Habitat Suitability, Restoration, and Vegetation Management at Monarch Grove Sanctuary, Pacific Grove California

Stuart B. Weiss, Ph.D.
Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305

Prepared for:
Thomas Reid Associates
560 Waverley Street, Suite 201
Palo Alto, CA 94301

July 1997

INTRODUCTION

The Monarch Grove Sanctuary (MGS) in Pacific Grove, California supports thousands of overwintering monarch butterflies in a typical year. However, the continued suitability of MGS is at risk from a number of factors. The major threat to habitat suitability at the site is changes in the forest canopy structure from both natural tree senescence and pitch canker disease in the Monterey Pines. This report reviews previous work at the site, presents the results of new studies of canopy structure and tree health, and makes recommendations for short-term and longer-term vegetation management at the site.

PRESENT SITE SUITABILITY FOR OVERWINTERING MONARCH BUTTERFLIES

The continued use of MGS by thousands of monarch butterflies indicates that at present the site often contains the essential habitat features required by monarch butterflies. Here we will review previous studies (Leong 1994), examine relevant weather data, quantify canopy structure with hemispherical photography, and make a general assessment of overall habitat suitability within MGS. The major focus is on the micrometeorological factors, and the canopy structure that regulates those factors, that determine the use of habitats by monarch butterflies.

Previous studies

Environmental Impact Report (EIR)

The original EIR for the Diveley property identifies it as a major overwintering site for monarch butterflies. The site is the only largely undeveloped parcel of forest habitat in the area, except for Washington Park (which has also supported monarch butterflies). Considerable controversy over the fate of the site is evident in the comments before, during, and after the EIR process. The property was divided into a small developed area (eastern extension) and a larger monarch reserve that was purchased by the city of Pacific Grove through a bond measure. The division of the property maintained the key habitat features and continued use of the site indicates that the suitability of the site for monarchs was not overly compromised. A detailed site map with tree locations, species, size, and other features of the site was made in 1993, and provides a key data source for future vegetation management.

Leong Report

The 1994 report by Kingston Leong provides detailed micrometeorological data on a 30 meter grid across MGS for 10 sampling dates through the 1993-94 overwintering season. The techniques closely follow those implemented at several other sites in California (Leong 1990, Leong et al. 1991). The measurements indicate that monarchs at the Sanctuary are seeking the same set of conditions that they seek elsewhere in California, with the key variables being wind speed and solar radiation/light. Monarch butterflies do not stay at sites where windspeeds exceed 2 meters/second (m/s), and seek filtered light for thermoregulation.

Monarchs clustered at heights of 25-35 ft in Monterey Pines and *Eucalyptus* in the southeast corner of the site. A Monterey Pine (tree #27 in the Leong 1994) on adjacent private property often supported the largest clusters, and was occupied 75% of the time. Monterey Pines within the row of *Eucalyptus* were also frequently used (38% of the time). Movements of butterflies were associated with changes in wind direction, as butterflies moved from the windward to the leeward sides of the trees. When the wind is from the northwest, monarch butterflies tend to cluster on trees south of the row of *Eucalyptus*, off the Sanctuary property. When the wind is from southerly directions, the butterflies cluster north of the row of *Eucalyptus*.

Leong is optimistic about the potential for habitat restoration at the site, because of its long-term use by monarchs (since the late 1800's), occupancy through most of the winter months in most years, and high ambient moisture. He presents a habitat restoration design that includes a mix of open and forested areas that provides wind shelter and access to moisture and mating sites. That restoration design provides a firm conceptual basis for enhancing MGS as monarch habitat, and is incorporated into proposed restoration plans.

Weather station data

A weather station was installed at the site in spring 1995, on the north side of the row of *Eucalyptus* at an height of approximately 35 ft. The location of the station is in the middle of the typical monarch aggregation area. Weather measurements taken include temperature, relative humidity, solar radiation, wind speed, and wind azimuth. A whole overwintering season was recorded from October 1995 to March 1996, and data collected provides information on temporal variability of temperature and wind.

Temperature and relative humidity

The location of MGS close to the ocean minimizes the danger of freezing temperatures that are deadly to monarch butterflies. The weather station data collected from November 1995 through February 1996 provide quantitative evidence of the mild winter climate at the site (Fig. 1a). Air temperatures never dropped below 40° F during that time period. The winter of 1995-96 was particularly warm in Central California, and does not represent the full range of winter cold. Occasional outbreaks of arctic air reach Pacific Grove -- the "50 year" freeze in December 1990 brought temperatures in the 20's for several days. This extreme weather event caused substantial (30-40%) mortality of monarchs at Ardenwood Regional Park (on the east shore of San Francisco Bay), and caused severe damage to *Eucalyptus* trees. Coastal sites in southern California, where temperatures were more mild, did not suffer high mortality nor extensive damage to *Eucalyptus*.. However, little can be done to specifically ameliorate such rare freeze events.

The relative humidity was generally high, but there were several periods when humidity dropped below 50% (Fig. 1b). However, these are very mild conditions relative to other monarch sites in southern California, where humidity levels can drop below 30% during Santa Ana winds in the autumn.

Minimum temperatures likely vary through the site and tree canopy. High canopy cover can reduce radiative heat losses at night, and cluster sites higher in the canopy can avoid colder temperatures close to ground level. The site slopes away from the main cluster area, and cold air will tend to drain away downslope. The open area below Brokaw Hall may accumulate colder air. Given the mild macroclimate of Pacific Grove, these temperature variations may take on significance only at night during unusual freeze events.

Wind

The record of maximal hourly wind speeds from November 1995 to February 1996 shows that the weather station site could be exposed to substantial winds during the winter (Fig. 1c). High winds (> 5 m/s) were observed intermittently through the winter, usually, but not always associated with strong winter storms. This period included an extreme windstorm from December 11-12, 1995. The strong southerly storm winds penetrated into the grove and wind speeds at the weather station exceeded 10 m/s

The combination of wind direction and speed is especially important in determining habitat quality. The strongest winds (>10 m/s) come from southerly directions, but strong northwest winds are common (Fig. 2a). Maximum hourly winds exceeded 2 m/s about 25% of the time (Fig. 2b). Of the times when winds exceeded 2 m/s, the most common wind direction was northwest (50% of the time), followed by southwest (20%) and south (10%) (Fig. 2c).

Monarchs do not stay in a site when maximum wind speeds exceed about 2 m/s near the ground (Leong 1990, 1994, Leong et al. 1991, Frey et al. 1992). The monarchs abandoned this site following the December 1995 windstorm; however, other monarch aggregations in northern California (i.e. Ardenwood) were also abandoned following that event. Mitigating the effects of wind is a major component of forest canopy assessment and habitat restoration plans.

Solar Radiation

The solar radiation measurements showed anomalous behavior that suggests that the sensor was obstructed by fallen material, so the data have not been used.

Summary

MGS has a mild maritime climate during the winter, with freezing temperatures rare and high relative humidity the norm. Winds can be very strong from southerly and northwesterly directions during and following storms. Wind exposure appear to a primary micrometeorological factor reducing habitat suitability at MGS.

Forest Canopy Structure

The forest canopy structure at a monarch overwintering site is the prime determinant of its suitability. The canopy regulate the microclimate within a forested site; it reduces nighttime heat losses, provides a mixture of shade and sunlight, and provides wind protection. Importantly, the branches and trunks of the trees provide cluster locations at varying heights in the canopy. The ability of a forest to provide all of the factors required by monarchs goes far beyond the immediate cluster trees - nearby trees contribute to local canopy cover and wind protection, and trees that are 100 or more meters away can provide important wind breaks. Vertical foliage profiles are also important for windbreak purposes -- a dense canopy with little or no middlestory and understory provides poor protection from wind within the canopy.

The exact tree species present are of lesser importance than the structure. *Eucalyptus globulus* forests are the favored sites in California, because of their widespread distribution along the coast, dense foliage, and provision of wintertime nectar. The rapid growth response to available light means that along forest edges, foliage can be nearly continuous from ground-level to canopy top. Such a structure tends to seal the edges of forest groves against wind. While *Eucalyptus* can often grow extremely dense in the middle of groves, it tends to form heterogeneous canopies that provide a variety of light conditions for monarch butterflies.

Sites in Monterey Pine forests (i.e. Washington Park and Cambria) have supported monarchs in past years. Monterey Pines, however, lose low foliage and branches as the trees grow, leaving open understory. Lower growing Coast Live Oaks (*Quercus agrifolia*) at Washington Park provide dense understory and middlestory. Clustering monarchs are also sometimes found in riparian forests (near Santa Barbara and Malibu) in deep canyons that provide the right microclimatic regime.

In this section, the current forest canopy structure at MGS is assessed using a map of the existing trees, recent aerial photography, and hemispherical photography. All three approaches provide important information, and features identified on one map/photograph can be identified on the other two data sources.

Tree map

A map of trees on and adjacent to MGS was created in 1993 as part of the planning process (Fig. 3). That map was updated by Thomas Reid Associates in February 1997, as many trees had been removed, and others planted in the interim. The map shows the position, species, and identification number of each tree on MGS. The identification numbers on each tree are keyed to the table that contains DBH, health assessment, and notes about each tree (Table 1). In this section, discussion will focus on current forest structure as it relates to monarch habitat suitability-- the assessment of tree health and management guidelines are presented in a separate report (Tree Assessment by Steven Scott).

The most important feature of the forest structure on MGS is the "L"-shaped grove of *Eucalyptus globulus* on the south and far eastern boundary of the site. These trees provide the densest forest canopy, the best wind protection, and it is not surprising that the vast majority of monarch butterfly clusters are found on and near these trees. Several Monterey Pines are interspersed in the *Eucalyptus*. Foliage is relatively dense at all heights, and the trees appear to act as an effective wind barrier to the south.

The large number of Monterey Pines north of the kiosk and viewing area are a mix of young trees and declining older trees. The canopy is quite open, with no significant understory at present. Several Monterey Cypress, as well as one *Eucalyptus*, are present in the stand just east of the MGS boundary. These trees, although they are not in the MGS property, are an important component of the monarch habitat.

Toward the north, a number of large Monterey Cypress are interspersed with large Monterey Pines. These trees screen MGS from the north. There are few trees where an old roadbed parallels the north boundary.

More Monterey Pines form the western boundary, interspersed with some *Acacias*. The *Acacias* are relatively low growing. Because the ground slopes towards the west, these trees do not substantially contribute to wind shelter at the cluster sites higher on the slope.

Aerial photography

Aerial photography flown in 1996 was obtained from the City of Pacific Grove (Fig. 4). The black and white image provides information on areas surrounding MGS proper. Because wind conditions within MGS are affected by forest structure in surrounding areas, some consideration of the wider area is necessary, The unique position of MGS as an undeveloped and largely forested area within the larger matrix of suburban development is clear (Fig. 4). The *Eucalyptus* row forms the densest canopy, and the canopy extends south of the Sanctuary boundary. The canopy north of the cluster sites is more broken, but the canopy appears more dense toward the northern boundary of MGS. Large open areas are seen west of Brokaw Hall, with a narrow band of trees running along Grove Acre Ave.

Hemispherical Photography

The methods of hemispherical photography are presented in detail in the "Methods in Weiss et al. 1991 (Appendix A). In short, several "Site Factors" are calculated by digital analysis of the photographs. The digital analysis first identifies areas of open sky versus obstructions. "Indirect Site Factor" (ISF) is the overall proportion of sky seen from the photograph point, and is an integrated measurement of overall canopy openness. "Direct Site Factor" (DSF) is the openness along all sunpaths through the year, and measures direct light penetration through the canopy.

"Wind Site Factor" (WSF) is a new measure that estimates canopy cover in the horizontal directions. WSF is calculated for eight directions in 45° azimuth segments centered on N, NW, W, SW, S, SE, E, and NE, and measures canopy openness at elevation angles up to 30° -- the majority of wind penetration is at lower elevation angles parallel to the ground. The calculation of WSF also uses a correction for the sin of the elevation angle - lower angles (i.e. closer to the ground) are weighted more than higher elevation angles. Absolute WSF values are lower than ISF and DSF, because they represent only a small portion of the hemisphere -- maximum WSF values as calculated here are around 0.04. This value would represent a completely open sky from ground-level up to 30° elevation angle in a 45° azimuth interval. As seen below, WSF values of greater than 0.015 represent relatively open conditions in that wind direction.

In early February 1997, 26 hemispherical photographs were taken across MGS in a configuration that captured the major features of canopy structure (Fig. 5). Areas of high and low canopy cover were specifically selected, and important places such as monarch cluster sites, the south boundary, and the weather station site were included. The selection of sites allows for interpolation of Site Factors across MGS for mapping purposes.

Sample Photographs

Sample hemispherical photographs show the important features of the forest canopy at MGS (Fig. 6, twelve photographs are presented by photo number keyed to Figure 5). Because the photographs are taken looking up, east and west are reversed. Also, although these scanned photographs show a grey scale, in the digital analysis all trees and obstructions are turned black, and only the white areas represent open sky. The calculated ISF, DSF, and eight WSF's for all photos are presented in Table 2, and the 14 photos discussed in some detail below are highlighted by asterisks.

Figures 6.2 and 6.3 (the suffixes refer to the photograph number on Fig. 5) show canopy conditions just north and south of the *Eucalyptus* row along the south boundary of MGS. In photo 6.2, the row of *Eucalyptus* is seen along the south side of the image, with a narrow gap just east of south. To the north, the stand of declining Monterey Pines with bare trunks and sparse canopies are clearly seen. ISF is 0.20, indicating a moderately closed canopy, and DSF is 0.05, indicating that most direct light from the south is blocked by the trees. The northwest octant is quite open, and WSF_{NW} is very high (0.033). In contrast, WSF_{SW} is low (0.000), indicating complete blockage of the wind from that direction.

In Photo 6.3, the row of *Eucalyptus* is to the north. The Monterey Pine that often has supported monarch clusters off MGS (Leong tree #27) is seen just west of south has lower ISF (0.13), indicating a more closed canopy, but higher DSF (0.23) indicating less obstruction of the sunpaths. WSF_{nw} is low (0.004), but WSF_S is moderate (0.015) indicating that the site is somewhat exposed to south winds. The fact that these two photos were taken just 3 meters apart highlights the high degree of spatial heterogeneity in site factors at MGS.

Photo 6.5 was taken directly below the automated weather station. ISF is moderately low (0.17) and DSF is low (0.06). As in Photo 6.2, the site is open to the northwest (WSF_{NW} is 0.27), explaining the high proportion of winds > 2.0 m/s from that direction. WSF from southerly directions is low (0.002, 0.003, 0.002 for SE, S, and SW, respectively), explaining the relative shelter of the weather station from southerly winds. However, when southerly storm winds are high (the December 1995 storm had hurricane force wind gusts outside forests), the position of the weather station high in the canopy leads to relatively high wind speeds (> 10 m/s) in the canopy (substantially lower than winds outside the forest, but still high enough to be unsuitable for monarchs).

Photo 6.7 was taken west of Photo 6.5, on the south side of the *Eucalyptus* row. ISF is moderately low (0.15), but DSF is relatively high (0.24). WSF_{NW} is low (0.006), but WSF_s and WSF_{SW} are relatively high (0.015 and 0.011, respectively). This photo highlights the importance of off-site trees -- the prominent stand of trees just west of south plays an important role in attenuating southerly winds. These trees can be made out on the aerial photograph (Fig. 4). The trees lower on the horizon also play a role in attenuating the wind. The major cluster tree (Leong #27) is seen in the due east position in this photo.

Photo 6.16 was taken at the information kiosk area. The south and east rows of *Eucalyptus* are clearly seen. To the north and northwest is the open Monterey Pine canopy. ISF and DSF are relatively high (0.31 and 0.25, respectively). This site is highly exposed to northwest winds (WSF_{NW} = 0.037), but well protected from southeast, south, and southwest winds (WSF_{SE} = 0.003, WSF_S = 0.004, WSF_{SW} = 0.002). The entrance trail through the trees can be seen in the northeast quadrant of the photograph.

Photo 6.1 was taken at the southeast corner of MGS, just at the junction of the "L" -shaped *Eucalyptus* stand. ISF and DSF are low (0.13 and 0.06, respectively). The site is well protected from southerly winds (WSF_{SE} = 0.000, WSF_S = 0.000, WSF_{SW} = 0.005), but is very exposed to northwest winds (WSF_{NW} = 0.028). Some trees off the property can be seen between the large *Eucalyptus* trunks towards the southeast. Monarch butterflies have been observed on these offsite trees.

Photo 6.17 was taken along the eastern boundary of MGS. The canopy is dominated by senescent and declining Monterey Pines (the tree due west is dead). The row of *Eucalyptus* is clearly seen along the southern horizon. ISF and DSF are high (0.34 and 0.37, respectively). WSF_{NW} and WSF_W are high (0.027 and 0.030, respectively), while WSF is low from the south winds (WSF_{SE} = 0.009, WSF_S = 0.005, WSF_{SW} = 0.006). A large Monterey cypress (the flattened canopy to the northeast) provides wind break from the northeast (WSF_{NE} is 0.005, but WSF_E is higher at 0.012), and trees to the north provide shelter from northerly winds (WSF_N is 0.006, similar to WSF from the southerly directions. The trees east of the photo site are on adjacent property.

Photo 6.9 was taken at the SE corner of Brokaw Hall. The building can be seen in the northwest quadrant of the photo (note the chimney). There is little canopy (ISF and DSF are 0.42 and 0.47 respectively) The *Eucalyptus* row is seen in the southeast quadrant, but there is a prominent gap just west of south. A number of *Eucalyptus globulus 'compacta'* have been planted in this gap (Fig. 3).

