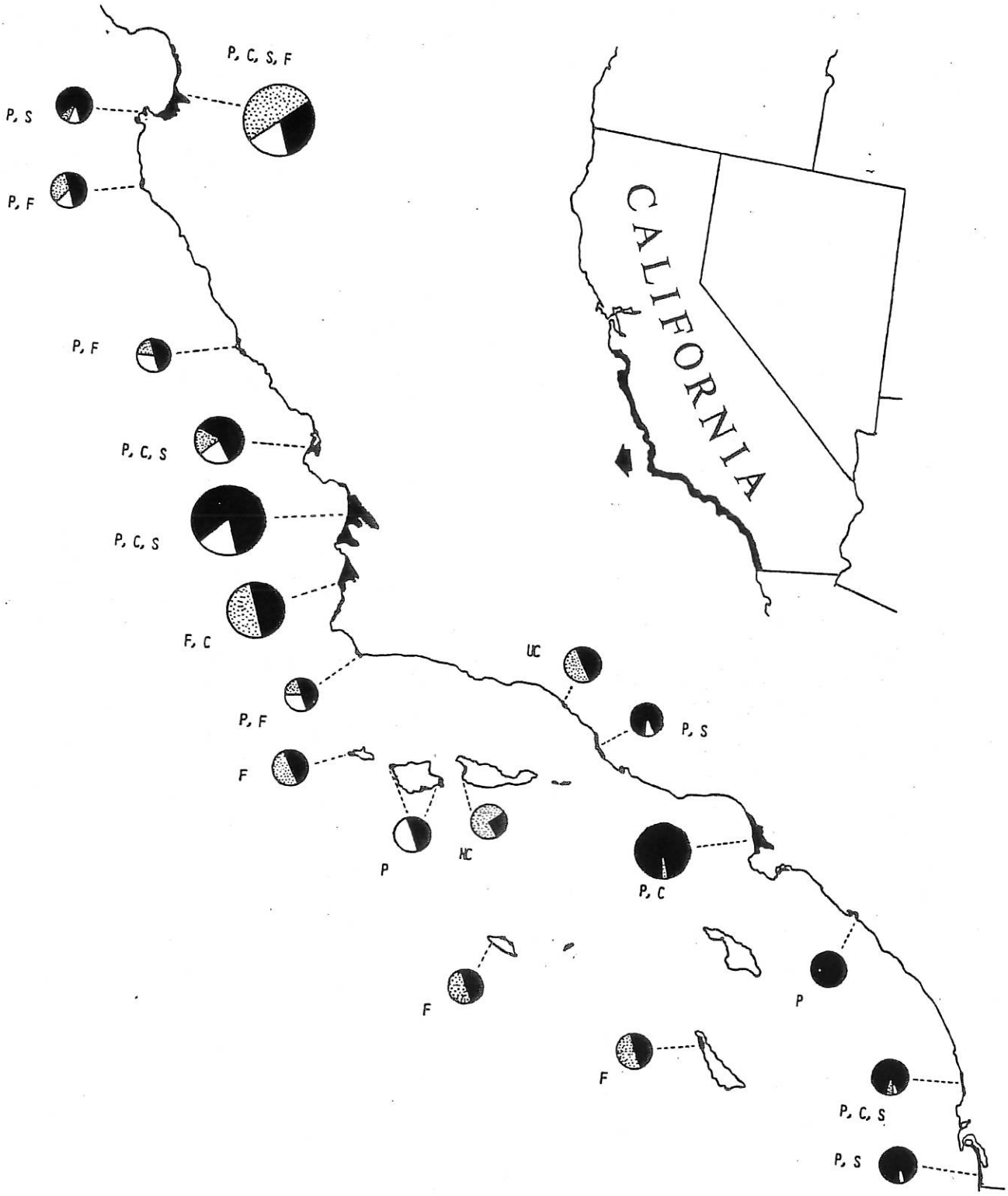
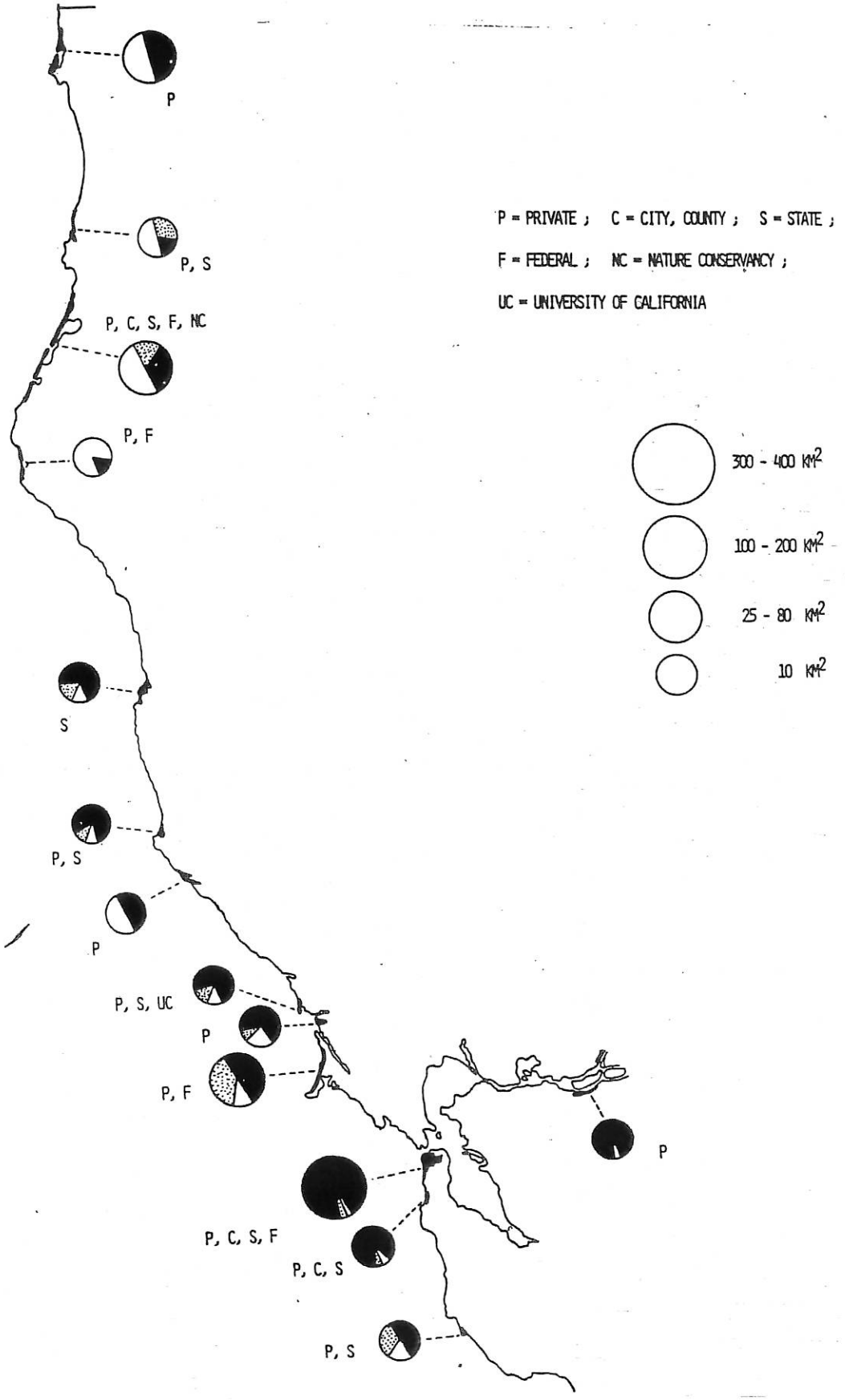


Figure 2: Distribution, size, ownerships, and estimated condition of one riverine and 32 coastal dune systems in California. Line on left page traces coast from Oregon border to Monterey Bay, on right page, from Monterey Bay to the Mexican border. Pie diagrams indicate estimated proportions destroyed by effects of man (black portion) and proportion held in some kind of preserve (shaded portion). Remaining portions (white) are relatively undisturbed and are unprotected.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P, S
P = PRIVATE ; C = CITY, COUNTY ; S = STATE ;
F = FEDERAL ; NC = NATURE CONSERVANCY ;
UC = UNIVERSITY OF CALIFORNIA
300 - 400 KM2
100 - 200 KM2
25 - 80 KM2
10 KM2

size and to what extent they reflect sampling effort is unknown. The third source of problems lies in the state of taxonomic knowledge of insects. Reliable identifications can be obtained in some families of small moths but not others, and often in this discussion "recognized" species does not mean named species. The survey to date has revealed about 200 species of microlepidoptera including the pyraloid moths, but the taxonomic status is uncertain for 30 or 40 others. It is not known whether these are the same species as similar looking moths at other localities. Even so there are some preliminary generalizations concerning the fauna that can be surmised from available data.

Table 1 indicates the total number of microlepidoptera species recorded from each of 18 dune systems, the dune system areas, and the number of sampling days at each locality. Owing to discrepancies in the seasonal distribution of sampling days and the low number of sampling days in southern California these figures cannot be compared statistically. However, disregarding localities only sampled once or twice, we have an indication that the largest dune systems have the most complex communities of these moths.

In Fig. 3, species associated with non-dune plants are omitted, and three basic components of the distribution pattern are evident among the 101 remaining species: (1) Northern species, those extending from Oregon or beyond southward into California. Among species which are adequately surveyed, some extend to Mendocino County, others through the central portion to Monterey, and still others as far south as Point Conception. (2) A southern group which extends into coastal southern California or the Channel Islands from the coast of Baja California or from the desert region. This makes up the largest portion, with many known only from the Santa Maria dune system in my samples. (3) Endemic species, those restricted to the central part of California's coast. As indicated in Figure 3A, 19 species range from Sonoma County south to either Monterey or the San Luis Obispo County dune systems, while another 17 (Fig. 3B) are known from only one or two locations.

The northern group comprises about 21 percent, the southern group 38 percent, and the California endemics about 35 percent of these moth species. Possible narrow endemics, those restricted to one or two adjacent dune systems, are indicated in Fig. 3B. Careful survey will probably reveal several of these to be more widespread. Only a few species are so widespread as to exceed portions of all three distributional groups, making up about 6 percent of the non-dune plant associates.

Figure 3B indicates the possible narrow endemics among the microlepidoptera. Of those for which adequate samples appear to be available, only a few have been documented as narrowly endemic. These include one at San Francisco, one at the Monterey dune system, one at the Santa Maria dune system, and another three or four which occur both at the Santa Maria dune system and Morro Bay. Two species described from the El Segundo sand dunes in Los Angeles have never been collected elsewhere, but the condition of habitats and their survey are poor in this area of the state. Two species appear to be restricted to the Monterey and San Luis Obispo dune systems. Table 2 compares some examples of endemic insects in other orders, most of which also occur on several adjacent dune systems.

Status of Selected Major Dune Systems

The following briefly reviews the status of three localities of special interest: (1) Antioch, the only major riverine dune system in California; (2) San Francisco, both of which have been nearly eliminated by urban and industrial development; and (3) the Santa Maria dune system, which has the largest pristine areas of coastal dunes remaining in California.

Antioch. The Antioch sand dunes comprised a unique ecological area from several standpoints. Although largely decimated by industrialization and sand mining, remnants worthy of consideration for preservation still exist. Biologically the place was a kind of "island" that contained the northern extension of many plants and animals of desert affinities--a biogeographic element that probably extended along the western margin of the Central Valley in prehistoric times. Later, natural processes reduced this biota to a few small areas, of which the largest and most northern sand dunes community was at Antioch. Fig. 4 is redrawn from a 1953 United States Geological Survey topographical sheet, giving an indication of the extent of the dunes. They ranged to 20 meters in elevation and extended 3-4 kilometers along the south shore of the San Joaquin River. Because this site is near Berkeley, it became the best known of the localities harboring desert elements in the Central Valley. Although the dunes resembled coastal dunes in general aspects, such as genera of some of the plants, species of plants and animals are quite different. Most of them are desert species with only a few that also occur in the Pacific coastal beach dunes (compare Table 3, Fig. 1). The long isolation from relatives in the Mojave resulted in considerable local differentiation, or endemism.

This place was discovered entomologically in 1932, and considerable effort was expended in discovery and study of the insect fauna during the subsequent decade and for several years after World War II. Large-scale industrialization around 1952-1954 and subsequent sand mining have greatly reduced the available areas of native community. The overlay of dotted lines in Fig. 4 is based on a 1968 revision of the topographical sheet, and gives an indication of the extent to which industrialization eliminated the habitat.

Although several of the plants appear to be unique ecological types of their species and at least two of these were named, evidently no systematic floral list was compiled during the pre-industrial period. During my field work in 1976-1977, about 40 species of conspicuous plants were observed in the flora, of which 15 are the principal components of the sand dune, desert-interior valley community (Table 3). Antioch represents the northern limit of these elements, and they form the basis of the sand dune insect community.

Although I have not seen photographs of the area in its pristine condition, a 1952 aerial photograph shows the habitat generally to be a stabilized dune community with scattered Coast Live Oak (*Quercus agrifolia* Nee) and relatively little open sand. A *Life* magazine article (issue of 8 September 1955), "The world of the insects," contained a six-page section entitled "Communal life on the dunes" that described interrelationships of the plant and animal community at Antioch, primarily through paintings of Walter Linsenmaier. This was reprinted in the Life Nature Library book, *The Land and Wildlife of North America* (Farb, 1964: 44-49). Thus the habitat and its insects received national attention, although no protection.