Photo 6.19 was taken toward the northeast corner of MGS. The typical form of mature and declining Monterey Pines, with no lower branches and spreading upper branches with foliage, dominate the canopy. The lack of understory and middlestory in the forest is particularly apparent in this photo. The *Eucalyptus* row can barely be seen on the south horizon. ISF and DSF are high (0.31 and 0.33, respectively). WSF is moderate to high from the critical wind directions (WSF_S = 0.009, WSF_{SW} = 0.017, WSF_{NW} = 0.031).

Photo 6.11 was taken north of Brokaw Hall at the edge of the northern stand of trees. Late-season monarchs were clustering directly above this photograph in February 1997. ISF is moderately high (0.26), and DSF is high (0.47). This site is highly exposed to morning sun (note the lack of obstruction in the southeast sky), which may explain the presence of monarchs here late in the season when morning flight for mating is especially important.

Photo 6.24 was taken near the southwestern corner of MGS. The *Eucalyptus* row is seen toward the east, and the clump of *Eucalyptus* and Monterey Pine in the far southwest corner are clearly seen. The trees low on the southern horizon are on adjacent property, and provide what little wind shelter exists from due south (WSF_S = 0.016). ISF and DSF are high (0.30 and 0.30, respectively).

Photo 6.14 is taken in the northwest corner of MGS, in a relatively dense stand of Monterey Pines. Several Live Oaks off site can be seen in the southwest direction, and the dense stand of trees along the northern boundary can be seen to the east. ISF and DSF are moderately high (0.24 and 0.27), and the site is moderately exposed to southwest winds (WSF_{SW} = 0.01) and highly exposed to west winds (WSF_W = 0.022).

Photo 6.20 was taken near the northeastern corner of MGS. The Monterey Pine canopy is clearly seen to the south. Trees rapidly thin towards the north (see also Fig. 3 map). ISF and DSF are relatively high (0.29 and 0.31, respectively). The trees to the east are on adjacent property. While this site is well protected from northwest winds (WSF_{NW} = 0.003) it is relatively exposed to southwest winds (WSF_{sw} = 0.018).

Photo 6.13 was taken in the densest part of the forest along the northern boundary of MGS. ISF and DSF are relatively low (0.13 and 0.18, respectively). This site is well protected from northwest winds (WSF_{NW} = 0.002) and from southwest and south winds (WSF_{SW} = 0.002, WSF_S = 0.006). This site is the only area besides the *Eucalyptus* row that provides a proper mix of site factors, but it may be too far from other suitable sites in MGS to attract butterflies.

Site Factors across MGS

Maps of the various site factors (ISF, DSF, and eight WSF) across MGS provide an overall view of canopy structure, and highlight the opportunities and problems for monarch butterflies that overwinter here. It is important to note that the computerized method of drawing contours may create artifacts well away from sample points, but the critical areas have been well sampled and these artifacts do not apply there.

Indirect Site Factor (ISF) within the Sanctuary varies from 0.13 under the *Eucalyptus* on the south boundary, to 0.47 in the large clearing west of Brokaw Hall (Fig. 7a). The lowest ISF values are the eastern half of the south boundary and along the north boundary. The cluster area has ISF values between 0.13 and 0.21; these values fall in the narrow range that was observed at other sites in California (0.10 to 0.25, Weiss et al. 1991, Weiss and Murphy 1993). The only areas that fall within the highly suitable range of ISF (0.10 to 0.20) are the cluster site and the center of the north boundary. Most of the site is too open for monarchs.

Direct Site Factor within the Sanctuary vary from 0.05 just north of the southern row of *Eucalyptus* to 0.73 in the clearing (Fig. 7b). DSF within the cluster areas ranges from 0.24 south of the row of *Eucalyptus*, to 0.05 just north of the *Eucalyptus*. These values fall within those observed at other sites in California (0.05-0.3, Weiss et al. 1991). Because DSF varies substantially with height, ground level measurements do not accurately reflect conditions at canopy heights where monarchs cluster.

WSF varies across the site by wind direction (Fig. 8). A relatively high WSF (> 0.02) indicates much open sky up to 30° elevation, and relatively low WSF (< 0.01) indicates little open sky up to 30° elevation. For example, WSF_{NW} is highest in the southeast corner of the sanctuary (maximum 0.037) , and WSF_{SW} is highest north of Brokaw Hall (0.26). WSF across the site is highest during northwest and west winds, and lowest during southeast and northeast winds, so that the site is relatively well protected from south and southeast winds, but is highly exposed to northwest and west winds.

Parts of the cluster site have high WSF_{NW} Within the cluster site, WSF_{NW} changes dramatically from the north side of the *Eucalyptus* row (0.025 to 0.032) to the south side (0.005 and 0.006). Conversely, WSF_S is 0.015 on the south side of the Eucalyptus, but is 0.004 to 0.012 on the north side of the row. The cluster area appears to be well protected against

Summary of conditions in the cluster area

The cluster area is one of only two areas within MGS that has enough sufficient canopy cover for monarch butterflies. The spreading canopies of the large *Eucalyptus* create a narrow band 15-30 meters wide along the southern boundary that has ISF and DSF within the ranges observed at other monarch butterfly sites in California. The small area of relatively dense canopy north of Brokaw Hall rarely supports clustering monarchs, although several clusters were observed along the southern edge of this stand in February 1995, after most butterflies had already left MGS.

The major problem at the cluster site is highly exposure to northwest winds. Kingston Leong's studies have repeatedly demonstrated that butterflies move within a site, or leave it completely in response to wind speeds greater than 2 m/s. Monarch Grove Sanctuary is no exception. During northwest winds, the butterflies move from the exposed north side of the *Eucalyptus* to the more sheltered south side, often in a Monterey Pine that is off the MGS property. Because the prevailing winds during sunny conditions are northwesterly, and these winds can be quite strong and continuous, for much of the time conditions are not suitable except south of the *Eucalyptus*. Conversely, during southerly winds preceding and during winter storms, butterflies may move to the north of the *Eucalyptus*.

Summary of Habitat Suitability at Monarch Grove Sanctuary

1) MGS does contain areas that meet the requirements of monarch butterflies through many, if not most overwintering seasons, as evidenced by their continued occupancy of the site.

2) The cluster sites often have micrometeorological parameters that fall within the ranges preferred by monarchs at other sites in California. The key parameters appear to be solar radiation/light and wind. Locations within MGS where monarchs do not cluster have those conditions less often (Leong 1994).

3) These cluster sites have the densest canopy cover on MGS, and have ISF and DSF values that fall within the range observed at other heavily used sites in California. Most of MGS currently has too little canopy cover for monarchs.

4) Wind exposure from the northwest is high on the north-side of the row of *Eucalyptus*. Because northwest winds are common and often strong, it is not surprising that butterflies often cluster on trees just south of the MGS border, on private property.

RESTORATION PLAN

Specific Site Enhancements

The proposed tree planting scheme presented in the Leong report contains the general elements of needed habitat enhancements. A combination of dense tree stands and windbreaks in appropriate areas, combined with more open areas will provide roosting sites, wind protection, and proper light conditions for the monarchs. The major conceptual plan is to create an open area around the current viewing area surrounded by dense tree stands that act as windbreaks and provide canopy cover. An open area on the west end of the site will provide areas for mating and collection of dew water by the butterflies.

By creating sufficient wind shelter from northwest winds within MGS, it is hoped that the majority of butterflies will cluster within the site rather than on adjoining properties.

Short-term plantings

The most important site-enhancement is the creation of a windbreak of trees running from the south border to the abandoned house, and from there to the eastern property line. The ideal structure of this windbreak includes tall trees, and sufficient middle story and understory to create a complete barrier to the wind. Because the windbreak will be on the north side of the monarch aggregation area, light penetration is not an issue and the foliage can be very thick and dense.

The tree species discussed below have been considered for planting, and each has its advantages and disadvantages.

Monterey Pine (*Pinus radiata*)

Monterey Pine is the primary native forest tree on the Monterey Peninsula. For many reasons, it would be the preferred species for restoration. Monarchs continue to use pines as clustering sites at MGS. Few monarch overwintering sites in Monterey Pine Forests remain, and it would be desirable to maintain a substantial proportion of pines at MGS. The tree is well adapted to the climatic conditions in Pacific Grove, and could be expected to grow well under normal weather conditions. When young (<20 years) and into middle age (20-50 years), the trees provide foliage at many heights. When trees mature, however, lower branches are lost and the understory and middlestory open up. The lifespan of Monterey Pines is about 100 years -- many of the trees on the site are approaching that age and are in obvious decline (see Scott report).

The major factor that prevents widespread use of Monterey Pines at MGS is the pitch canker fungus, which has been positively identified on the site (see Scott Report). Since mortality rates from pitch canker are expected to be on the order of

85%, it is impossible to plan an adequate forest structure using Monterey Pines at present. Widespread use of Monterey Pine at MGS will have to wait for a pitch canker resistant strain to be developed. Monterey Pines are also highly flammable, and native forest appear to require fire for successful stand replacement.

Blue gum (*Eucalyptus globulus*)

Eucalyptus globulus is the most commonly used tree in monarch overwintering aggregations in California. Its tall stature, rapid growth, plastic response to light conditions, potentially dense foliage at all heights, and wintertime flowering habit all make for high quality monarch habitat. The canopy structure lets in appropriate amounts of filtered light, provided that the trees are not too densely planted. At MGS, a single row of *Eucalyptus globulus* provides substantial wind shelter, and butterflies often cluster on the pendulous branches and foliage.

The major disadvantage of *Eucalyptus* is that it is not a native tree and has a reputation as an invader into native habitats. In dense stands, it crowds out native plants and can poison the soil for other species when downed branches and foliage are allowed to accumulate. Downed material can also be a major fire hazard, and trees can develop unbalanced branches that can drop at any time and are a major hazard to people and structures. The species is susceptible to the Eucalyptus long-horned borer, and sites elsewhere in California have been severely impacted. However, *Eucalyptus globulus* at MGS does not appear to be threatened by the borer at this time (see Scott Tree Assesment report).

Additional plantings of *Eucalyptus globulus* is recommended at MGS only with reluctance, with an attempt to minimize its use to a single row to create a northwest wind barrier, and for eventual replacement of the row of *Eucalyptus* along the southern boundary (see below). However, widespread use of *Eucalyptus globulus* would be the fastest and surest way to enhance the quality of the site for monarch butterflies, so a *Eucalyptus* oriented plan is also presented as an option.

A variety of *Eucalyptus globulus* (var. *'compacta'*) has been planted in several locations. The only potential use of *'compacta'* is where a dense screen less than 50 ft. tall is desired -- the variety does not let in enough light, nor provide a good branch structure for monarch clusters. The existing plantings are in spots appropriate for this purpose, so no removals are recommended.

Other *Eucalyptus* species may be considered (i.e. a *Eucalyptus filicifolia* has been planted near Brokaw Hall), but *Eucalyptus globulus* has so many known advantages for monarchs that these other species do not appear to have any particular advantage at MGS.

Specific vegetation management guidelines for *Eucalyptus* are presented in the Scott Tree Assessment report.

Monterey Cypress (*Cupressus macrocarpa*)

The third major canopy tree at MGS is Monterey Cypress. The species is native to two small groves, but has been widely planted on the Monterey Peninsula. Monterey Cypress can form a large spreading canopy, but, like Monterey Pine, loses branches and foliage in the understory and middlestory as trees reaches middle age. Monarchs will form clusters in Monterey Cypress at MGS and elsewhere in California.

The disadvantage of Monterey Cypress is that is it relatively slow growing, and will not reach sufficient heights for wind screen purposes as fast as *Eucalyptus globulus*. However, it can be incorporated into the wind screen as an adjunct to *Eucalyptus*, and may be planted within the wind-sheltered area in lieu of Monterey Pine to provide some canopy cover. The tree is also brittle when it gets older, so hazard management is necessary for mature trees.

Coast Live Oak (*Quercus agrifolia*)

Coast Live Oaks are a common element in Monterey Pine forests, and can provide dense understory foliage when the pines lose lower branches. They do not generally grow large enough to provide sufficient high canopy-level wind protection. Live Oaks do not generally serve as cluster trees (but may be used as in Washington Park), and their role is primarily limited to understory and middlestory foliage.

Coast Redwood (*Sequoia sempervirens*)

Coast Redwood was considered as a wind screen tree, because it is capable of rapid growth and provides dense foliage. However, the species does not do well when directly exposed to winds off the ocean, and MGS is not a suitable site for this species.

Douglas Fir (*Pseudotsuga menzesii*)

Several Douglas Fir trees are growing on Ridge Road, just south of the entrance to MGS. These trees appear healthy and have dense crowns, and would form an effective wind block. Unlike Coast Redwood, Douglas Fir does grow in sites exposed to winds directly off the ocean. However, Douglas Fir is susceptible to pitch canker, but experimental plantings may be appropriate within MGS.

California Bay Laurel (*Ubellularia californica)*

Bay laurels can provide dense screens against wind, but are relatively slow growing and are sensitive to salty winds off the ocean (Bay laurel plantings show considerable wind burn at the MGS). No monarchs cluster sites are known from Bay laurel forests.

Planting schemes

Three planting schemes are considered. Each has similarities in that the overall structure will be the same, but the chosen tree species differ. *It is important to note that these three plans are points along a continuum, and elements of each can be chosen to meet restoration goals.*

These plans are described below as:

Plan 1) Moderate *Eucalyptus* plan

Plan 2) Full *Eucalyptus* plan

Plan 3) Minimized *Eucalyptus* plan

All three plans include replacement *Eucalyptus globulus* trees for the southern *Eucalyptus* row

Most of the discussion below will focus on the need to maintain and enhance appropriate wind shelter and canopy cover at the existing cluster sites in the *Eucalyptus* row. The open area west of Brokaw Hall will be maintained as suggested in the Leong (1994) report for nectaring, watering, and mating. Existing plantings will not be disturbed unless specifically noted.

Eucalyptus Row replacement (All Plans)

The eucalyptus along the southern and eastern borders of the site are approximately 80 years old, and have several decades of useful life remaining in the absence of catastrophic fire or windfall. These trees will eventually need to be replaced with a new stand in the same location, so new plantings of *Eucalyptus globulus* will be necessary within a decade. New trees planted about 15 ft. north of the existing trees will begin the replacement process, and as individual older trees are thinned or removed, the increased light will stimulate growth of the replacement trees.

Plan 1: Moderate Eucalyptus plan (Figure 9)

The first planting scheme -- the "minimized Eucalyptus plan" -- attempts to balance the needs of the monarchs with a desire to minimize the amount of *Eucalyptus* planted, and maintain options into the future with regard to Monterey Pine plantings. The drawback of this plan is that the windscreen is farther from the cluster site than is optimal for rapid establishment of effective wind protection. This plan also crosses the "*Eucalyptus* Line" along the sewer easement, but is designed to minimize

The structure of the windbreak in this plan is as follows. First, on the outside (north and west sides) a row of *Eucalyptus globulus* will be planted densely enough (about 15' apart) so that the foliage will be continuous when the trees mature. *Eucalyptus globulus* is suggested because it is the fastest growing tree species available, and will provide wind protection relatively quickly. In front of the eucalyptus by about 20', a row of Monterey cypress will fill the gaps between the *Eucalyptus* trunks. The trees in the windbreak will be planted at a relatively high density for two reasons: first, so that trees will grow vertically at the maximal rate; and second, so that some trees may be thinned and others planted to provide a mixed age structure.

This plan reserves a 40' wide zone in front of the Monterey Cypresses for plantings of pitch canker resistant Monterey pine if and when they become available. The many recent plantings of Monterey Pine in this zone will not be disturbed unless the trees exhibit signs of pitch canker, in the hope that at least some individuals will prove resistant to the fungus. A scattering of Monterey Cypress about 50' apart is suggested for the area within the ring of *Eucalyptus*, to eventually provide increased canopy cover.

The planted trees should be of the largest possible size (15 gallon is most desirable, but 5 gallon may be necessary from a cost/availability viewpoint), so that they can put on substantial height growth in a relatively short time period. Watering and fertilization during the first two years would help speed establishment and growth (see Scott report for tree planting guidelines). This recommendation applies to all planting schemes.

Plan 2: Full Eucalyptus Plan (Figure 10)

This plan is focused on rapidly establishing wind protection and canopy cover using *Eucalyptus globulus* and assumes that pitch canker resistant Monterey Pine will not be available in the foreseeable future. The windbreak will be closer to the cluster sites, in the area currently planted with Monterey Pine just north of the main path. *Eucalyptus* will be planted at the same 15 ft intervals as in the shelterbelt in the minimized *Eucalyptus* plan. The open area within the site is planted with individual *Eucalyptus* spaced about 50 ft. apart.

Plan 3: Minimized Eucalyptus plan (Figure 11)

In this plan, the area from the shelterbelt to the path will continue to be planted densely with Monterey Pines in the hope that enough pitch canker resistant trees will become established to create effective wind shelter. As trees grow and start to lose lower branches, the understory should be planted with Live Oaks for wind protection at low levels. Monterey Cypress will form the outer edge of the windbreak, in approximately the same position as in Plan 1, and more cypress could be mixed in with the pines as insurance.

This plan is risky for monarchs, because there is no guarantee that Monterey Pines and Cypresses will grow rapidly enough to provide adequate wind shelter. Repeated plantings will be necessary as attrition of pine seedlings is expected to be quite high. A variety of local stock should be used so that the chance of canker resistance is maximized.

Away from the cluster sites

In areas away from the cluster sites -- the areas north of the proposed shelterbelt and in the northwest portion of MGS, it is suggested that replacement trees be planted near older trees so that the current species composition is maintained largely as a Monterey Pine forest. Because these areas are not presently as critical for monarchs as the cluster sites, failure of Monterey Pines from pitch canker is not as pressing, and by planting numerous trees, at least some may survive to form a canopy. These areas also provide the wildlife benefits of a largely native forest.

Eucalyptus Row trimming

As mentioned in the Scott report, several *Eucalyptus* branches along the main row of trees appear to be at risk of failure. Critical immediate hazards obviously need to be removed, but indiscriminate large scale trimming and removal of these trees will result in a loss of habitat suitability for monarchs. It is fortunate that *Eucalyptus globulus* can rapidly form new shoots and branches, so negative impacts of careful trimming may be mitigated after a few years.

Conformity with previous plans for MGS

These plans may conflict with previous plans for the site; for example the "nectar garden" site is in the path of the proposed windbreak. Given the overriding importance of providing wind shelter for the cluster sites, the "nectar garden" should be relocated into open areas west of the windbreak. The existing plants in the "nectar garden" will survive for many years until the canopy of the windbreak closes; in any case, provision of additional nectar besides that provided by winter-flowering *Eucalyptus* is a minor component of habitat suitability at the site.

Medium term plantings

A second wave of plantings should be considered in 10-20 years -- it is important to avoid even-aged stands of trees over the long-term, so additional eucalyptus and Monterey cypress may be added in appropriate areas of the windbreak and elsewhere on the site. We do not recommend planting *Eucalyptus* outside of the existing *Eucalyptus* area and the proposed windbreak area. Understory oaks may be added in the windbreak areas as the lower branches of the cypresses and eucalyptus open up.

Outside the MGS `boundaries

Monarch Grove Sanctuary does not exist in a vacuum. Maintenance of forest cover surrounding MGS is an important factor in allowing for MGS to continue to function as monarch habitat. Tall trees within a few hundred yards of the site can provide important windbreak functions. Many of these trees can be seen on the southern horizon of Photos 6.3 and 6.7. Although the restoration plan attempts to create suitable habitat within MGS independent of the surrounding areas, any changes in the forest outside the boundary may have impacts within MGS

Many of the trees to the south of MGS are Monterey pines that are nearing their effective lifespans, and may be infected with pitch canker; it may be difficult to maintain pines in the near future. It is important that the neighbors of MGS, especially those to the south, be encouraged to maintain large trees on their properties, given constraints on safety and tree health. An education program for surrounding property owners is an essential component for long-term planning at MGS.

Continued Monitoring at Monarch Grove Sanctuary

Continued monitoring of monarch butterflies and trees will form the basis for adaptive management at MGS. Adaptive management views management activities as experiments from which to learn, and consistently collecting data on a regular basis is a critical activity. The following monitoring activities are suggested:

1) The automated weather station has proven difficult to maintain, and has largely served its purpose in identifying the key climatic elements relevant to monarchs. If the weather station is to continue functioning, regular maintenance will be necessary, as the anemometer and wind vane are vulnerable to fouling by *Eucalyptus* debris, and the solar radiation meter is easily covered by fallen material. However, further weather data of that level of detail may not be necessary until a shelterbelt is well established (10-20 years from now) and wind attenuation needs to be measured.

However, short-term measurements of wind under particular wind conditions (similar to those done by Kingston Leong) can be done with inexpensive hand-held anemometers and can provide more spatial coverage than the fixed weather station. Such measurements can be done by trained docents, and can be correlated with wind conditions measured at local weather stations.

2) Continued monitoring of monarch numbers and spatial distribution will provide the best measure of habitat suitability at MGS. The docents at the site should be trained in a standard protocol for mapping monarchs, and distribution maps should be compiled at least every two weeks, and if possible, immediately following strong wind events. Accurate estimation of absolute numbers is less important than good data on relative numbers and positions (tree number, approximate height, and side of tree) in the grove. In reviewing previous data, the lack of a standardized map has hindered interpretation of the data. The tree maps and numbering system provided in this report should be used a baseline, and the locations of additional cluster trees outside the MGS boundary added as necessary.

3) Continued monitoring of tree health by a qualified forester. Further large tree removals will be necessary as trees age and pitch canker progresses. Removal of canker infected saplings, and monitoring of new plantings on a yearly basis will catch infections early, and proper sanitation may prevent or slow the spread of the disease in MGS, as well as identifying tree stock that is potentially resistant. Identification of immediate critical hazards in the *Eucalyptus* is important for safety concerns. The tree data base (Table 1) should be updated, and yearly measurements of the heights of new plantings will monitor the progress of restoration efforts.

Other issues

Control of Exotic Invasive Species

The site has a number of exotic species that are potentially invasive. Because the site is relatively small, and numerous ornamental plantings already exist, identification and control of invasive plants should be relatively straightforward.

Eucalyptus globulus is potentially invasive, and any seedlings that establish outside of designated *Eucalyptus* zones should be pulled in wintertime.

A few individuals of French Broom (*Cytisus monspessulanus*) were noted along the entrance path from Ridge Road. Any individuals of this species found on MGS should be removed by hand during the winter months, when the plants are easily pulled up by the roots.

The understory is dominated by introduced annual grasses. Little can be done to eliminate these species. Native perennial grasses could be reestablished in the understory by plantings, but the annual grasses will always be a substantial part of the vegetation at MGS.

Other Wildlife

MGS is frequented by a herd of deer. Because much of the site will be maintained as pine-cypress forest with a grassy understory, these deer should not be greatly affected by restoration for monarch butterflies. All plantings of deer-edible species will need to be protected by fencing. Similarly, the raccoons and other small mammals on the site that use pine-cypress forest will still have habitat remaining during and after restoration.

The removal of snags and downed trees for safety and sanitation purposes will eliminate habitat for woodpeckers and other cavity nesting birds. This is an unavoidable impact if forest health and safety are to be maintained.

Literature Cited

Frey, D., K.L.H. Leong, D. Fredericks, and S. Raskowitz. 1992. Clustering patterns of monarch butterfly (Lepidoptera: Danaidae) at two California central coast overwintering sites. Annals of the Entomological Society of America 85: 907-910

Leong, K.H.L. 1990. Microenvironmental factors associated with the winter habitat of monarch butterfly (Lepidoptera: Danaidae) in central California. Annals of the Entomological Society of America 83: 907-910

Leong, K.H.L. 1994. Monarch Grove Sanctuary Restoration program: First year study, winter 1993-1994.

Leong, K.H.L., D. Frey, G. Brenner, S. Baker, and D. Fox. 1991. Use of multivariate analysis to characterize the monarch butterfly (Lepidoptera: Danaidae) winter habitat. Annals of the Entomological Society of America 84: 263-267.

Weiss, S.B., P.M. Rich, D.D. Murphy, W.H. Calvert, and P.R. Ehrlich. 1991. Forest canopy structure at overwintering monarch butterfly sites: measurements with hemispherical photography. Conservation Biology 5:165-175.

Weiss, S.B., and D.D. Murphy. 1993. Final report on scientific studies of monarch butterfly overwintering sites at Ardenwood and Point Pinole. Prepared for East Bay Regional Park District by; Institute for Conservation Biology, Department of Biological Sciences, Stanford University.

Fig. 1 Weather data Nov-Feb 1995-1996

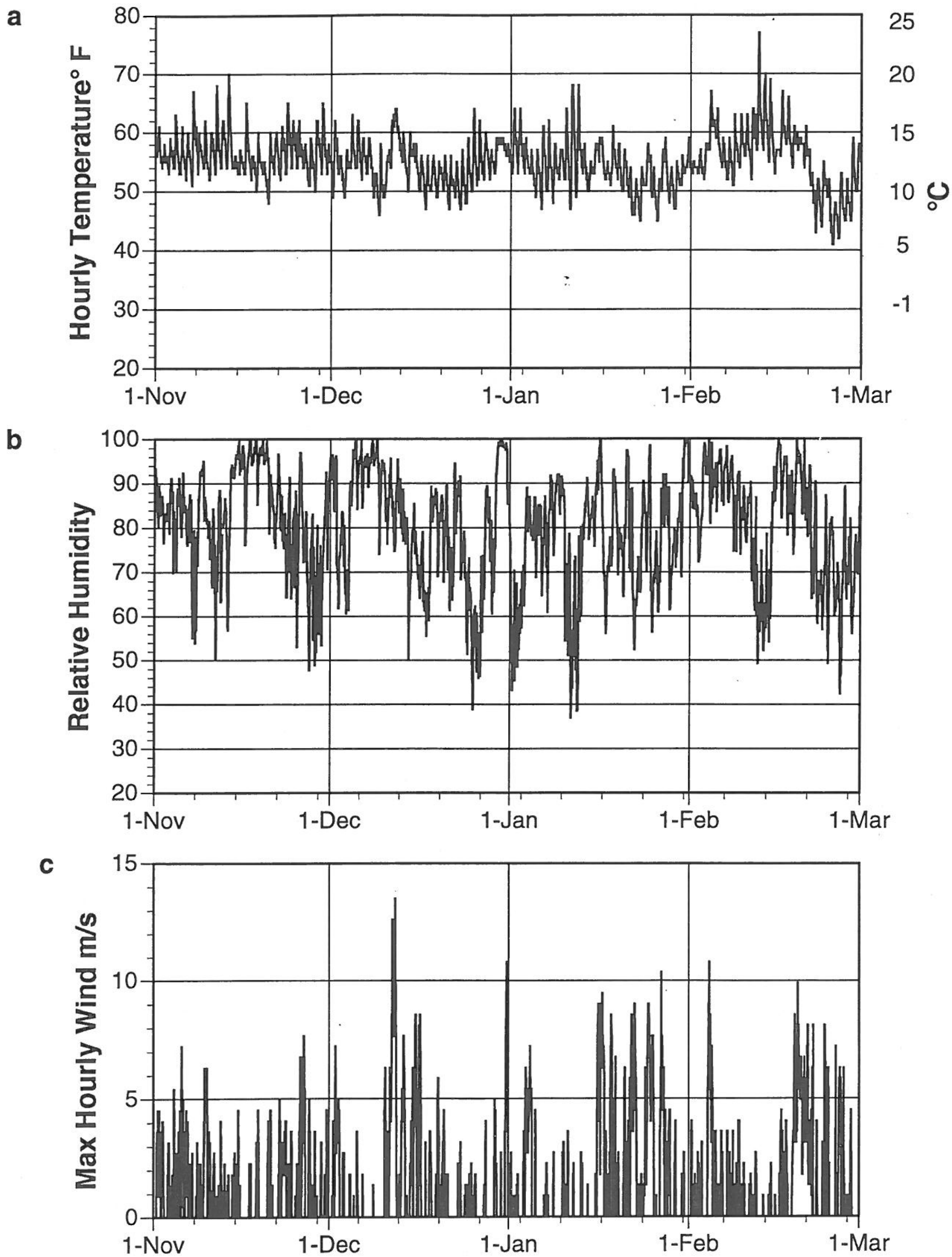
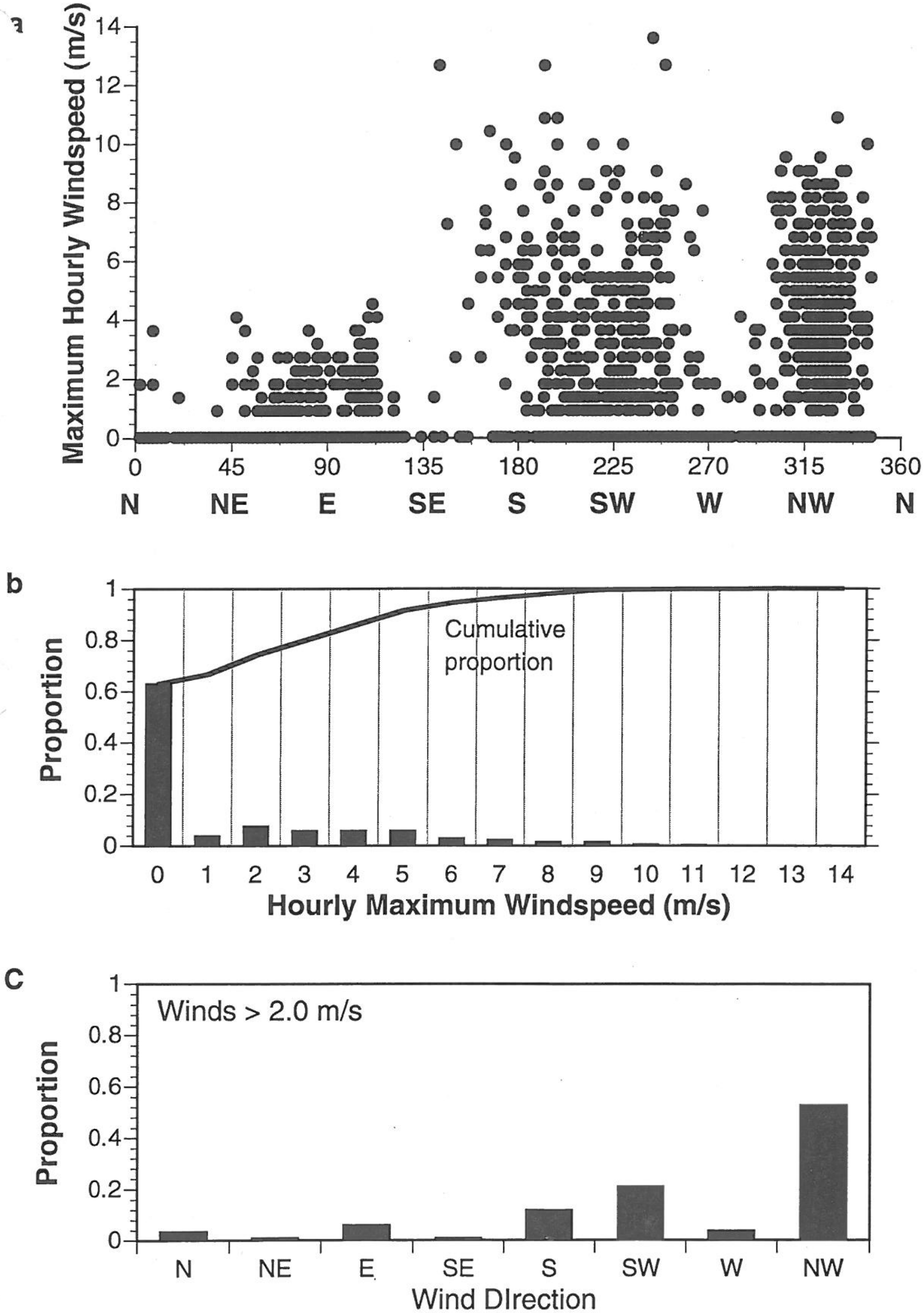
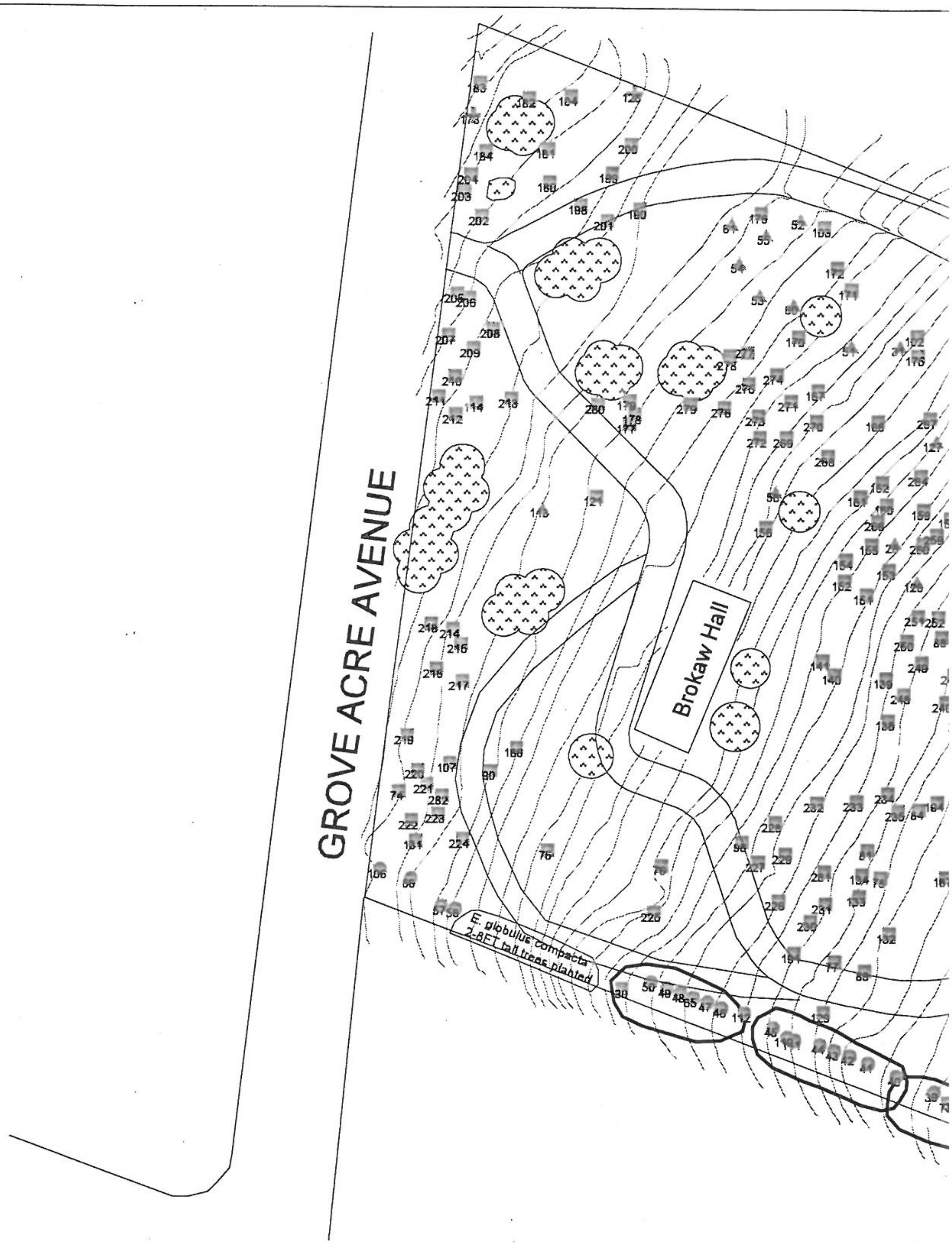