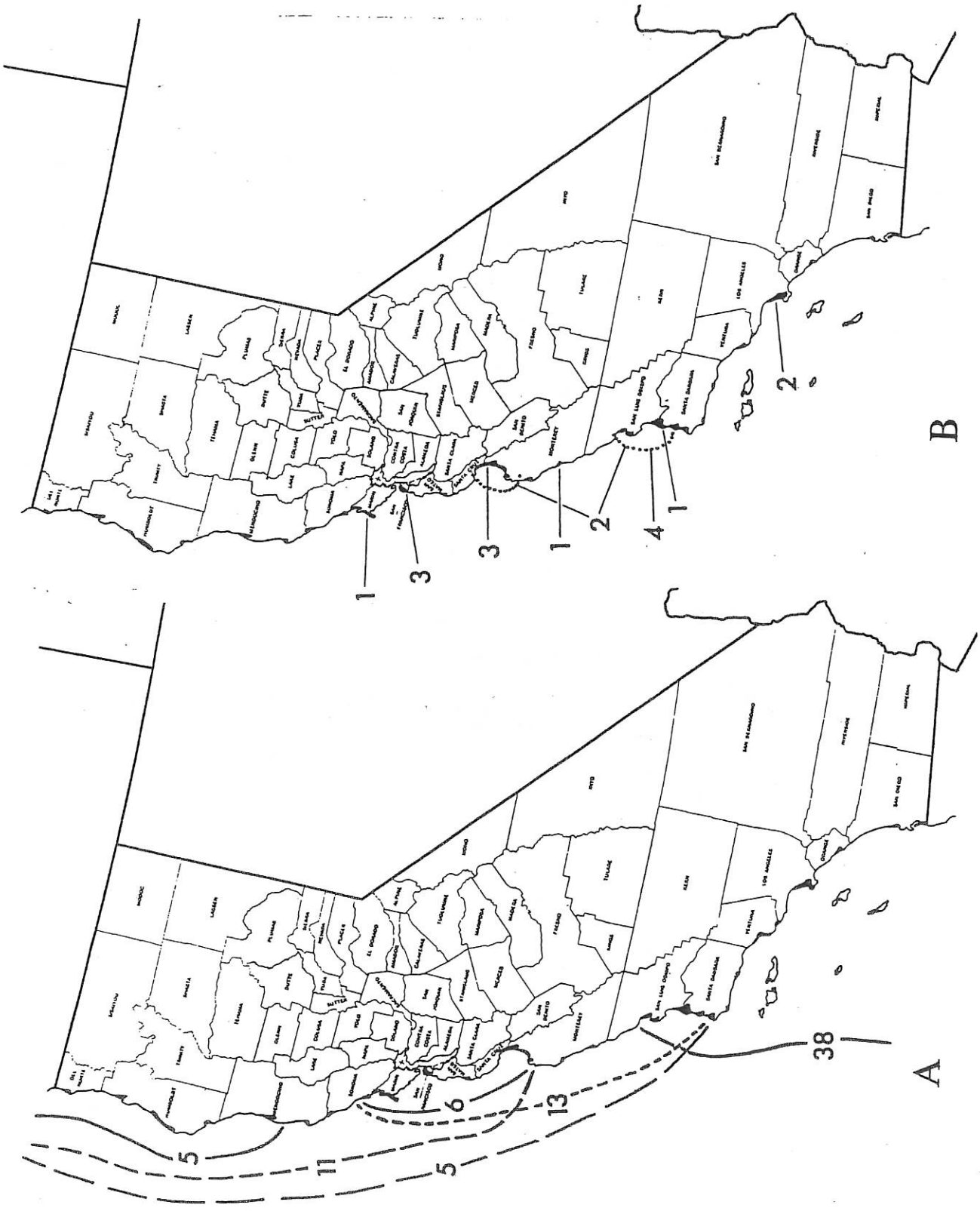

Figure 3: Distribution of Coastal dune and strand Microlepidoptera (species associated with non-dune plants excluded). A. number of species recorded by geographical component: northern (21), central (19), and southern (38). B. occurrence of possible new or only endemic species. Further survey probably will show several of these to be more widespread. An additional 7 species extend the length of California and beyond.

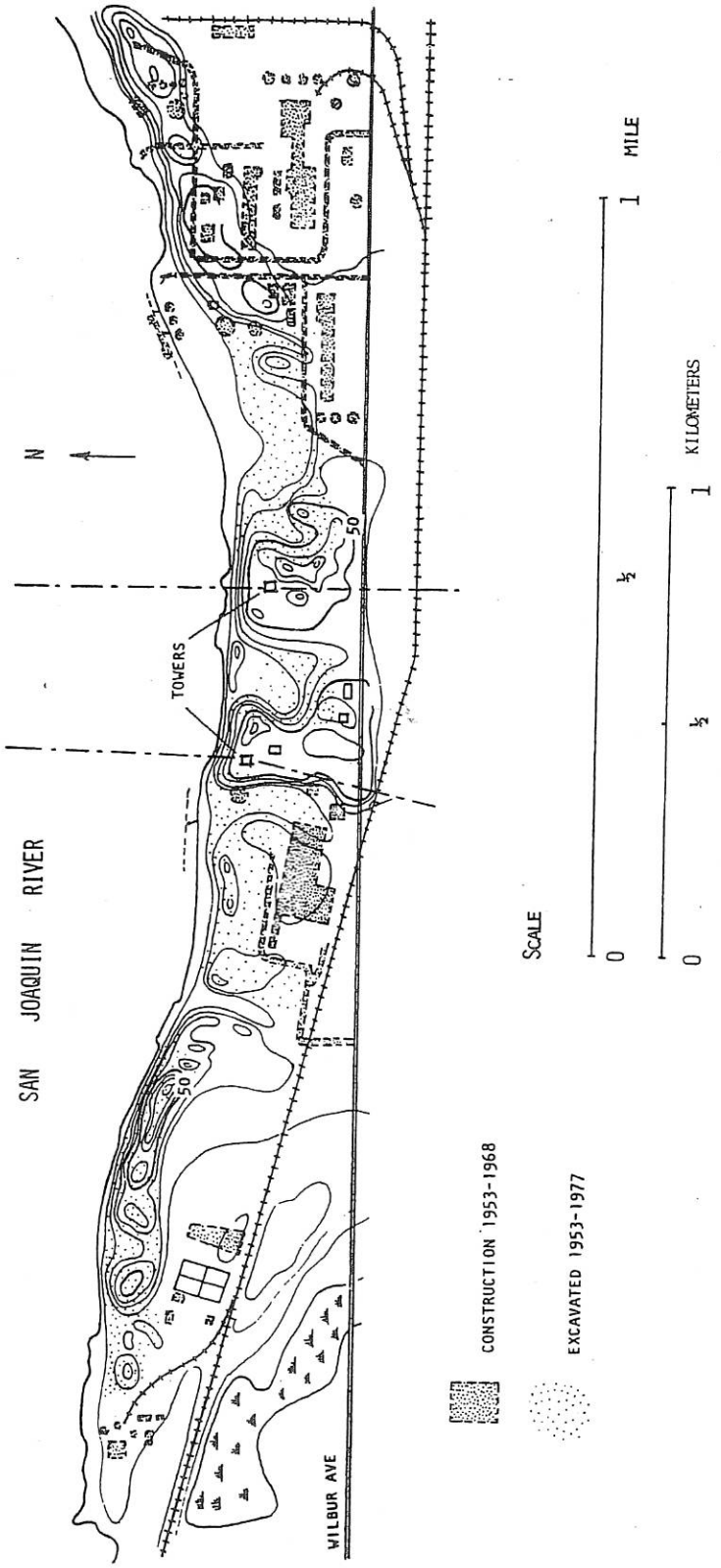

Figure 4: Map of Antioch sand dunes area (left edge is approximately coincident with eastern city limits of Antioch, Contra Costa County, California). Drawn from Antioch North Quadrangle, 7.5. minute series, United States Geological Survey topographic map, 1953. Contour interval ten feet, topography by plane-table surveys in 1906-1907 and from aerial photographs taken in 1949. Overlay delineated by dotted lines indicates construction, 1953-1968, compiled from aerial photographs taken 1968. Sparsely dotted areas depict sand-mining excavations during 1953-1977 in addition to areas leveled for construction of roads and buildings. The two parcels occupied by Pacific Gas & Electric Co. towers are the only unexcavated hills remaining.

One noteworthy aspect of Antioch to entomologists is the extraordinarily large number of insects that have been originally described from there. Zoological literature is not organized in such a way that information by locality can be easily retrieved, but there are at least 25 species or subspecies that have Antioch as the type locality (Table 4). This means it will remain of considerable interest to insect taxonomists and biologists to be able to study populations or specimen samples from Antioch. Among these 25, 11 appear never to have been discovered elsewhere, and another seven are known only from likewise endangered places in the delta or riverine situations of the Central Valley. Moreover, other insects originally described from sandy habitats in the Central Valley in pre-agriculture days may exist only at Antioch now. For example, the last known occurrence of the giant flower-loving fly (*Rhaphiomydes trochilus* (Coq.)) (type locality: Merced), was at Antioch in 1974.