Fig. 2 Maximum Hourly Windspeed and Direction Nov 1995 - Feb 1996





Source: 1993 Pacific Grove Tree Inventory Map
1997 TRA Inventory

Thomas Reid Associates 7/7/97

Figure 3. Tree Map

Figure 4, Aerial Photograph

NORTH

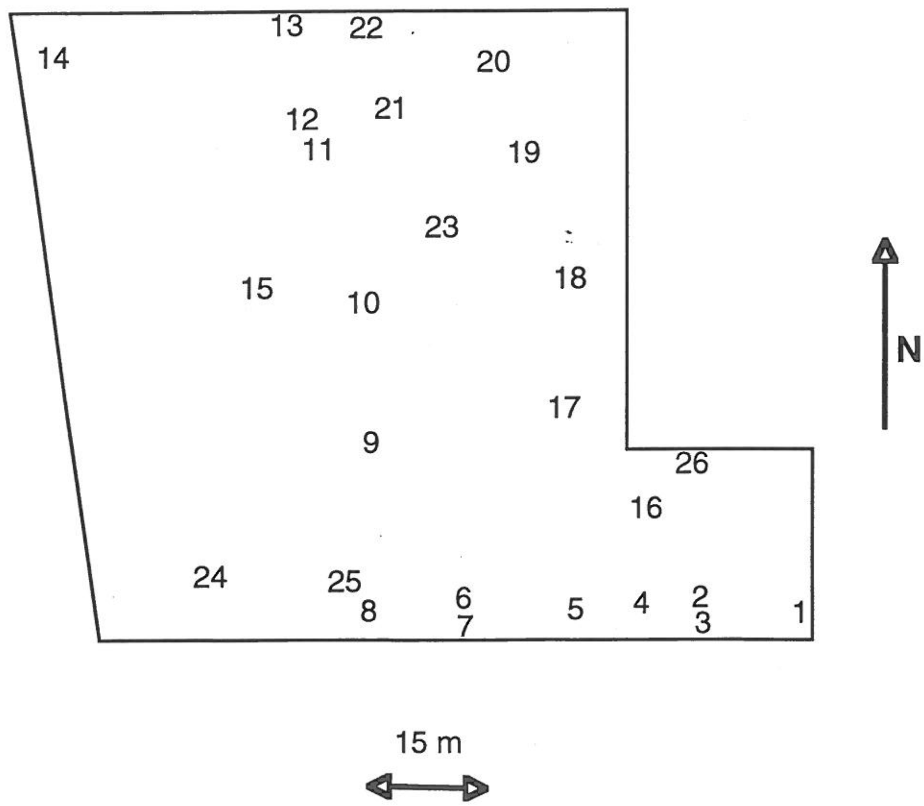
1inch = 80 ft.

Source: Pacific Grove Aerial Survey; Towill 1997

Approximate Site Boundary

Eucalyptus Canopy

Fig. 5 Photo Numbers



N

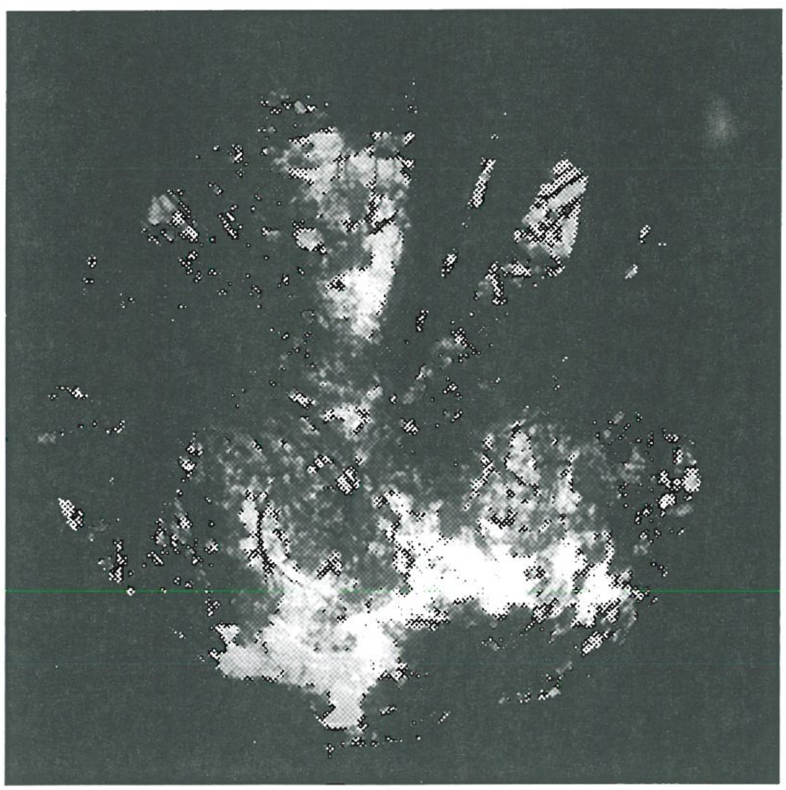
6.2

E

W

6.3

E

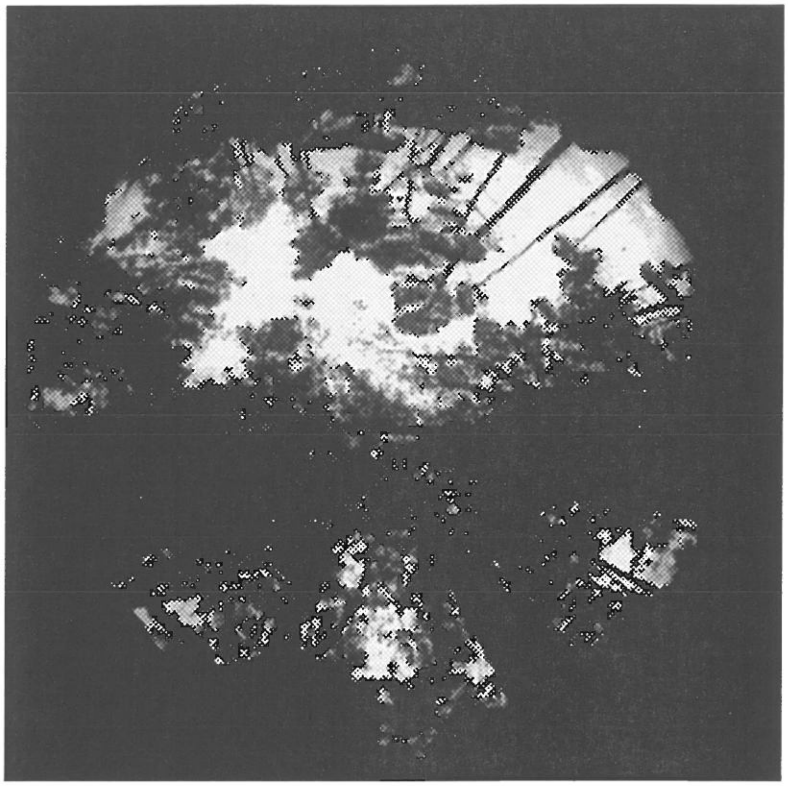


W

S

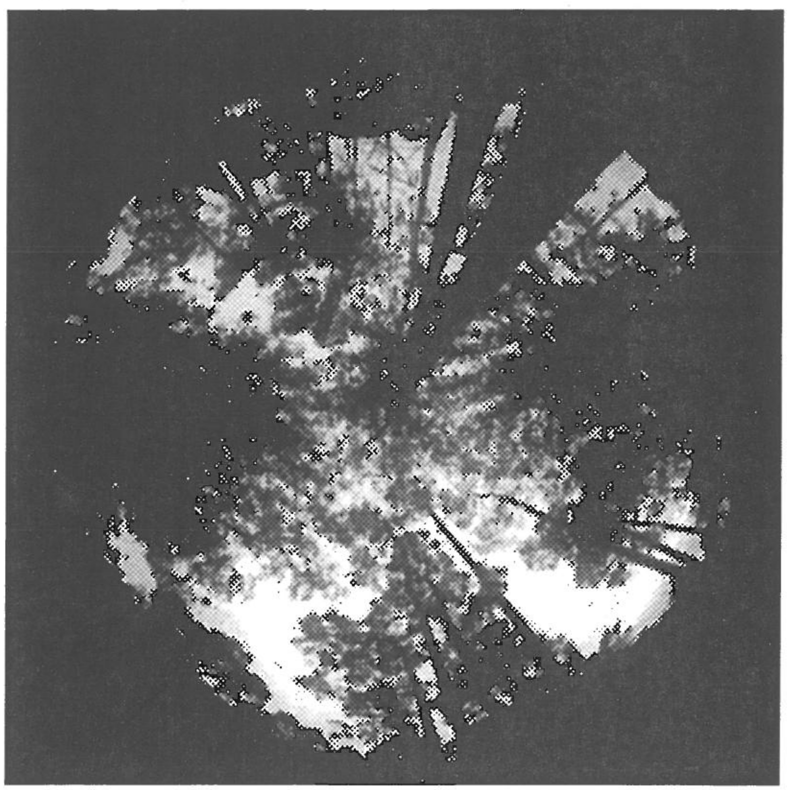
N

6.5



E W

6.7

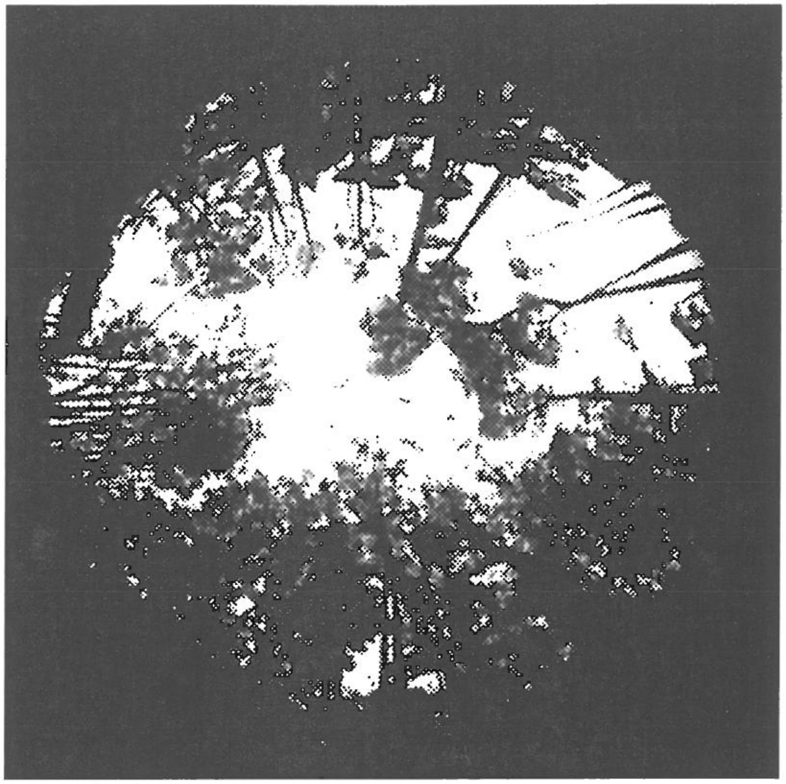


E W

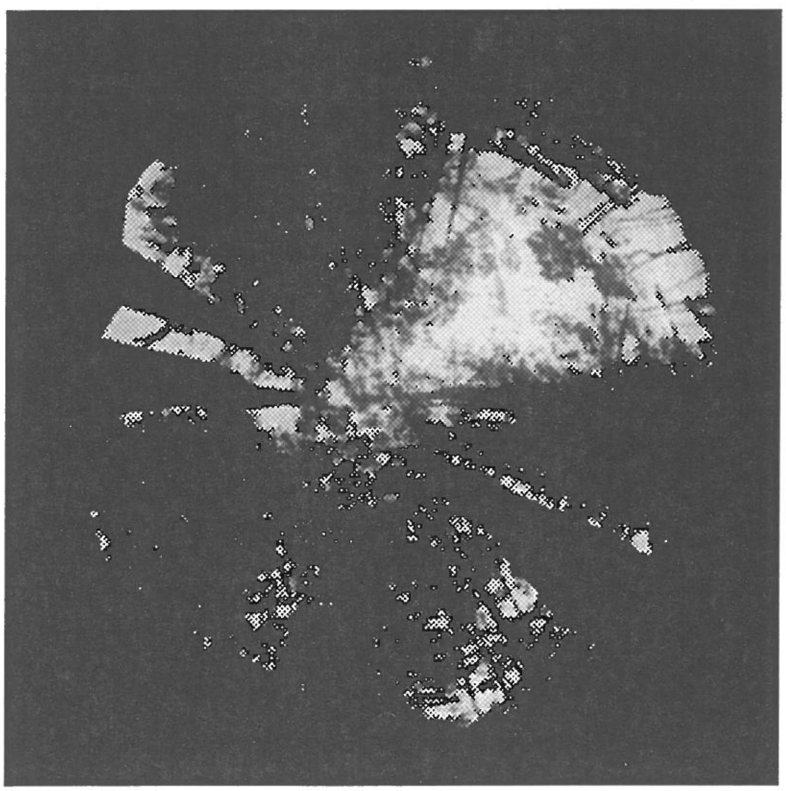
S

N

6.16

E  W

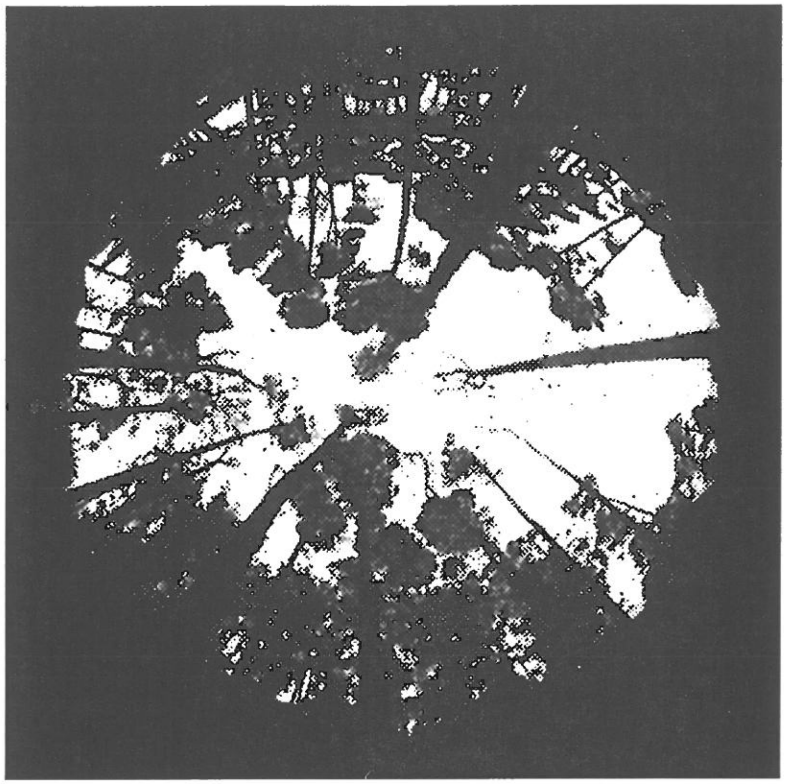
6.1

E  W

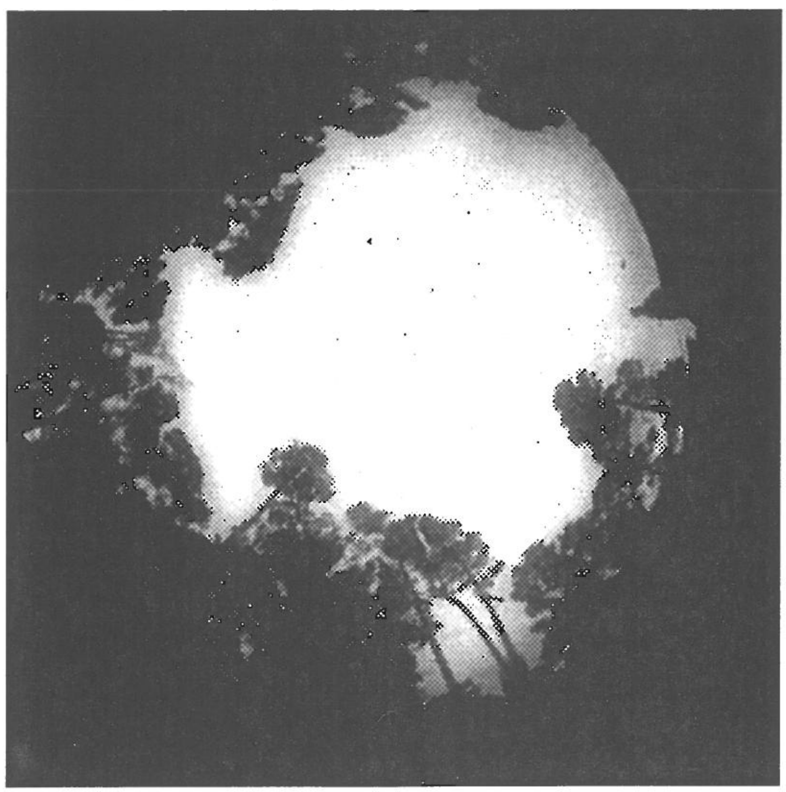
S

N

6.17

E  W

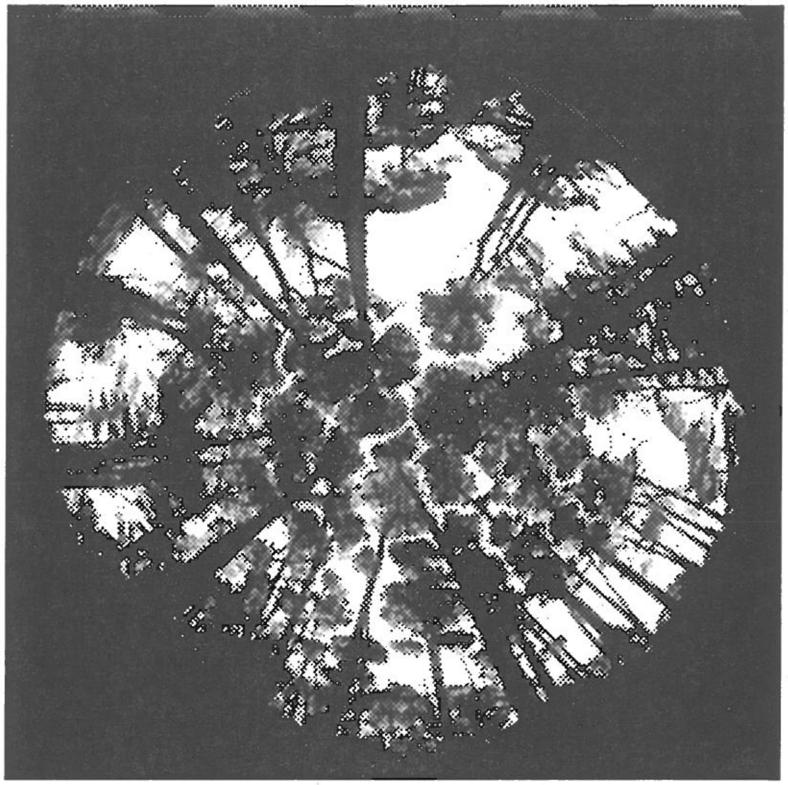
6.9

E  W

S

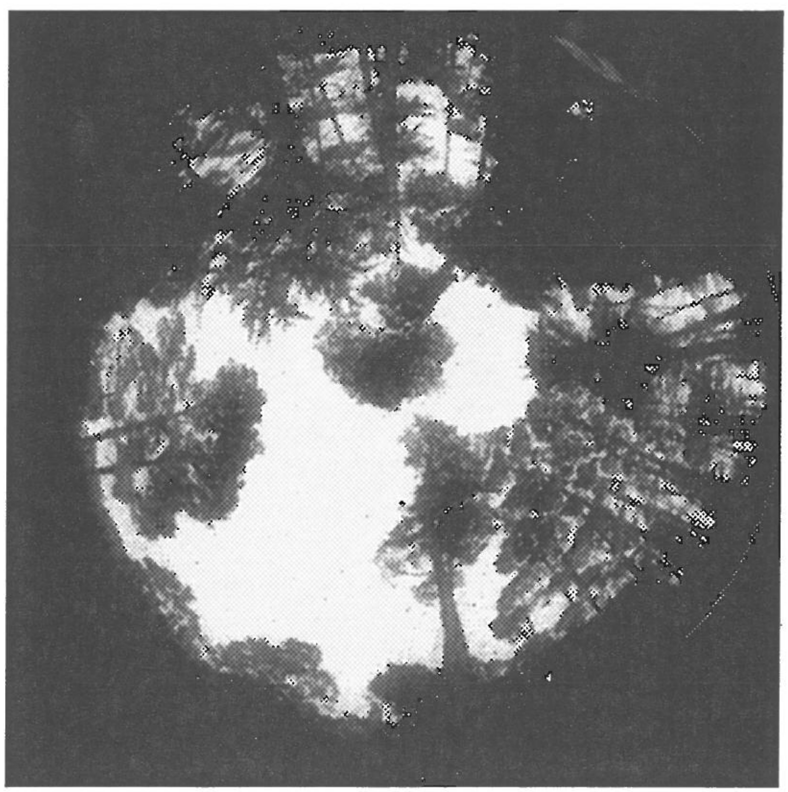
N

6.19



E W

6.11

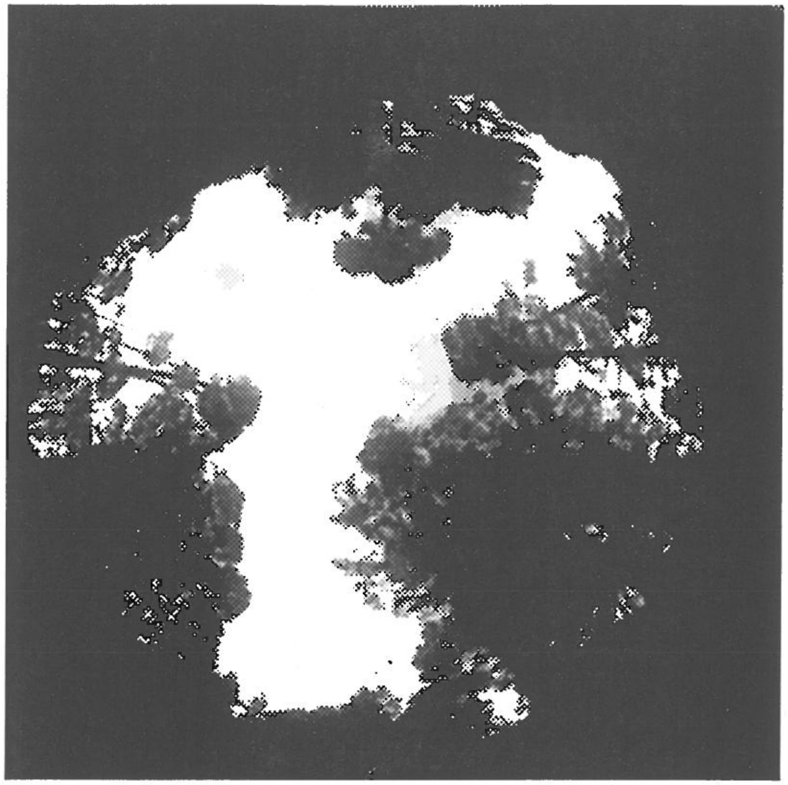


E W

S

N

6.24



E W

6.14

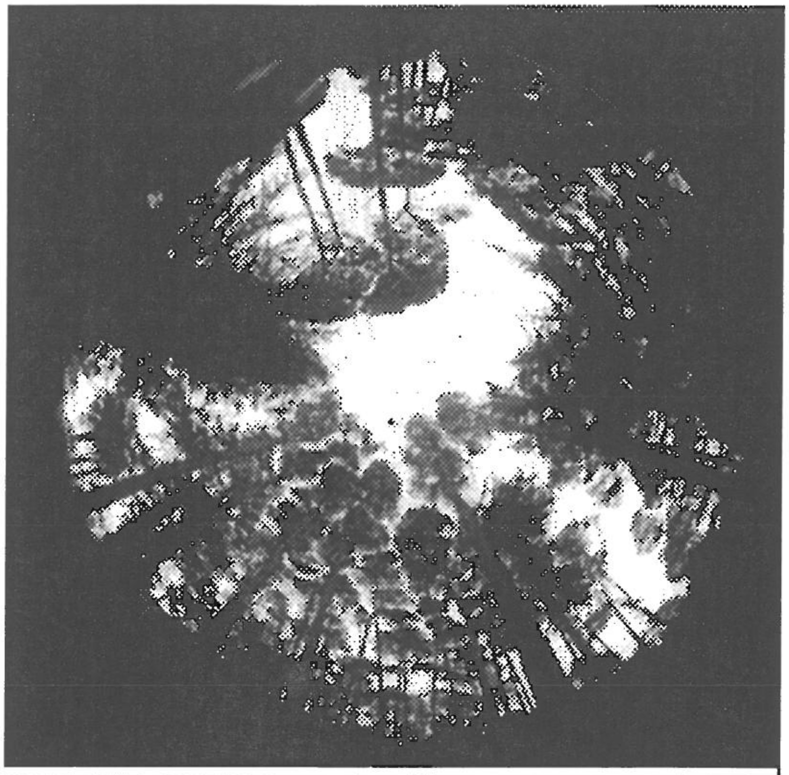
E W

S

N

6.20

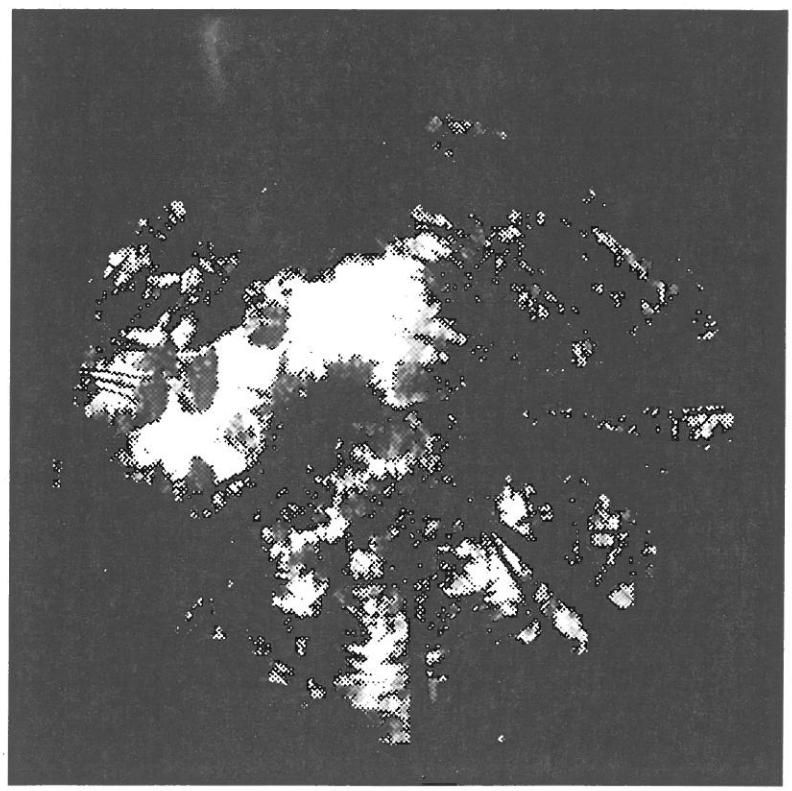
E



W

6.13

E



W

S

Fig. 7a   Indirect Site Factor

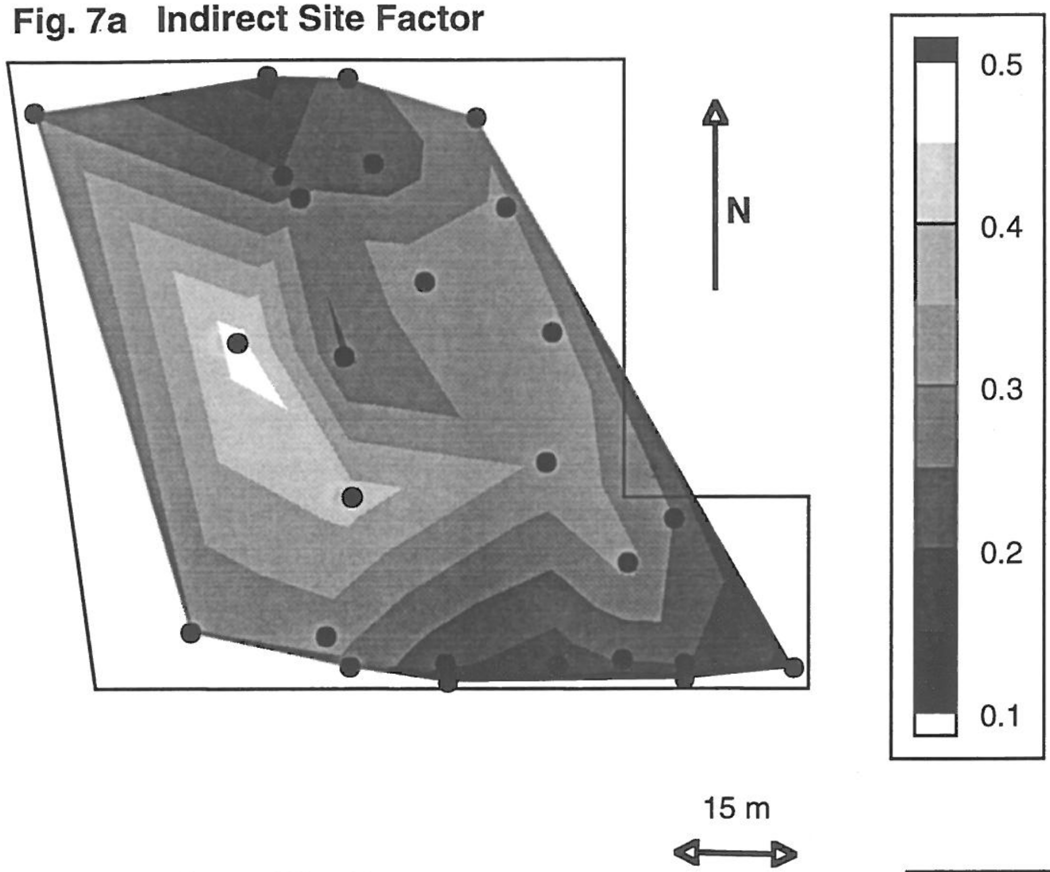


Fig. 7b   Direct Site Factor

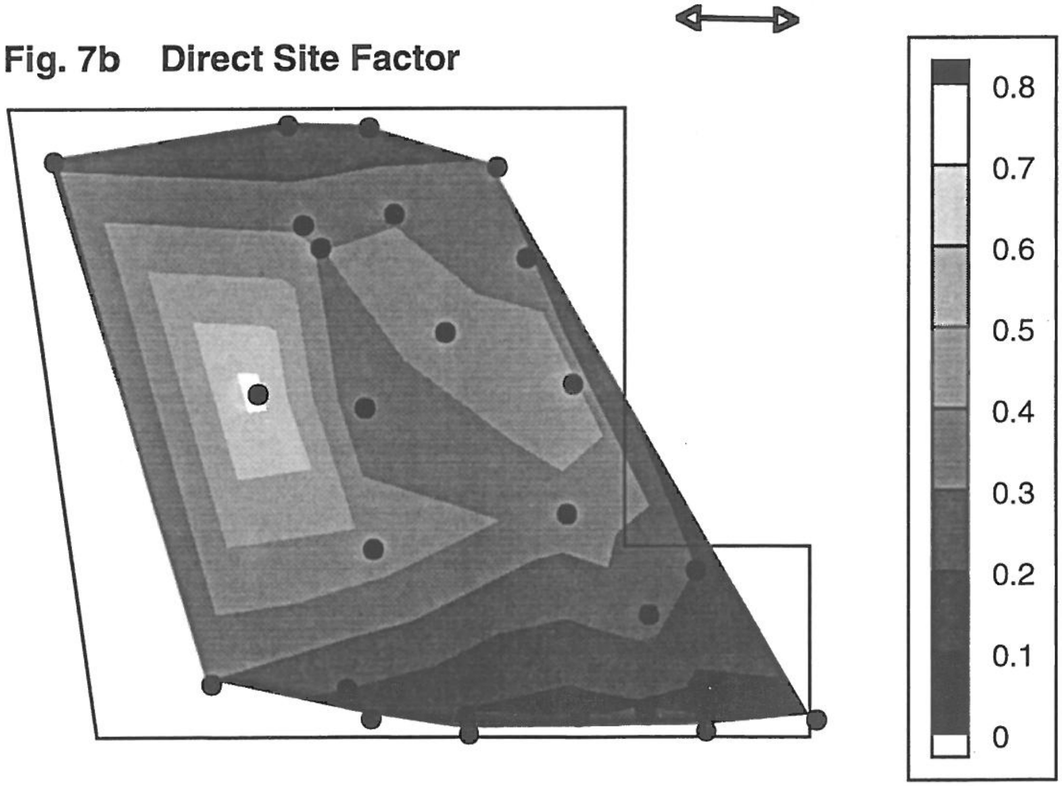
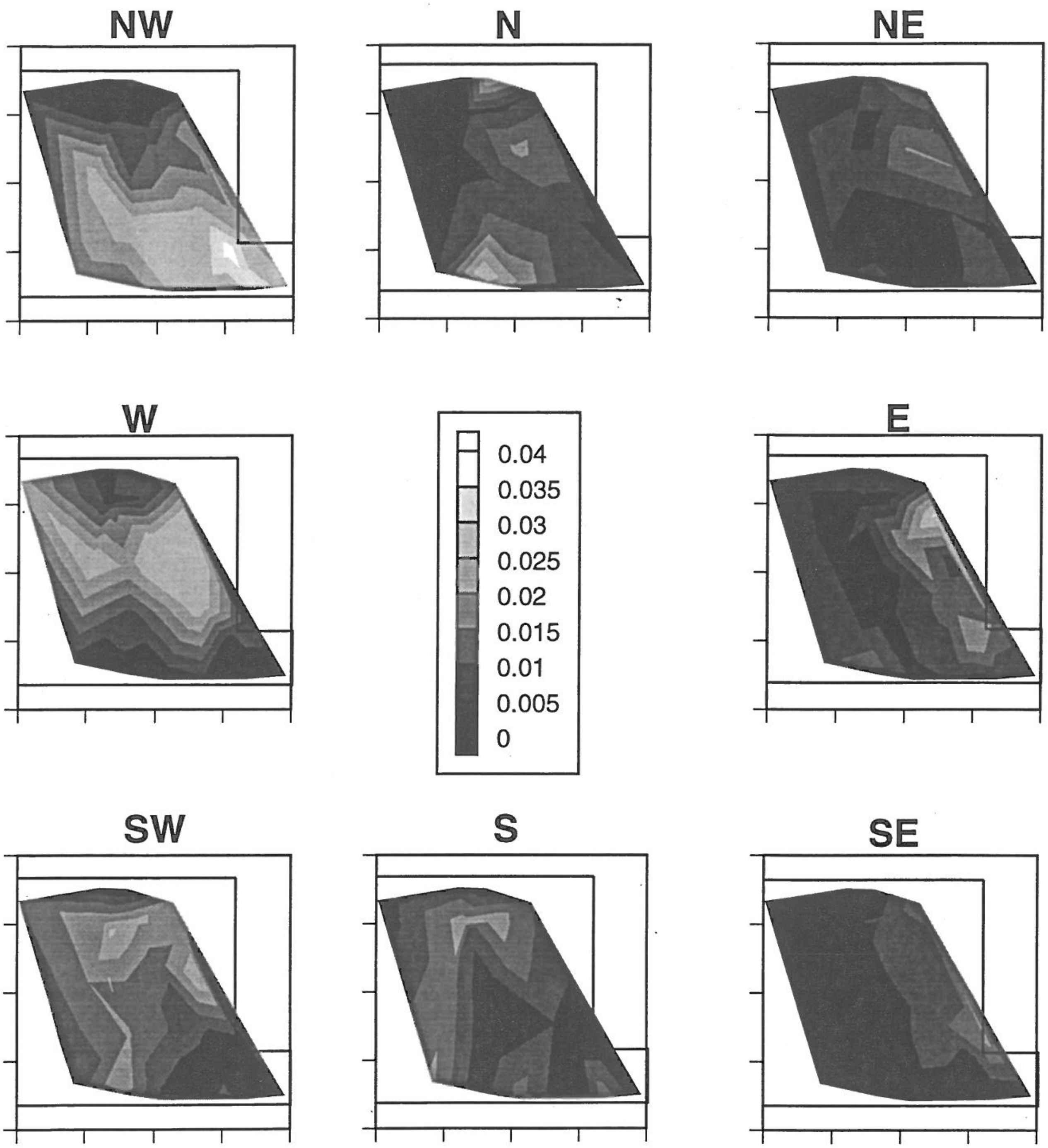
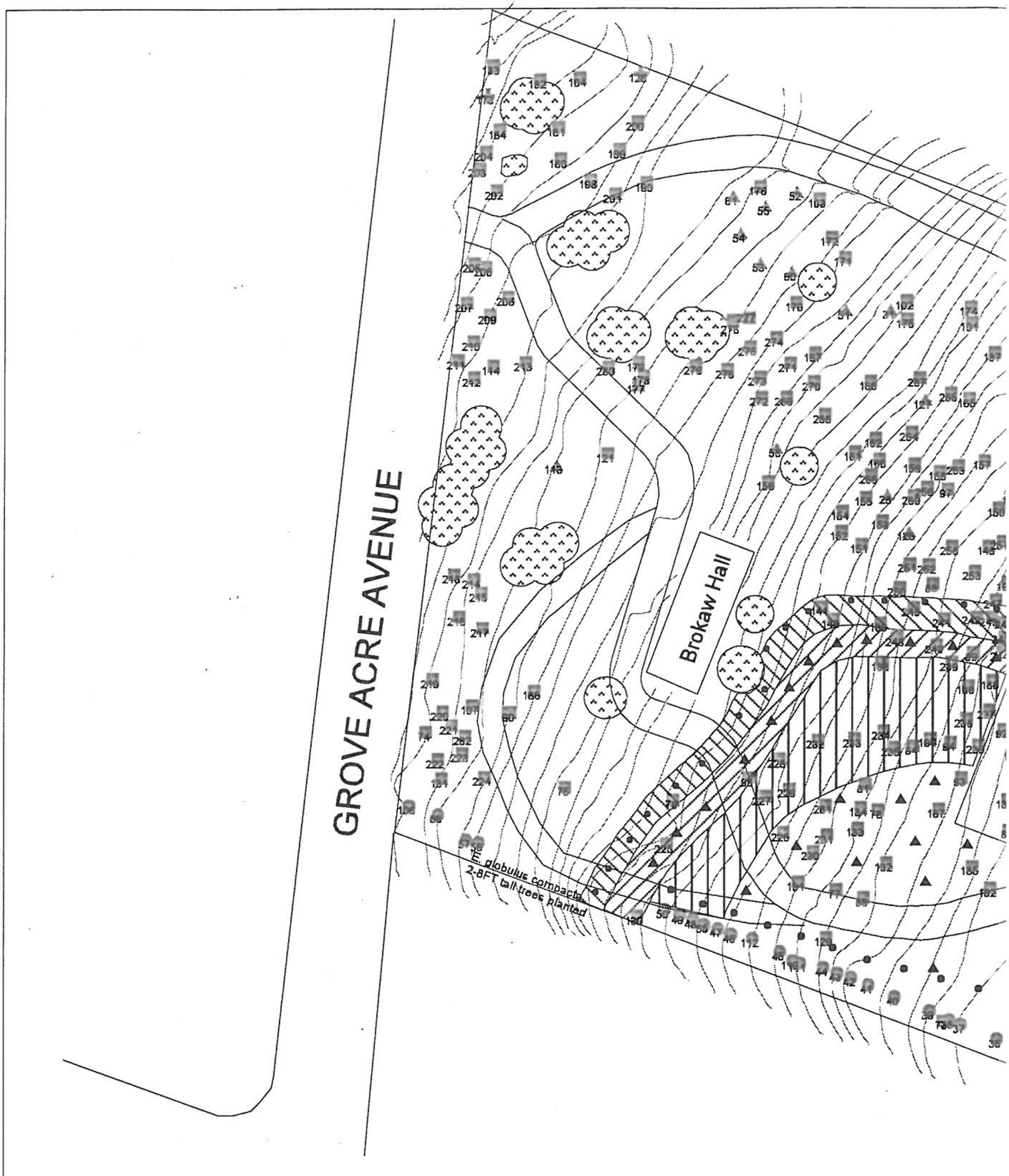


Fig. 8 Wind Site Factors (WSF)

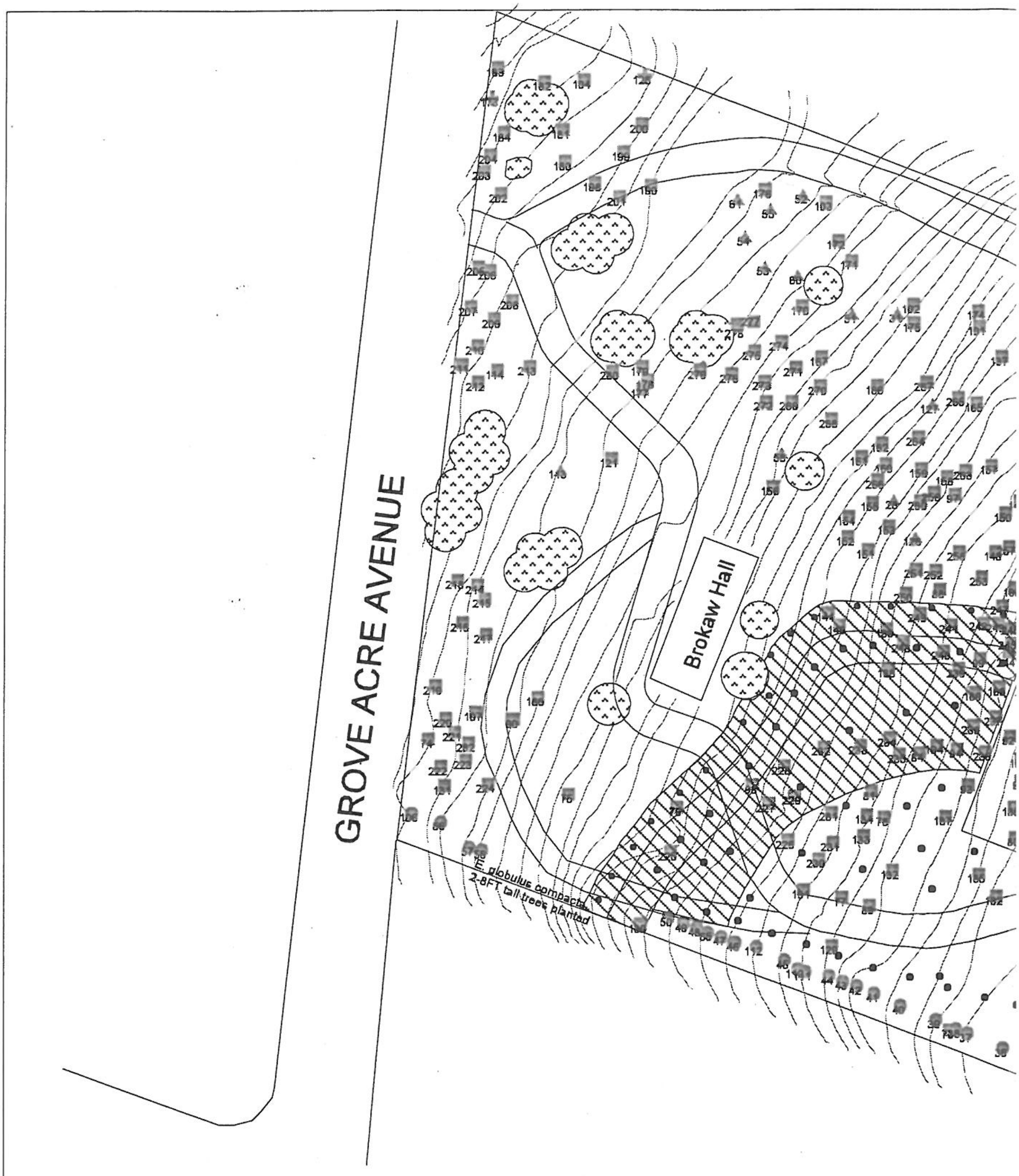




Source: 1993 Pacific Grove Tree Inventory Map
1997 TRA Inventory

Thomas Reid Associates 7/7/97

Figure 9. Plan 1



Source: 1993 Pacific Grove Tree Inventory Map
1997 TRA Inventory

Thomas Reid Associates 7/7/97

Figure 10. Plan 2

Source: 1993 Pacific Grove Tree Inventory Map
1997 TRA Inventory

Thomas Reid Associates 7/7/97

Figure 11. Plan 3

TREE#	TYPE	DBH	SOURCE	HEALTH	P_CANKER	HAZARD	REMOVE	NOTES
1	CYP	19	1993	FAIR				Private tree
2	CYP	15	1993	FAIR				Private tree
3	CYP	30	1993	FAIR				Private tree
4	CYP	28	1993	FAIR				Private tree
5	CYP	48	1993	FAIR				Private tree
6	CYP	18	1993	FAIR				Private tree
7	CYP	20	1993	FAIR				Private tree
8	CYP	28	1993	FAIR				Private tree
9	CYP	18	1993	FAIR				Private tree
10	CYP	28	1993	FAIR				Private tree
11	CYP	18	1993	FAIR				Private tree
12	CYP	32	1993	FAIR				Private tree
13	CYP	24	1993	FAIR				Private tree
14	CYP	21	1993	FAIR				Private tree
15	CYP	18	1993	FAIR				Private tree
16	CYP	20	1993	FAIR				Private tree
17	CYP	18	1993	FAIR				Private tree
18	CYP	18	1993	FAIR				Private tree
19	CYP	18	1993	FAIR				Private tree
20	CYP	27	1993	FAIR				Private tree
21	CYP	9	1993	FAIR				Private tree
22	CYP	15	1993	FAIR				Private tree
23	CYP	9	1993	FAIR				Private tree
24	CYP	12	1993	FAIR				Private tree
25	CYP	27	1993	VERY				Private tree
26	CYP	18	1993	N/A				
27	CYP	12	1993	N/A				
28	CYP	15	1993			LOTS OF DEADWOOD		
29	CYP	42	1993	FAIR				
30	CYP	18	1993	FAIR				
31	CYP	18	1993	FAIR				
32	EUC	48	1993	FAIR				
33	EUC	24	1993	FAIR				
34	EUC	27	1993	FAIR				
35	EUC	48	1993	FAIR				
36	EUC	48	1993	FAIR				
37	EUC	21	1993	FAIR				
38	EUC	36	1993	FAIR				
39	EUC	27	1993	FAIR				
40	EUC	24	1993	FAIR				
41	EUC	31	1993	FAIR				
42	EUC	27	1993	FAIR				
43	EUC	15	1993	FAIR				
44	EUC	15	1993	FAIR				
45	EUC	36	1993	FAIR				
46	EUC	15	1993	FAIR				
47	EUC	15	1993	FAIR				
48	EUC	15	1993	FAIR				
49	EUC	24	1993	FAIR				
50	EUC	18	1993	FAIR				
51	CYP	15	1993	FAIR				
52	CYP	12	1993	FAIR				
53	CYP	36	1993	FAIR				
54	CYP	15	1993	FAIR				
55	CYP	15	1993	FAIR				
56	EUC	36	1993	FAIR				
57	EUC	4	1993	FAIR				
58	CYP	30	1993	FAIR		DEADWOOD		