As noted in Table 4, several of the species described from Antioch are not known to have been observed there since the industrial build-up in the 1940's and early 1950's. Although this may in part be due to lack of adequate survey, or to lag in identification of cryptic species in museums, it seems certain that a few, including the Shield-backed Cricket, *Neduba extincta* Rentz, and the beetles *Coelus gracilis* Blasidell and *Anthicus antiochensis* Werner are extinct there now. In addition, it is obvious that some widespread species of arid regions to the south have not survived at Antioch. Several larger flies and wasps of desert affinities which were common there in the 1930's and 1940's have not been collected there since 1954-1958. Survey during 1976-1977 indicated that there has been a general decline in species diversity in some families with sand dune-based biologies, such as robber flies (Asilidae), stilleto flies (Therevidae), and velvet ants (Multillidae). In other groups, such as spider wasps (Pompilidae) and bee flies (Bombyliidae), it appears there are comparable species numbers now, but some are replacement species not known there in pre-industrial days. Further analysis will be necessary to interpret changes in faunal composition.

Among the surviving species is Lange's Metalmark Butterfly (*Apodemia mormo langei* Comstock) (Fig. 5A). This race was described in 1938 and is known only from the Antioch dunes. In 1977 it existed in two colonies, each less than 4.05 hectares (10 acres) in extent. This species feeds in the larval stage only on buckwheat, *Eriogonum nudum auriculatum* (Benth.) Tracy. Thus, it is dependent on the persistence of that plant. The butterfly survives despite extreme drought in 1976-1977, increased rototilling as a fire prevention measure, and a June 1976 fire that destroyed a major portion of one *Eriogonum* colony. During a mark-release study in 1977 (Arnold & Powell, unpublished), we tabulated about 170 individuals in one of the populations during the second half of the flight period. A number of females emigrated eastward with the prevailing wind into the 1976 burn area, and oviposition occurred there.

Negotiations are in progress by the United States Fish and Wildlife Service of The Department of the Interior to obtain ownership of one portion of one of the colonies and management of two adjacent areas owned by Pacific Gas and Electric ("Towers" in Fig. 4). If successful, this would preserve about half the remaining extent of *Eriogonum*. Other major portions of the dune community, including the best remaining fragments of unstable sand, are in private ownership, zoned for industrial use and are unlikely to be preserved.

San Francisco. Another example of destruction of a coastal dune system is that of the San Francisco peninsula, which contained the fourth largest sand dune community on the California coast. Cooper (1972) illustrated the supposed extent of the original dune system, which included most of the western half of the present city of San Francisco, with an eastward extension projecting well into the downtown area. As late as the turn of the century, most of the western area was open dunes. Therefore, many insects were discovered and described from here. Golden Gate Park was developed as a corridor through the center of the sandy "wasteland" during 1870-1920, and the last dunes in western San Francisco were converted to parks in the early 1950's. A few fragments remain, such as at Baker State Beach on the Presidio, Sutro Heights, and Sunset Heights.

Glaucopsyche xerces (Boisduval) (Fig. 5B) is a lycaenid butterfly that lived in the San Francisco sand dunes. It is the only species of North American Lepidoptera that is known to have become extinct in recorded history. It was noted to be on the decline as early as 1920, and the last known specimens were taken in 1943 (Downey & Lange, 1956). The last colony occurred near the Marine Hospital on the Presidio, and construction during World War II is believed to have destroyed that colony. Probably the larvae were host-specific on *Lotus* and *Lupinus* spp. and may have had a symbiotic relationship with ants. Both of these plants survive in relatively undisturbed habitats such as at Baker Beach, (Fig. 5C), but evidently the remaining islands of native community are too small to preserve populations like *G. xerces*.

On the other hand, this locality supports a population of the tortricid moth, *Grapholita edwardsiana* (Kft.) (Fig. 5D). This species was described in 1907 from specimens in the Henry Edwards collection ("Cal.," "S. Fran. Cal.") which are believed to have been collected in the 1880's around San Francisco. *G. edwardsiana* remained an enigma for more than half a century until it was discovered in association with *Lupinus arboreus* Sims. at the Presidio in 1960. Recent studies have shown the larva to be a host-specific stem borer in *L. arboreus*. Because this plant was one of the dominant elements of the sand dunes, the moth was probably widespread. Now, however, we know it only from three colonies: Baker Beach, the south end of Lake Merced, and at the mouth of Colma Canyon in Daly City. The species was listed on a notice of review for possible Threatened status by the Office of Endangered Species of the United States Fish and Wildlife Service.

Many other species were originally described from San Francisco because it was a coastal dune locality easily accessible to collectors in the early days of California. But most of these are known to occur elsewhere, e.g. the Bumblebee Beetle (*Lichnanthe ursins* (LeConte)), and the Pheres Blue Butterfly (*Icaricia icarioides pheres* (Bdv.)), both of which are believed to be extinct at San Francisco but are common at Point Reyes, Marin County.

Santa Maria. Originally the largest coastal dune system in California, extensive portions of the Santa Maria dunes have been destroyed by urban and agricultural growth and recreational use. Even so, the area contains the best undisturbed habitats of both unstabilized and stabilized dunes on the California coast. All of the immediate coastal area is in Pismo Beach State Park, including the highest parts of the dunes (up to 50 meters elevation), a zone some 20 kilometers in length. Much of the stabilized dunes inland are in private ownership.