59	CYP	24	1993	FAIR		DEADWOOD, HANGER		
60	CYP	18	1993	FAIR		DEADWOOD, HANGERS		
61	CYP	45	1993	FAIR		HANGERS		
62	CYP	12	1993					
63	CYP	12	1993	FAIR				
64	EUC	36	1993	FAIR				TAG # 31
65	EUC	42	1993	FAIR		END WEIGHTS OVER PATH		TAG #32
66	EUC	30	1993	FAIR				SPROUTS ON ST-SIDE TOUCHING 2ND ELECT.
67	GEUC	999	1993	FAIR				Multi-stemmed trees
68	GEUC	999	1993	FAIR				Multi-stemmed trees
69	GEUC	999	1993	FAIR				Multi-stemmed trees
70	GEUC	999	1993	FAIR				TAG #29
71	GEUC	999	1993	FAIR				Tag #30
72	PINE	12	1993	FAIR				Monarchs clustered
73	PINE	21	1993	FAIR				Monarchs clustered
74	PINE	21	1993	FAIR		BRKN LMB PRIM ELECT LINE		
75	PINE	21	1993	FAIR		DEADWOOD		

TREE#	TYPE	DBH	SOURCE	HEALTH	P_CANKER	HAZARD	REMOVE	NOTES
76	PINE	18	1993	FAIR		DEADWOOD		
77	PINE	12	1993	POOR			YES	SMALL CROWN
78	PINE	15	1993	DEAD		YES	YES	
79	PINE	18	1993	DEAD		YES	YES	
80	PINE	12	1993	DEAD		YES	YES	
81	PINE	15	1993	DEAD		YES	YES	
82	PINE	30	1993	DEAD		YES	YES	
83	PINE	27	1993	DEAD		YES	YES	
84	PINE	18	1993	DEAD		YES	YES	
85	PINE	21	1993	DEAD		YES	YES	
86	PINE	18	1993	DEAD		YES	YES	
87	PINE	15	1993	DEAD		YES	YES	
88	PINE	24	1993	GOOD		TRUNK DECAY 10FT UP,SOUTH		TRUNK DECAY 10FT UP,SOUTH SIDE
89	PINE	18	1993	FAIR				Good Crown
90	PINE	9	1993	POOR	SYMPTOMS		YES	BUSHY LOW TREE W/ P.CANKER
91	PINE	18	1993	FAIR				SPARSE CROWN
92	PINE	12	1993	POOR		YES	YES	NNE LEAN AND TRUNK WOUND
93	PINE	12	1993	POOR		YES	YES	TRUNK PRBLM @BASE TO 3 FT
94	PINE	18	1993					SPARSE TOP/MONITOR FOR REMOVAL
95	PINE	15	1993	FAIR		TRUNK DEFECT 10FT UP		FURTHER INSPECTION ADVISED
96	PINE	24	1993	FAIR		HEAVY ENDWEIGHTS ON E SIDE		
97	PINE	15	1993	FAIR		TRUNK BASE SUSPECT		FURTHER INSPECTION ADVISED
98	PINE	15	1993	FAIR				
99	MPIN		1997		PDR#1019782	YES	YES	
100	CYP		1997			YES	YES	YOUNG TREE
101	PINE	18	1993	DEAD		YES	YES	
102	PINE	12	1993	DEAD		YES	YES	
103	PINE	15	1993	DEAD		YES	YES	
104	PINE	21	1993	DEAD		YES	YES	
105	PINE	24	1993	DEAD		YES	YES	25FT, TRUNK W/POISON OAK
106	EUC		1997					
107	MPIN		1997					
108	CYP		1997					YOUNG TREE
109	CYP		1997					YOUNG TREE
110	EUC		1997					4FT E.g. compacta
111	EUC		1997					4FT E.g. compacta
112	EUC		1997					6FT E.g. compacta
113	CYP		1997					
114	MPIN	5	1993		SYMPTOMS		YES	20FT
115	EUC		1997					3-4FT E.g. compacta
116	EUC		1997					3-4FT E.g. compacta
117	EUC		1997					3-4FT E.g. compacta
118	EUC		1997					3-4FT E.g. compacta
119	EUC		1997					3-4FT E.g. compacta
120	EUC		1997					3-4FT E.g. compacta
121	MPIN		1997					
122	CYP		1997					15FT TALL
123	CYP		1997					25FT TALL
124	CYP	28	1993	FAIR				
125	CYP	24	1993	FAIR				
126	CYP	12	1993	FAIR				
127	CYP	24	1993	FAIR				
128	OAK	15	1993	FAIR				
129	PINE	14	1993	FAIR				
130	PINE	24	1993	FAIR				
131	PINE	29	1993	FAIR				
132	PINE	18	1993	FAIR				
133	PINE	21	1993	FAIR				
134	PINE	15	1993	FAIR				
135	PINE	18	1993	FAIR				
136	PINE	15	1993	FAIR				
137	PINE	24	1993	FAIR				
138	PINE	15	1993	FAIR				
139	PINE	15	1993	FAIR				
140	PINE	15	1993	FAIR				
141	PINE	18	1993	FAIR				
142	PINE	15	1993	FAIR				
143	PINE	18	1993	FAIR				
144	PINE	24	1993	FAIR				
145	PINE	24	1993	FAIR				
146	PINE	24	1993	FAIR				
147	PINE	15	1993	FAIR				
148	PINE	12	1993	FAIR				
149	PINE	12	1993	FAIR				
150	PINE	18	1993	FAIR				

Condition Assessment of Key Tree Species

TREE#	TYPE	DBH	SOURCE	HEALTH	P_CANKER	HAZARD	REMOVE	NOTES					
151	PINE	21	1993	FAIR									
152	PINE	18	1993	FAIR									
153	PINE	15	1993	FAIR									
154	PINE	18	1993	FAIR									
155	PINE	15	1993	FAIR									
156	PINE	24	1993	FAIR									
157	PINE	18	1993	FAIR									
158	PINE	15	1993	FAIR									
159	PINE	18	1993	FAIR									
160	PINE	15	1993	FAIR									
161	PINE	15	1993	FAIR									
162	PINE	15	1993	FAIR									
163	PINE	24	1993	FAIR									
164	PINE	24	1993	FAIR									
165	PINE	18	1993	FAIR									
166	PINE	21	1993	FAIR									
167	PINE	24	1993	FAIR									
168	PINE	24	1993	FAIR									
169	PINE	24	1993	FAIR									
170	PINE	21	1993	FAIR									
171	PINE	24	1993	FAIR									
172	PINE	21	1993	FAIR									
173	OAK	12	1993	FAIR									
174	PINE	21	1993	FAIR									
175	PINE	21	1993	FAIR									
176	PINE	27	1993	FAIR									
177	PINE	15	1993	FAIR									
178	PINE	15	1993	FAIR									
179	PINE	9	1993	FAIR									
180	PINE	27	1993	FAIR									
181	PINE	24	1993	FAIR									
182	PINE	24	1993	FAIR									
183	PINE	18	1993	FAIR									
184	PINE	20	1993	FAIR									
185	PINE	24	1993	GOOD									
186	PINE	33	1993	GOOD									
187	PINE	18	1993	GOOD									
188	PINE	15	1993	GOOD									
189	PINE	18	1993	GOOD									
190	PINE	48	1993	GOOD									
191	PINE	21	1993	STUM				10FT STUMP					
192	PINE	24	1993	STUM				1FT STUMP					
193	PINE	24	1993	STUM				2FT STUMP					
194	PINE	12	1993	STUM				1.5FT STUMP					
195	PINE	18	1993	STUM				20FT STUMP W/ WOODPECKER NEST					
196	EUC	12	1993	GOOD				45FT GLOBULUS					
197	CYP	10	1993	GOOD				40FT TALL					
198	MPIN		1997					4-8FT TALL					
199	MPIN		1997					4-8FT TALL					
200	MPIN		1997					4-8FT TALL					
201	MPIN		1997					4-8FT TALL					
202	MPIN		1997					4-8FT TALL					
203	MPIN		1997					4-8FT TALL					
204	MPIN		1997					4-8FT TALL					
205	MPIN		1997					4-8FT TALL					
206	MPIN		1997					4-8FT TALL					
207	MPIN		1997					4-8FT TALL					
208	MPIN		1997					4-8FT TALL					
209	MPIN		1997					4-8FT TALL					
210	MPIN		1997					4-8FT TALL					
211	MPIN		1997					4-8FT TALL					
212	MPIN		1997					4-8FT TALL					
213	MPIN		1997					4-8FT TALL					
214	MPIN		1997					4-8FT TALL					
215	MPIN		1997					4-8FT TALL					
216	MPIN		1997					4-8FT TALL					
217	MPIN		1997					4-8FT TALL					
218	MPIN		1997					4-8FT TALL					
219	MPIN		1997					4-8FT TALL					
220	MPIN		1997					4-8FT TALL					
221	MPIN		1997					4-8FT TALL					
222	MPIN		1997					4-8FT TALL					
223	MPIN		1997					4-8FT TALL					
224	MPIN		1997					4-8FT TALL					
225	MPIN		1997					4-8FT TALL					

TREE#	TYPE	DBH	SOURCE	HEALTH	P_CANKER	HAZARD	REMOVE	NOTES
226	MPIN		1997					4-8FT TALL
227	MPIN		1997					4-8FT TALL
228	MPIN		1997					4-8FT TALL
229	MPIN		1997					4-8FT TALL
230	MPIN		1997					4-8FT TALL
231	MPIN		1997					4-8FT TALL
232	MPIN		1997					4-8FT TALL
233	MPIN		1997					4-8FT TALL
234	MPIN		1997					4-8FT TALL
235	MPIN		1997					4-8FT TALL
236	MPIN		1997					4-8FT TALL
237	MPIN		1997					4-8FT TALL
238	MPIN		1997					4-8FT TALL
239	MPIN		1997					4-8FT TALL
240	MPIN		1997					4-8FT TALL
241	MPIN		1997					4-8FT TALL
242	MPIN		1997					4-8FT TALL
243	MPIN		1997					4-8FT TALL
244	MPIN		1997					4-8FT TALL
245	MPIN		1997					4-8FT TALL
246	MPIN		1997					4-8FT TALL
247	MPIN		1997					4-8FT TALL
248	MPIN		1997					4-8FT TALL
249	MPIN		1997					4-8FT TALL
250	MPIN		1997					4-8FT TALL
251	MPIN		1997					4-8FT TALL
252	MPIN		1997					4-8FT TALL
253	MPIN		1997					4-8FT TALL
254	MPIN		1997					4-8FT TALL
255	MPIN		1997					4-8FT TALL
256	MPIN		1997					4-8FT TALL
257	MPIN		1997					4-8FT TALL
258	MPIN	21	1993	FAIR				Trunk defect at 6FT
259	MPIN		1997					4-8FT TALL
260	MPIN		1997					4-8FT TALL
261	MPIN		1997					4-8FT TALL
262	MPIN		1997					4-8FT TALL
263	MPIN		1997					4-8FT TALL
264	MPIN		1997					4-8FT TALL
265	MPIN		1997					4-8FT TALL
266	MPIN		1997					4-8FT TALL
267	MPIN		1997					4-8FT TALL
268	MPIN		1997					4-8FT TALL
269	MPIN		1997					4-8FT TALL
270	MPIN		1997					4-8FT TALL
271	MPIN		1997					4-8FT TALL
272	MPIN		1997					4-8FT TALL
273	MPIN		1997					4-8FT TALL
274	MPIN		1997					4-8FT TALL
275	MPIN		1997					4-8FT TALL
276	MPIN		1997					4-8FT TALL
277	MPIN		1997					4-8FT TALL
278	MPIN		1997					4-8FT TALL
279	MPIN		1997					4-8FT TALL
280	MPIN		1997					4-8FT TALL
281	MPIN		1997		PDR#1019784		YES	4-8FT TALL
282	MPIN		1997		PDR#1019783		YES	
283	CYP		1997	DEAD		YES	YES	
284	CYP		1997	DEAD		YES	YES	

Table 2. Site Factors for 26 Hemispherical Photographs

Photo #	ISF	DSF	WSF_N	WSF_{NE}	WSF_E	WSF_{SE}	WSFS	WSF_{SW}	WSF_W	WSF_{NW}
1*	0.13	0.06	0.005	0.002	0.005	0.000	0.000	0.005	0.001	0.028
2*	0.20	0.05	0.007	0.006	0.007	0.000	0.013	0.000	0.001	0.033
3*	0.13	0.23	0.002	0.004	0.000	0.001	0.015	0.004	0.006	0.004
4	0.21	0.09	0.008	0.007	0.006	0.001	0.000	0.006	0.002	0.027
5*	0.17	0.06	0.009	0.004	0.006	0.002	0.002	0.003	0.005	0.027
6	0.21	0.10	0.018	0.003	0.004	0.002	0.012	0.004	0.002	0.025
7*	0.15	0.24	0.003	0.003	0.003	0.005	0.015	0.011	0.010	0.006
8	0.29	0.13	0.024	0.002	0.004	0.000	0.000	0.013	0.004	0.017
9*	0.42	0.47	0.012	0.000	0.003	0.001	0.001	0.015	0.008	0.029
10	0.24	0.32	0.005	0.008	0.001	0.000	0.001	0.014	0.024	0.010
11*	0.26	0.40	0.007	0.001	0.006	0.002	0.007	0.026	0.013	0.005
12	0.20	0.38	0.003	0.005	0.003	0.005	0.017	0.020	0.004	0.000
13*	0.13	0.18	0.000	0.000	0.008	0.001	0.006	0.002	0.002	0.001
14*	0.24	0.27	0.000	0.002	0.007	0.000	0.001	0.010	0.022	0.002
15	0.47	0.73	0.003	0.007	0.004	0.003	0.013	0.015	0.030	0.027
16*	0.31	0.25	0.007	0.007	0.020	0.003	0.004	0.002	0.004	0.037
17*	0.34	0.37	0.006	0.005	0.012	0.009	0.005	0.006	0.030	0.027
18	0.32	0.48	0.012	0.015	0.008	0.006	0.006	0.024	0.029	0.014
19*	0.31	0.33	0.013	0.008	0.031	0.009	0.009	0.017	0.028	0.017
20*	0.29	0.31	0.005	0.016	0.008	0.014	0.010	0.018	0.013	0.003
21	0.21	0.39	0.004	0.006	0.003	0.006	0.018	0.021	0.005	0.000
22	0.24	0.21	0.024	0.011	0.010	0.000	0.001	0.000	0.007	0.006
23	0.34	0.46	0.016	0.015	0.019	0.010	0.013	0.012	0.029	0.012
24*	0.30	0.30	0.005	0.004	0.010	0.001	0.016	0.004	0.002	0.016
25	0.32	0.22	0.030	0.006	0.013	0.000	0.001	0.020	0.004	0.017
26	0.25	0.22	0.004	0.004	0.014	0.016	0.001	0.002	0.009	0.024

Forest Canopy Structure at Overwintering Monarch Butterfly Sites: Measurements with Hemispherical Photography

STUART B. WEISS

Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305, U.S.A.

PAUL M. RICH

Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305, U.S.A.

DENNIS D. MURPHY*

Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305, U.S.A.

WILLIAM H. CALVERT

Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305, U.S.A.

PAUL R. EHRLICH

Center for Conservation Biology
Department of Biological Sciences
Stanford University
Stanford, CA 94305, U.S.A.

Abstract: *Using hemispherical photography and digital image analysis, we have quantified forest canopy structure and light conditions at monarch butterfly (*Danaus plexippus*) overwintering sites near Santa Barbara, California. Hemispherical photographs were taken from 1.75 m height in more than 30 forest groves, including permanently occupied, transient, formerly occupied, and unoccupied sites. Analysis of the photographs permitted us to calculate site factors that quantify the proportion of indirect and direct radiation received relative to completely open conditions. The permanently occupied sites exhibited a narrow range of indirect radiation and a slightly wider but still narrow range of annual direct radiation. Transient sites exhibited a wider range of indirect and annual direct radiation than the permanent sites. Within the largest aggregation site, horizontal and vertical variation in site factors was considerable. Changes in monthly direct radiation with height may be unpredictable and reduce confidence in extrapolations from near ground level to the height of butterfly clusters. Sites that formerly*

* *Correspondence should be addressed to this author.*
Paper submitted June 7, 1990; revised manuscript accepted October 10, 1990.

Resumen: *Utilizando la fotografía hemisférica y el análisis de imágenes digitales hemos cuantificado la estructura del dosel del bosque y las condiciones de luz en los lugares de invernación de la mariposa monarca (*Danaus plexipus*) cerca de Santa Barbara, California. Las fotografías hemisféricas se tomaron desde una altura de 1.75 m, en más de 30 lugares de muestreo en el bosque que incluyen áreas ocupadas permanentemente, transitoriamente o inicialmente y áreas sin ocupar. Con el análisis de las fotografías se calcularon factores del lugar que cuantificaron la proporción de la radiación indirecta o directa recibida en relación a condiciones completamente abiertas. Los lugares ocupados permanentemente exhibieron un rango estrecho de radiación indirecta y un nivel ligeramente más amplio, pero aún estrecho, de radiación directa anual. Los muestreos en los lugares transitorios exhibieron un nivel mayor de radiación indirecta y un nivel mayor de radiación directa anual en comparación con los sitios permanentes. Dentro del lugar de mayor concentración, la variación horizontal y vertical en los factores del lugar fue considerable. Los cambios en la radiación directa mensual en relación a la altura pueden ser impredecibles y disminuye la confiabilidad para hacer extrapolaciones de áreas desde cerca del nivel del suelo hasta la altura de las congregaciones de mariposas. Los lugares en* *supported aggregations and since have had trees removed exhibited high indirect and direct radiation and apparently now too open to support butterflies. We simulated proposed tree removals at two sites by editing digitized canopy photographs, which enabled us to predict resultant changes in indirect and direct radiation. These results provide quantitative guidelines for silvicultural management to maintain and enhance remaining aggregation sites along the California coast.*

los que incialmente se congregaban y en donde desde entonces se han cortado algunos árboles, presentaron mayor radiación indirecta y directa, y aparentemente ahora están demasiado expuestos para alojar a las mariposas. Nosotrossimulamos la tala de arboles propuesta para dos lugares, editando las fotógrafías digitales del docel y entonces pudimos predecir los cambios resultantes en la radiación directa e indirecta. Estos resultados ofrecen lineamientos cuantitativos para el manejo silvícola para mantener y realzar los lugares de congregación de la mariposa que quedan aún a lo largo de la costa de California.

Introduction

Monarch butterflies, *Danaus plexippus,* migrate long distances from late summer breeding grounds to overwintering sites where they annually aggregate in particular forest groves. Monarch populations that breed east of the Rocky Mountains migrate to the mountains of central Mexico (Urquhart & Urquhart 1976, 1978; Brower et al. 1977). Monarchs that breed west of the Rockies migrate to the Pacific coast (Urquhart & Urquhart 1977). Many overwintering sites in Mexico and California are threatened by lumbering, land development, overuse by visitors, tree senescence, drought, and insect pests. Declines in this essential habitat pose substantial risks to the health and long term persistence of the "monarch migration phenomenon" (Brower & Malcolm 1989).

On the Pacific coast of North America, monarch butterfly aggregation sites are distributed along more than 500 miles of coastline from Bolinas (Marin County) to northern Baja California (Sakai et al. 1989). Virtually all of these forest groves are within a kilometer of the Pacific Ocean, which moderates low winter temperatures and diurnal temperature fluctuations (Chaplin & Wells 1982). Subfreezing temperatures, high winds, and heavy rains or snow can cause direct mortality of monarchs (Calvert et al. 1983). Conversely, higher temperatures increase metabolic rates of adult monarchs, rapidly depleting their lipid reserves, and dry conditions can lead to dessication (Chaplin & Wells 1982; Masters et al. 1988). Shelter from strong winds also appears to be an important habitat characteristic (Leong 1990). Protection against such weather extremes is reliably found in western North America only in forest groves along the coast of central and southern California.

Most of the groves within which monarchs aggregate are dominated by *Eucalyptus globulus* (blue gum), a broadleaf evergreen species introduced to California in the late 1800s. Aggregation sites also occur within a few stands of Monterey pine (*Pinus radiata*) and Monterey cypress (*Cupressus macrocarpa*), native evergreen species that have been planted widely outside their narrow natural ranges.

Forest canopy structure is a primary determinant of microclimatic conditions within forest stands. Foliage intercepts solar radiation and wind to create an environment that is cooler, calmer, and more humid than that outside groves (Geiger 1965). Researchers have noted that monarch aggregation sites appear to have a characteristic canopy structure with moderate cover (Sakai et al. 1989), but no quantification of forest canopy structure has been reported to date.

Forest canopy structure is one of the few characteristics of monarch habitat that managers can both quantify and manipulate. Indeed, management of forest structure with standard silvicultural techniques is the only logistically feasible means of modifying insolation, wind, and relative humidity within a forest stand. Quantification of forest stand structure at monarch aggregation sites is a necessary first step in developing effective conservation and management plans for the monarch butterfly.