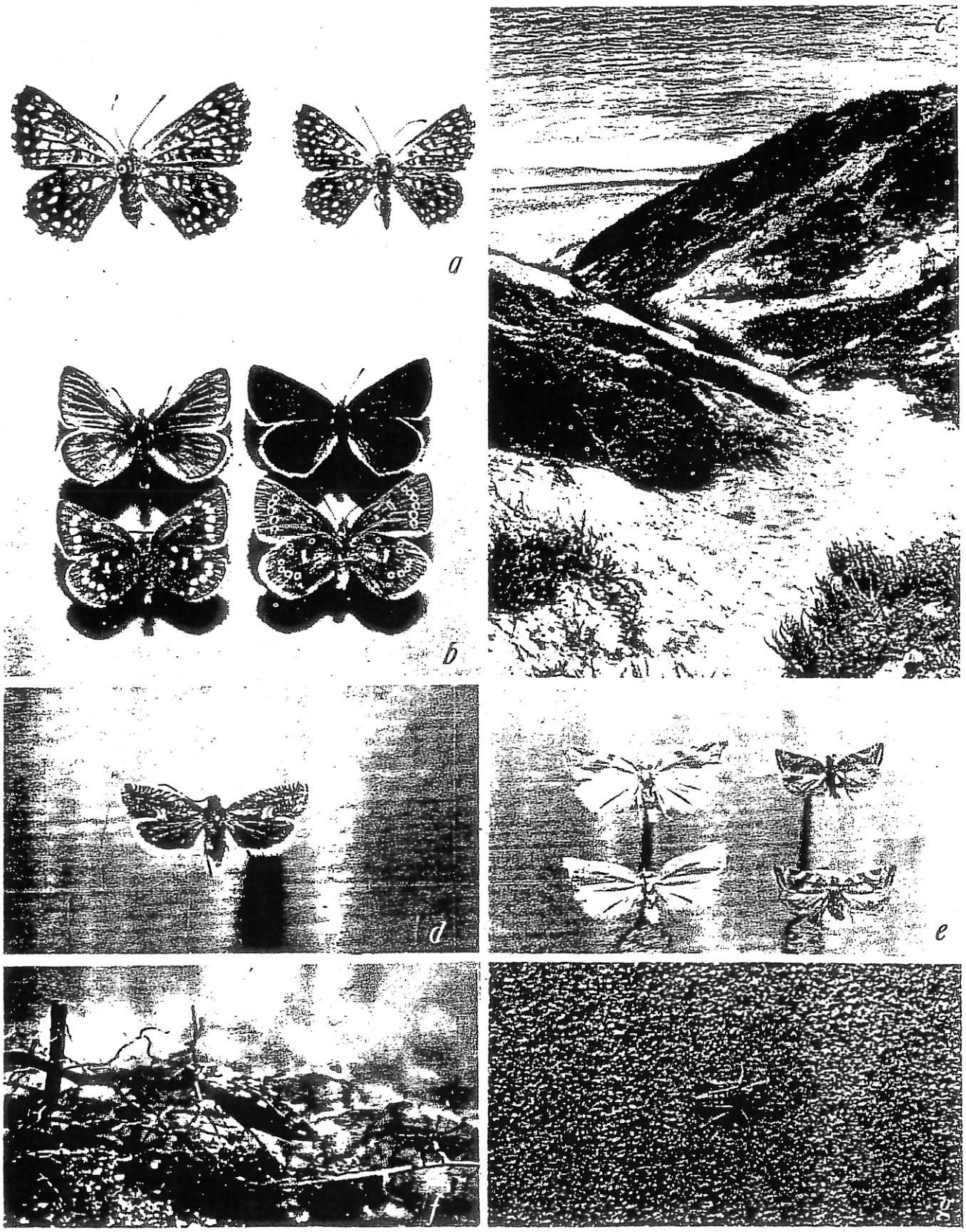

Figure 5: California Coastal dune insects. A. *Apodemia mormo langei* Comstock (Antioch). B. The extinct lycaenid, *Glaucopsyche xerces* (Boisduval) (San Francisco). C. Relatively undisturbed dune habitat above Baker Beach, San Francisco, in 1976. D. *Grapholita edwardsiana* (Kearfott) (San Francisco). E. *Argyrotaenia franciscana* (Walsingham) (left) and *Argyrotaenia* n. sp. (right) (Oso Flaco Lake). F. *Areniscythris brachypteris* Powell (Dune Lakes). G. *Ablautus schlingeri* Wilcox & Martin (Dune Lakes).

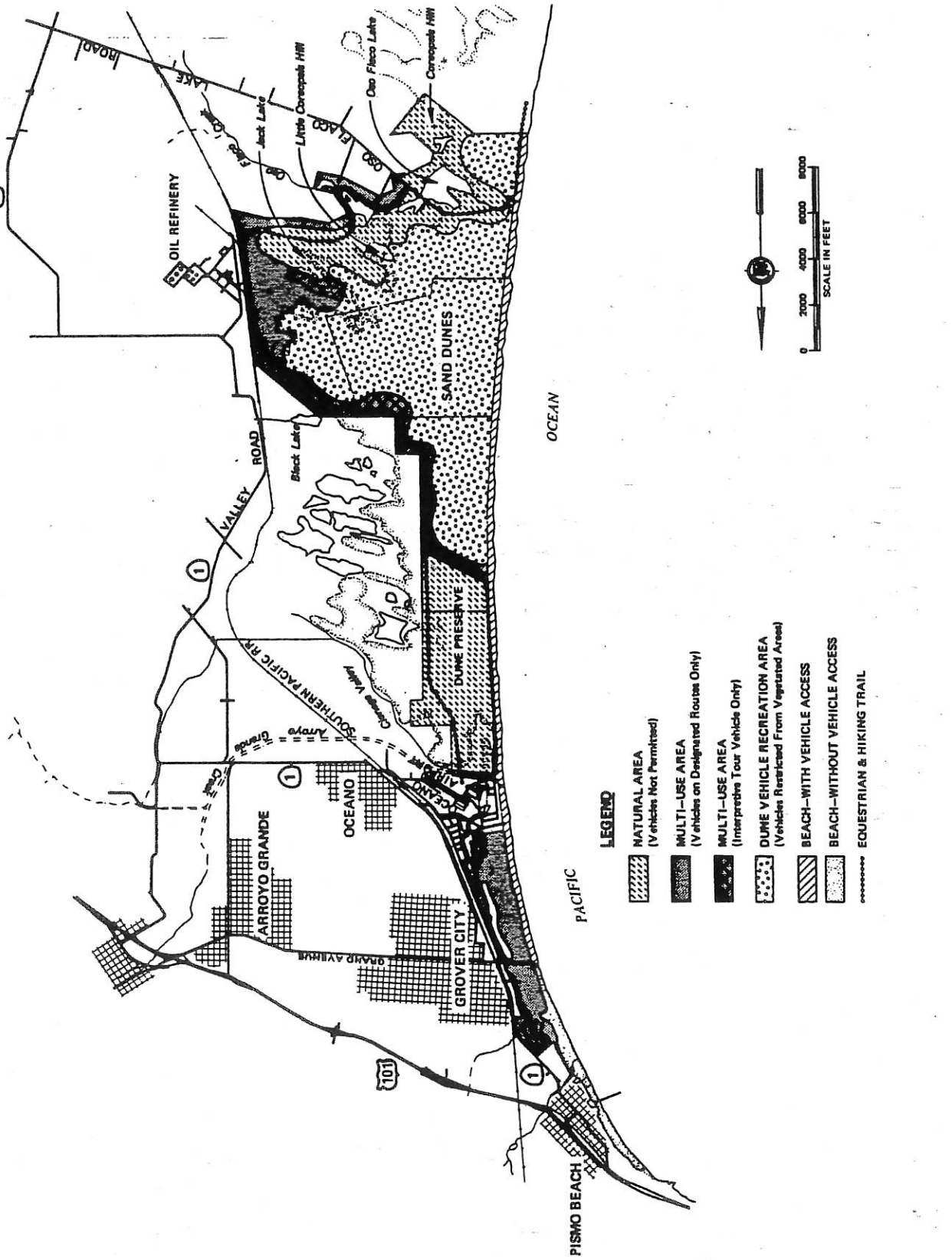

Figure 6: Map of Santa Maria dunes, San Luis Obispo County, including Pismo State Beach, Pismo Dunes State Vehicular Recreation area, and adjacent lands (private ownership). Map prepared by the California Department of Parks and Recreation; Land use plan indicated on legend (See Fig. 7 for effects of recreational vehicular use of land adjacent to Oso Flaco Lake, here designated as "Natural Area, vehicles not permitted").

A rich flora occurs here, including both northern and southern, more desert-like elements such as *Abronia umbellata* Lam. and *Croton californicus* Muell.-Arg., as well as many insects that do not range north to the San Francisco Bay. This area includes the largest number of endemic coastal strand plants in California, with about 10 species and races known only from here and the Morro Bay area (Stebbins & Major, 1965; Hoover, 1970). In contrast to most insect species, which are known from a series of coastal dunes (Table 2), several insects are known to be endemic to the Santa Maria system. The most remarkable of these is the recently described *Areniscythris brachypteris* (Fig. 5F, cover illustration), a flightless, jumping moth that buries itself at night. This is the only known continental Lepidopteran in the world that is flightless in both sexes (Powell, 1976). Among other endemic insects here are the small robber fly (*Ablautus schlingeri* Wil. & Mart.) (Fig. 5G), whose relatives live in the deserts, and the grasshopper (*Trimeritropis pogonata* Stroh.) the sand-colored nymphs of which burrow into the loose sand.

Unfortunately, these unique insects must share the habitat with creatures which buzz about the dunes in a much less restricted fashion (Fig. 7B). Off-road-vehicles constantly course over the open dunes, opening ever-widening sand roads through stabilized flora. Pismo Beach State Park encourages ORV activity, providing a map of designated areas (Fig. 6). The so-called "natural areas" include The Oso Flaco Lake area, a county park which has become a center for ORV activity during the past decade. Although many ORV enthusiasts insist that vehicle activity does not affect the flora and fauna, compare Figs. 7A-B, 7C-E-G, and 7D-F-H, which give some indication of the effect of vehicles on stabilized flora in coastal dunes. The pictures are of the same area in the vicinity of Oso Flaco Lake from 1965-1977.

Owing to problems in restricting ORV activity, the best hope for preservation of dune habitats in the Santa Maria dune system now lies in lands that are in private ownership. The unstabilized sand areas are so extensive that excellent, nearly pristine areas of stabilized and unstabilized dune flora lie well inland, a kilometer or more from the ocean, outside the state park lands.

Conclusions

Preservation of coastal dune and strand areas in California is occurring through various agencies: federal and state government, University of California, Nature Conservancy, and others. However, most of the preserves are small and involve only foredune, unstabilized habitats. Ideally, preservation requires designation of parcels of land of sufficient size to support all elements of the community, yet we have little data to establish minimum sizes of "islands" necessary to support arthropod communities over long periods of time. Habitats preserved through state agencies or otherwise and designated for multiple use may not act as preserves for many of the community members when ORV activity is permitted. If it is prohibited, active guarding may be necessary with patrolling and/or heavy duty fencing because ORV enthusiasts often know no boundaries where sand dunes are involved, and in fact often believe they are causing no appreciable alteration of the habitat.

At the state and county level, land has been designated primarily for recreational use, which has been disastrous to natural habitats in most cases. Nearly all of the dunes in beach and county state parks have been destroyed by intensive pressure of surfers, campers and ORV during the past two decades.

The largest islands of coastal habitats that remain are primarily in federal holdings. The most effective of these is the Point Reyes National Seashore in Marin County, which has set aside the whole foredune community as a natural preserve, a shoreline distance of some 20 kilometers. The inner dunes in this area were stabilized long ago by grasses and grazing. The largest remaining inland native, stabilized dune habitats occur on military reservations, Fort Ord in Monterey County, and Vandenburg Air Force Base in Santa Barbara County. There are small preserves designated in these areas, but the proportion of disturbance due to military activity and especially unnatural grass and Iceplant stabilization is excessive. There is not much promise of large segments of remaining native habitat being preserved.

Endemic insect species, those restricted to particular portions of the California coastal dune community, occur in several major taxa. In most cases (for example, sand-dwelling Coleoptera, predaceous Diptera) each species ranges along a series of localities in the central part of the coast. There are only a few examples of quite narrow endemics, those restricted to one or two adjacent dunes (for example in Microlepidoptera, of about 120 species as many as 40 may be endemic in California, but only about 10 are narrowly endemic). Those that are reasonably well documented occur either in the San Francisco, Monterey, Santa Maria, or El Segundo dunes, originally our largest dune systems.

Owing to the north-south shift in community composition, preservation of one or a few coastal dunes would not be sufficient to preserve all elements of the fauna and flora, especially if the areas preserved are small and involve only foredunes. The largest remaining pristine areas of unstabilized and stabilized dunes are those of the Santa Maria dune system. The greatest degree of endemism in plants and insects of all California coastal strand areas occurs in this region. To protect the best examples of diversity and narrow endemics, the greatest emphasis should be directed to preservation of parcels of the formerly largest dune systems, San Francisco, Monterey, and particularly the Santa Maria dunes.

Acknowledgments

J. T. Doyen and P. A. Rude, University of California, Berkeley, made many field collections in my interest, as did P. A. Opler, Office of Endangered Species, Department of Interior, Washington, D. C., and all three helped with development of plant lists. J. L. Strother, U. C. Berkeley Herbarium, provided identifications of plants throughout this and related studies. Assistance with compilation of data and preparation of some of the maps were provided by J. T. Sorensen, while the drawing of *Areniscythris brachypteris* was made by C. Green, Department of Entomological Sciences, U. C. Berkeley. Cooperation by authorities of various coastal dune lands made available information and access to properties under their jurisdiction, including P. Churchward, manager, Dune Lakes Ltd., P. Dubsky, Land Management Office, Ft. Ord, and R. F. Dering, U. C. Natural and Water Reserves System.

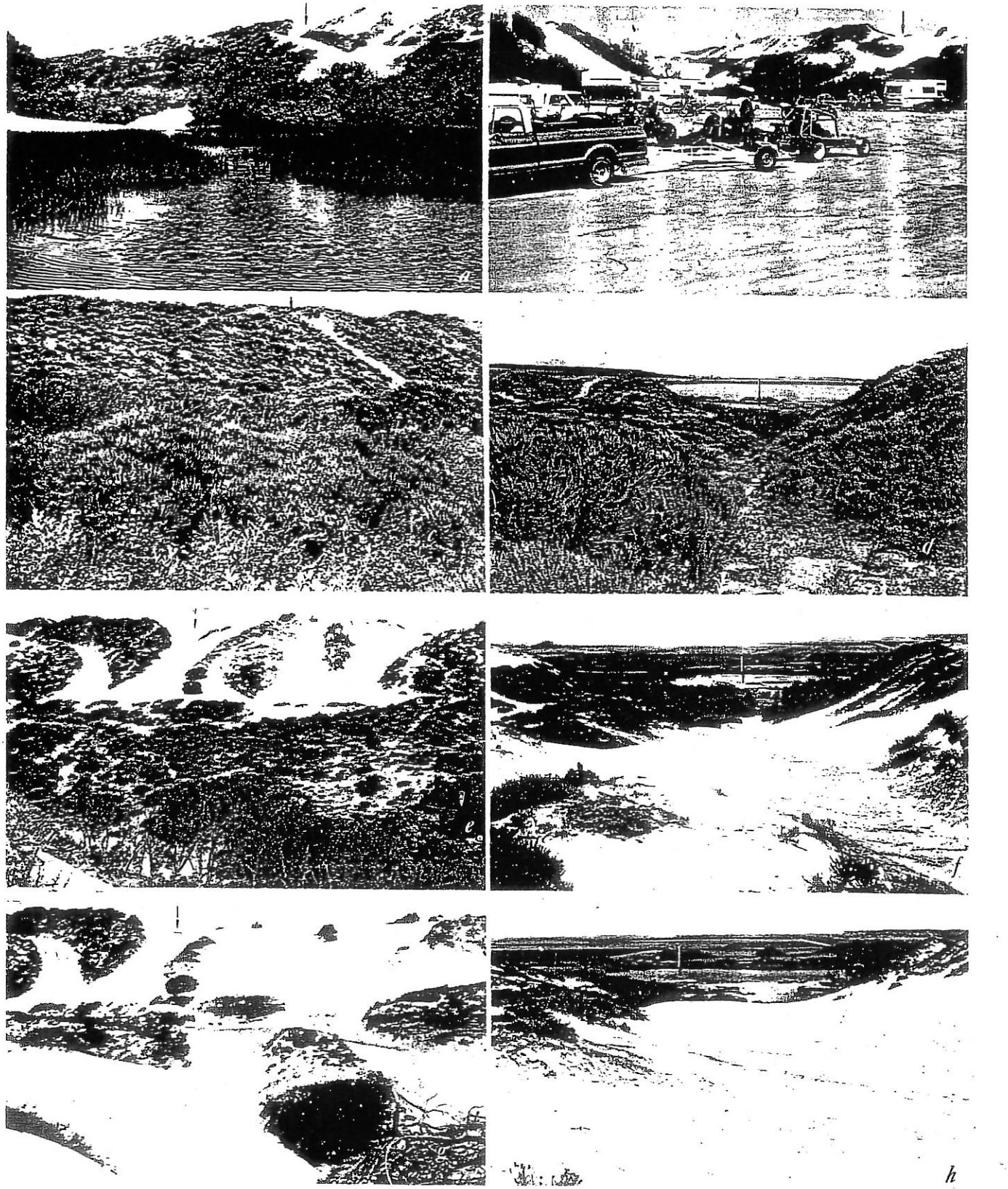

Figure 7: Dune areas adjacent to Oso Flaco Lake, San Luis Obispo County. A. looking NNW across freshwater marsh at foot of dunes, with sand encroachment already well advanced, in June, 1973. B. the same site in April, 1977 (arrows indicate primary sand road over ridge as equivalent point of reference, also pinpointed in 7C, 7E, 7G). C, D. stabilized chaparral habitat in May, 1965 (C, looking NW from ridge at left in 7A, 7B; D, looking south to Oso Flaco Lake (arrow) and the Santa Maria River Valley). E, F. the same sites, in June, 1973 and August, 1973 respectively. G, H. the same sites, in April, 1977 and October, 1977, respectively. (Arrows indicate equivalent points of reference in each series.)

Literature Cited

Breckon, G., J., & M. G. Barbour. 1974. Review of North American Pacific Coast vegetation. Madrono 22: 333-360.

Cooper, W. S. 1967. Coastal dunes of California. Geol. Soc. Amer. Memoir 104: 1-131.

Downey, J. C., & W. H. Lange, Jr. 1956. Analysis of variation in a recently extinct polymorphic lycaenid butterfly, *Glaucopsyche xerces* (Bdv.) with notes on its biology and taxonomy. Bull. So. Calif. Acad. Sci. 55: 153-170.

Farb, P., & *Life* editors. 1964. The land and wildlife of North America. Life Nature Library, Time Inc., New York. 200 pp.

Hoover, R. F. 1970. The vascular plants of San Luis Obispo County, California. U. Calif. Press, Berkeley, Los Angeles: 350 pp.

Munz, P. A. & D. D. Keck. 1959. A California Flora, with Supplement (1968). U. Calif. Press, Berkeley, Los Angeles, London. 1681 + 224 pp.

Pierce, W. D., & D. Pool. 1938. The fauna and flora of the E Segundo sand dunes. 1. General ecology of the dunes. Bull. So. Calif. Acad. Sci. 37: 93-97.

Powell, J. A. 1960. San Francisco sand dune Microlepidoptera. *In*: Proc. Pacific Coast Ent. Soc., 264th Meeting. Pan-Pacific Ent. 36: 51-52.

_____. 1964. Biological and taxonomic studies on tortricine moths, with reference to the species in California. U. Calif. Publ. Ent. 32: 1-318.

_____. 1965. Supplementary notes on North American and Mexican species of *Decodes* and *Argyrotaenia*, with descriptions of new species. Proc. Biol. Soc. Wash. 76: 65-80.

_____. 1976. A remarkable new genus of brachypterous moth from coastal sand dunes in California. Ann. Ent. Soc. Amer. 69: 325-339.

Slobodchikoff, C. N. & J. T. Doyen. 1977. Effects of *Ammophila arenaria* on sand dune arthropod communities. Ecology 58: 1171-1175.

Stebbins, G. L., & J. Major. 1965. Endemism and speciation in the California flora. Ecol. Monogr. 35: 1-35.

Table 1: California Coastal Sand Dune Microlepidoptera (all species).

LOCALITY (COUNTY)	ORIGINAL AREA (SQUARE KILOMETERS)	NO. DAYS SURVEYED	NO. OF SPECIES
Point St. George (Del Norte)	60	1	3
Samoa-Mad. River (Humboldt)	77	7	18
Mattole River (Humboldt)	1	1	3
Ten Mile River (Mendocino)	9	8	43
Bodega Head (Sonoma)	6	2	4
Dillon Beach (Marin)	8	1	5
Point Reyes (Marin)	26	13	32
San Francisco (San Francisco)	113	21	45
Monterey Bay (Monterey)	340	5	48
Point Sur (Monterey)	1	1	5
Morro Bay (San Luis Obispo)	55	6	16
Santa Maria (San Luis Obispo)	420	30	110
Goleta-Coal Oil Point (Santa Barbara)	2	6	18
Santa Cruz Island (santa Barbara)	2	1	3
Ventura River (Ventura)	2	1	3
El Segundo (Los Angeles)	181	1	8
San Clemente Island (Los Angeles)	2	2	14
Border Field (San Diego)	1	1	14

Table 2: Selected examples of insect species endemic to coastal dunes in California.

SPECIES (FAMILY)	DISTRIBUTION
ORTHOPTERA:	
Trimeritropis pogonata Strch. (Acrididae)	Santa Maria
COLEOPTERA:	
Psammodius sacalayi Cartwright (Scarabaeidae)	San Francisco to Newport
Psammodius doyeni Cartwright (Scarabaeidae)	Point Sur to Santa Maria
Diahamatha wrena (LeConte) (Scarabaeidae)	Dillon Beach to San Francisco
Diahamatha new species (Carlson) (Scarabaeidae)	Santa Maria
Coniontis escholtzii Mann. (Tenebrionidae)	Mendocino County to San Luis
Eleodes clavicornis Esch. (Tenebrionidae)	Sonoma to San Luis Obispo
Helaretrus obesus (LeConte) (Tenebrionidae)	Point Reyes to San Luis Obispo
Beaydalis rudis Linsley & Chemsak (Cerambycidae)	Santa Maria
LEPIDOPTERA:	
Glaucopsyche xerces (Boisduval) (Lycaenidae)	San Francisco
Lasionycta colorasea Riley (Noctuidae)	Point Reyes to Ventura
Eucosma hennei Clarke (Tortricidae)	El Segundo
Eucosma new species (Powell) (Tortricidae)	Monterey Bay
Grapholita edwardsiana (Kft.) (Tortricidae)	San Francisco
Argyrotaenia new species (Powell) (Tortricidae)	Morro Bay-Santa Maria
Carolella baevorana Comstock (Cochylidae)	El Segundo
Diahamaris new species (Hodges) (Gelechiidae)	Monterey to San Luis Obispo
Arenicostaris brachypteris Powell (Scythrididae)	Santa Maria
Litochariptenyx new species (Powell) (Heliodinidae)	Monterey to San Luis Obispo

Table 2 Continued.

DIPTERA:	
Brennania hera (Osten-Sacken) (Tabanidae)	Marin to San Luis Obispo & San Miguel Island
Brennania belkini (Philip) (Tabanidae)	El Segundo to Ensenada
Apatolestes actites Philip & Stef. (Tabanidae)	Mendocino County to Santa Barbara and Santa Cruz Island
Ablautus schlingeri Wilcox & Martin (Asilidae)	Santa Maria
Parathalassius melanderi Cole (Empididae)	Laguna Beach
Chersodromia cana Hal. (Empididae)	Laguna Beach
Chersodromia insignata Hal. (Empididae)	Monterey

Table 3: Native plants observed at Antioch Sand Dunes, 1976-1977. Species occurring in interior California, its Central Valley, or desert affinities are indicated by an asterisk (*).

* *Croton californicus* Nyekk.-Arg.
Eschscholzia californica Cham.
* *Erysimum capitatum* variety *angustatum* (Greene) G. Rossb.
* *Eriogonum nudum* spp. *auriculatum* (var.) Benth. S. Stokes
Gilia capitata staminea (Greene) V. Grant
* *Heliotropium curassivicum* L. variety *oculatum* (Heller) Jtn.
* *Datura meteloides* A. D. C.
* *Lupinus albifrons* Benth.
Lotus formosissimus Greene
Lotus purshianus (Benth.) Clem. & Clem.
Lotus scoparius (Nutt. in T. & G.) Ottley
Quercus agrifolia Nee.
Salix lasiolepis Benth.
* *Clarkia unguiculata* Lindl.
* *Oenothera deltoides* Torr. & Frem. variety *howelli* Munz
Heteromeles arbutifolia M. Roem.
Sambucus mexicana Presl.
* *Hemizonia kelloggii* E. L. Greene
* *Grindelia camporum* Greene
* *Gutierrezia californica* (D. D.) T. & G.
* *Heterotheca grandiflora* Nutt.
Baccharis pilularis D. C.
Ambrosia psilostachya D. C.
* *Senecio douglasii* D. C.
Bidens laevis (L.) B. S. P.
* *Lessingia glandulifera* A. Gray
* *Chrysopsis echioides* (Benth.) Gray

Taxa	Known only from Antioch	Known also similar arid places in Central Valley	Widespread	Last known collected date at Antioch
ORTHOPTERA:				
Neduba extincta Rentz, 1977	1			1937
Idiostatus middlekauffi Rentz, 1973	1			1965
NEUROPTERA:				
Hesperoleon infuscatus Adams, 1956		1		1949
COLEOPTERA:				
Anthicus antiochensis Werner, 1975	1			1953
Coelus gracilis Blasidell, 1939		1		1938
Dytiscus rotundicollis Van Dyke, 1953	1			1952
LEPIDOPTERA:				
Apodemia mormo langei Comstock, 1938	1			1977
Lithocolletis antiochella Opler, 1971			1	1977
DIPTERA:				
Efferia antiochi Wilcox, 1966		1		1959
Cophura hurdi Hull, 1960	1			1939
Metapogon hurdi Wilcox, 1964		1		1977
Myopa perplexa Camras, 1953			1	1937
Eumachronychia persolla Reinhard, 1965			1	1958
Thaumatomyia rubrivittata Sabrosky, 1943			1	1936
HYMENOPTERA:				
Leptochilus arenicolus Bohart, 1955	1			1939
Polistes dorsalis californicus Bohart, 1949			1	1959
Episyron quinquenotatus hurdi Evans, 1950			1	1977
Myrmosa pacifica Mickel, 1940	1			1952
Eucerceris ruficeps Scullen, 1948		1		1959
Philanthus nasalis Bohart, 1972	1			1959
Melissodes hurdi LaBerge, 1961		1		1958
Perdita acitula antiochensis Timberlake, 1960	1			1977
Perdita interserta ciliata Timberlake, 1958		1		1977
Perdita hirticeps luteocincta Timberlake, 1960	1			1936
Andrena (Cnemidandrena) luteihirta Donovan, 1977			1	1969
TOTALS: (25)	11	7	7	

Table 4: List of insect species originally described from Antioch, Contra County, California.

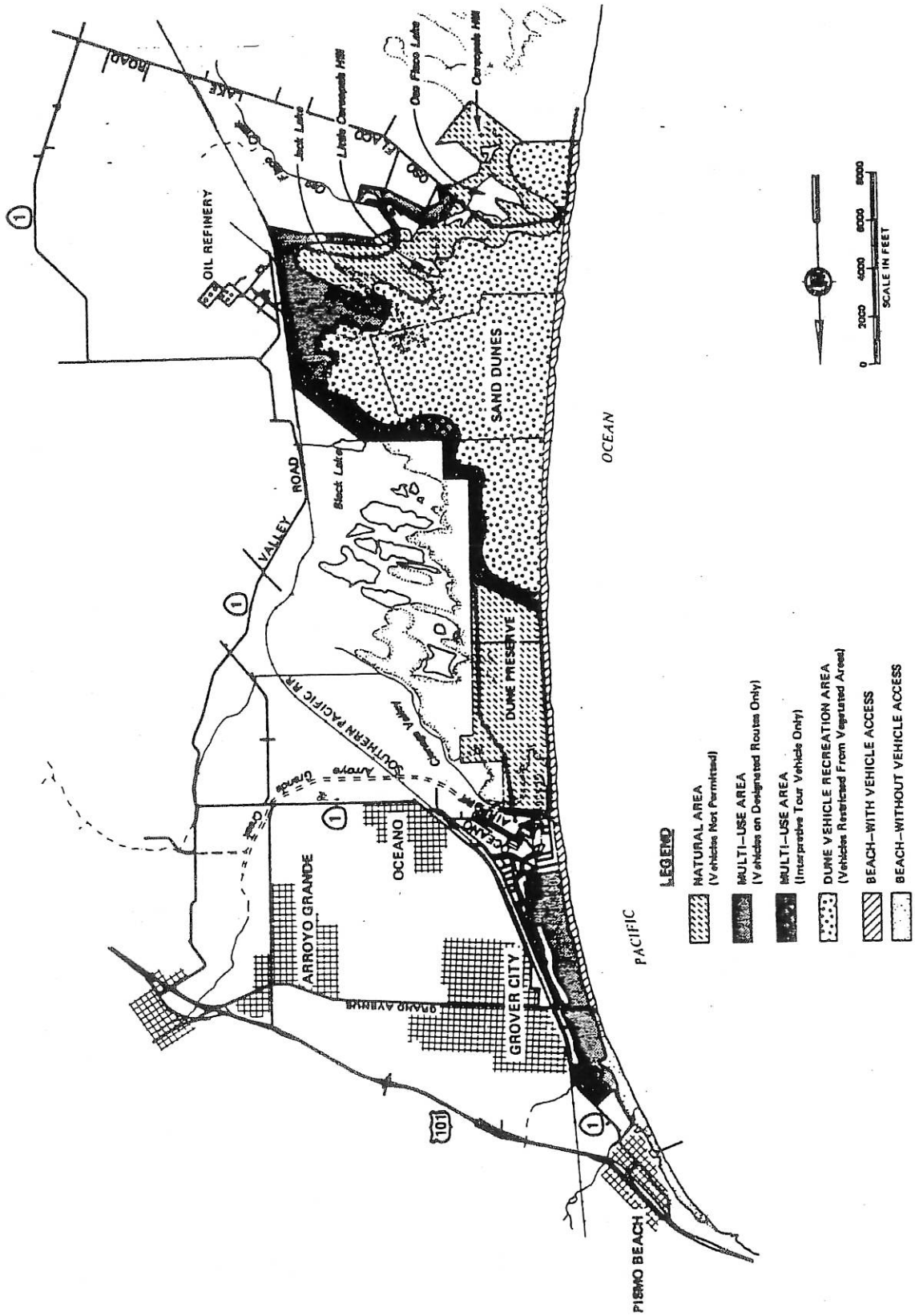

Figure 6: Map of Santa Maria dunes, San Luis Obispo County, including Pismo State Beach, Pismo Dunes State Vehicular Recreation Area, and adjacent lands (private ownership). Map prepared by the California Department of Parks and Recreation; Land use planned for legend (See Fig. 7 for effects of recreational vehicular use of land adjacent to Oso Flaco Lake, here designated as "Natural Area, vehicles not permitted").