Hemispherical (fisheye) photography appears to be the best available technique for quantifying forest canopy structure (Anderson 1964; Pearcy 1989; Bunnell & Vales 1990; Rich 1990). The technique has been widely used in plant ecology (e.g. Anderson 1964; Pearcy 1983; Chazdon & Field 1987*a*; Neumann et al. 1989). It has also been used in studies of animal habitats, including bird nest surveys (Burger 1972), light environments and herbivory (Lincoln & Mooney 1984), and microsite utilization by butterflies (Warren 1985). Until recently, hemispherical photographs were analyzed by hand with overlaid sampling grids — a slow and error-prone process. Recent advances in digital image analysis now allow rapid and accurate analysis of large numbers of photographs (Chan et al. 1986; Chazdon & Field 1987*b*; Rich 1988, 1989, 1990; Becker et al. 1989).

In this study, we use hemispherical photography to quantify forest canopy structure in monarch butterfly overwintering habitats. With digital image analysis we calculate the amount of diffuse and direct light penetrating the canopy to points from which photographs were taken. We document the range of existing light conditions within and surrounding present monarch aggregation sites, and at former aggregation sites that have been altered by tree removal. Importantly, the digital image analysis system allows us to edit the digitized images and thus simulate the effects of tree removals on light conditions. By establishing the range of canopy structure correlated with monarch butterfly aggregations, this study can help predict effects of changes in canopy structure caused by tree growth, death, and removal. Lastly, this study documents the value of hemispherical canopy photography for conservation research that requires quantification of forest structure and light conditions.

Materials and Methods

Studies were undertaken during January 1990 at a series of monarch butterfly aggregation sites in Santa Barbara County, California. Some sites support aggregations throughout the overwintering season (October through March) and are referred to here as "permanent sites." "Transient sites" support aggregations for only part of the season. "Former sites" are those that once supported aggregations but no longer do so.

Hemispherical photographs were taken through a Nikkor f/4 hemispherical lens (180° field of view) fitted on a Nikon F2 body with a Nikon MF16 databack, using Kodak Tri-X (ASA 400) film and a red filter to increase contrast between sky and foliage. The camera and lens were held in a custom-made mount that leveled the lens. All photographs were taken with magnetic north oriented to the top of the image, allowing simulation of the solar path during analysis. Most photographs were taken 1.75 m above the forest floor, although a limited number of photographs were taken at approximately 7 m, with the photographer holding the assembly overhead while standing on a 3-meter-high folding ladder. Most photographs were taken near sunrise or sundown to prevent direct sunlight in the field of view. Midday photographs were taken in local shade.

Where monarchs were present, the photographs were taken directly below the butterfly clusters. In forest stands where no clusters were present, photographs were taken from a central location in the forest stand. Photographs were also taken along a transect running south to north from forest edge to forest edge through the most extensive aggregation site at Ellwood Main.

Photographs were analyzed with a microcomputer image analysis system using the program CANOPY (Rich 1988, 1989, 1990; Rich et al. 1989). This system allows for input of backlit negatives with a video camera, digitization with a video framegrabber, interactive determination of an intensity threshold that distinguishes openings from foliage, correction for the projection of the lens on the film and for lens distortion, and quantification of the geometric distribution of the openings to produce estimates of the amount of indirect and direct solar radiation that is expected to penetrate the openings.

Understory light conditions are characterized by two "site factors" — indirect site factor (ISF) and direct site factor (DSF) (Anderson 1964). The term "site factor" comes from analysis of lighting conditions in architecture and is defined as the proportion of potential solar radiation (indirect or direct) that reaches a given point (Walsh 1961). Site factors range from 0 (a completely blocked sky) to 1.0 (completely open sky). Indirect radiation is light scattered by the atmosphere or clouds; it is relatively uniform across the sky and has a low energy flux density. In contrast, direct beam radiation emanates from the solar disk, is highly directional, and has a high energy flux density. We did not perform a cosine correction of ISF and DSF relative to a horizontal surface (as is common for some applications) because we were interested in potential solar radiation from any sky direction.

Indirect site factor is the proportion of indirect solar radiation that penetrates the canopy from any sky direction. If the energy flux density of indirect radiation is assumed to be evenly distributed across the sky, then ISF is a measure of canopy openness weighted equally across all sky directions. ISF does not change through the year in these evergreen forests. ISF is an excellent measure of canopy openness as seen from beneath the canopy and serves as a correlate for interrelated microclimatic factors such as overall heat balance, rate of radiative heat loss to the night sky, humidity, and wind penetration.

Direct site factor is the proportion of direct radiation that penetrates the canopy. CANOPY calculates the angular coordinates (zenith and azimuth direction) of the sunpaths as they change through the day and through the year. From the intersection of sunpaths with canopy openings, CANOPY calculates annual DSF and monthly DSFs. Here, we have also calculated a winter DSF, the average of the monthly DSFs for October through February.

Because most hemispherical photographs were taken at 1.75 m above ground level, they provide only indirect measurements of the highly site-specific light conditions (particularly DSF) at the heights at which the butterflies cluster — generally 5 to 25 m above ground. Measurements at 1.75 m and those taken higher in the canopy are expected to be correlated, especially where understory vegetation is not dense. A dense understory can obscure overstory structure (Rich 1990). Identifying such a correlation is complicated by shifts in the angular position of canopy openings with height. In an initial exploration of this important issue, we examined verti- variation in ISF and DSF at several subsites within the .wood Main grove at heights of 1.75 m and 6.5 m.

Environmental changes brought by tree growth and senescence, wind throw, and human disturbance of many kinds may affect ISF and DSF. The editing capabilities of CANOPY were used to remove the canopies of particular trees from the images and assess resultant changes in ISF and DSF. This procedure helps predict changes in light conditions that occur as trees are removed or planted, or as buildings are constructed in or near monarch aggregation sites.

Results

Example Photographs

The analysis includes a total of 33 hemispherical photographs (Table 1). Six photographs are shown as examples of the range of conditions observed in this study (Fig. 1). Photos 1a and 1b are of unoccupied sites with low ISF and DSF. Photos 1c and 1d are of permanently occupied sites. Photo 1e illustrates the apparent upper limit of canopy openness for monarchs: this site supports only a small transient aggregation. Photo 1f (Thinned Grove) is of a former site that was thinned of understory and moderate-sized trees and does not currently support monarchs. It exhibits extremely high ISF 1 DSF.

.he qualitative observations that particular canopy structures are correlated with monarch butterfly aggregation sites are confirmed by ISF and annual DSF data plotted as a scattergram on ISF and annual DSF axes (Fig. 2a). ISF for occupied sites (both permanent and transient) ranges from .17 to .28; permanent sites range from .19 to .22. Yearly DSF at all occupied sites ranges from .07 to .30, while permanent sites again exhibit a smaller range than the transient sites (.17 to .24).

Winter DSF does not appear to be as well correlated with the presence of butterfly clusters (Fig. 2b). Ground-level winter DSF at Cementerio (one of the largest permanent sites), for example, is extremely low (.04) (Table 1) as a result of dense foliage to the south that blocks low winter sunpaths (Fig. 1d). Winter DSF at the small transient site at Llano Avenue is high (.35), indicating that the canopy is relatively open to the south. Winter DSF at a given site is usually lower than yearly DSF, because foliage in these forest stands tends to be denser along low winter sunpaths. However, a canopy gap along winter sunpaths may allow a high winter DSF at a particular site, such as that at Llano Avenue.

Within-site Variation in ISF and DSF

ZONTAL VARIATION

.thin a large aggregation site, both ISF and DSF can vary over short horizontal distances. Along a 130 m north-south transect from forest edge to forest edge through the Ellwood Main site, ISF ranged from .11 to .40 and DSF from .12 to .30 (Fig. 3a). On the coast side of the transect (50 and 70 m from the center of the aggregation) the canopy is dense and ISF and DSF are low. On the inland side (−50 to −60 m), the canopy is more open and ISF is high. At −40 m and −50 m the disparity in ISF (high) and DSF (low) is great because canopy cover is most dense to the south along monthly sunpaths. Similarly, the low ISF and high DSF at the forest edge (70 m) is the result of a canopy that is dense overhead and to the north, but relatively open to the south.

Winter DSF also varies along the same transect (Fig. 3b). The high winter DSF at the center of the Ellwood Main site results from the large canopy opening low in the southern sky (also see Fig. 1c). High winter DSF in the center of the aggregation site suggests that winter

Table 1. Characteristics of monarch aggregation sites in which hemispherical photographs were taken. Status refers to occupancy status—permanent sites support monarch butterflies through entire overwintering seasons; transient sites support butterflies for only portions of overwintering seasons; unoccupied sites do not support or attract monarch butterflies; and former occupied sites support large numbers in the recent past, but no longer do so. Superscripts a–f refer to sites illustrated in Figures 1a–f.

Site	*Status*	*ISF*	*DSF*	*Winter DSF*
Ellwood Main[c]	Perm	.214	.205	.182
Cementerio[d]	Perm	.192	.138	.039
Cementerio 2	Perm	.207	.162	.037
Tecolote	Perm	.198	.227	.183
Arroyo 10 m	Perm	.190	.177	.101
Arroyo −10 m	Perm	.226	.249	.202
Arroyo 30 m	Trans	.215	.214	.059
Arroyo −20 m	Trans	.191	.197	.070
Arroyo −30 m	Trans	.232	.250	.150
W. Ellwood	Trans	.214	.216	.068
N. Ellwood (1988)	Trans	.261	.277	.127
N. Ellwood	Trans	.220	.227	.208
E. Ellwood	Trans	.201	.071	.048
Ellwood Ck Bot	Trans	.197	.203	.122
Ellwood −2p	Trans	.187	.180	.050
Ellwood 10d	Trans	.197	.250	.168
Ellwood 12g	Trans	.160	.193	.126
Coronado[e]	Trans	.282	.297	.309
Llano Ave.	Trans	.230	.268	.351
Wilcox Mesa	Trans	.283	.274	.230
Honda Valley	Trans	.215	.279	.177
Butterfly Lane	Trans	.225	.225	.155
Arroyo 70 m	Unocc	.110	.162	.314
Arroyo 50 m[b]	Unocc	.196	.159	.108
Arroyo −50 m	Unocc	.305	.118	.059
Arroyo −60 m	Unocc	.396	.298	.096
Forest 20 m[a]	Unocc	.137	.129	.071
Forest 40 m	Unocc	.265	.242	.216
Music Acad. NW	Former	.308	.366	.347
Music Acad. S	Former	.265	.483	.566
Music Acad. E	Former	.409	.316	.251
Music Acad. Int.	Former	.199	.235	.300
Thinned Grove[f]	Former	.476	.593	.506

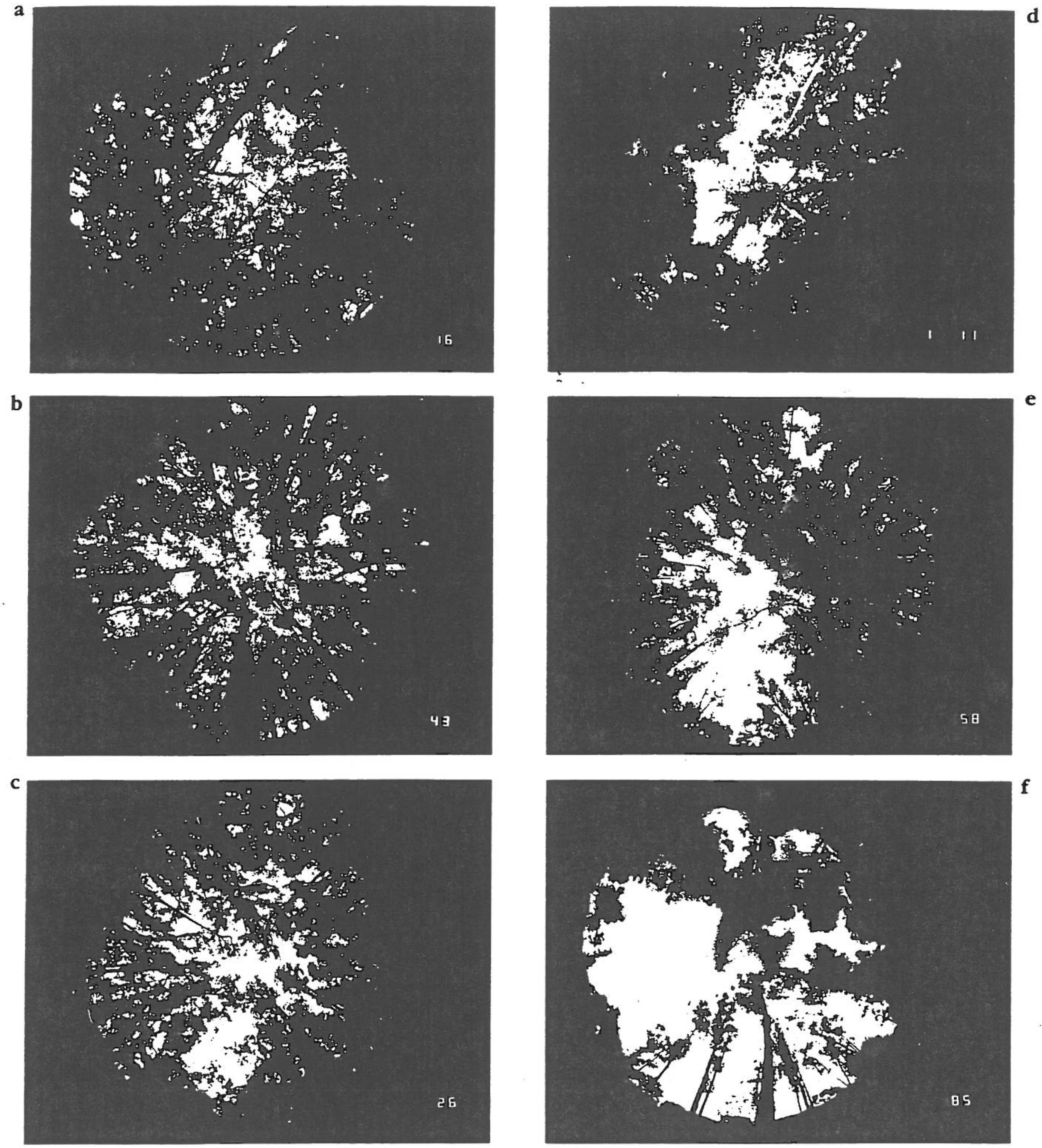


Figure 1. Hemispherical photographs of a sample of sites. 1a and 1b are unoccupied sites with low ISF and DSF; 1c and 1d are the centers of the two largest permanent sites (Ellwood Main and Cementerio); 1e (Coronado) illustrates the upper limit of canopy openness that attracts monarchs; 1f is a grove that has been thinned of understory and moderate-sized trees. See Table 1 for ISF and DSF at each site.

and even monthly DSF may play a role in determining microhabitat use within large aggregation sites, but we cannot make any assertions regarding microhabitat use without further data.

VERTICAL VARIATION

ISF and yearly DSF are generally higher at 6.5 m than at 1.75 m, but the increases are not necessarily large (Ta-

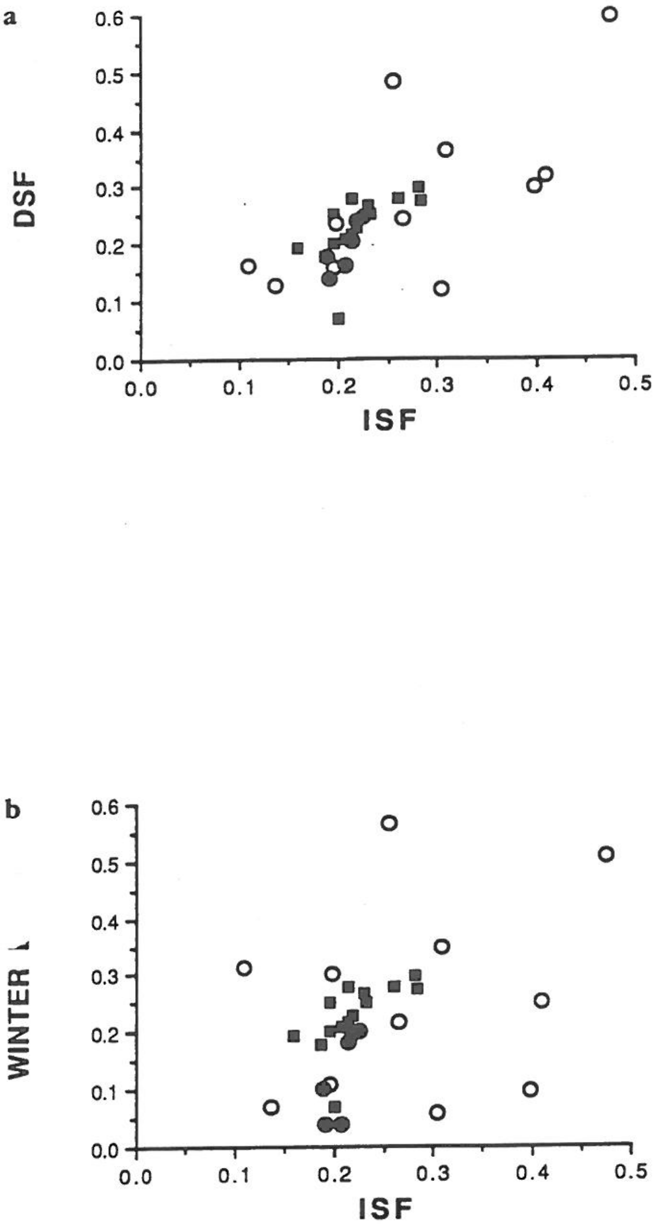


Figure 2. Scattergram of photographed sites on ISF and DSF axes. Dark circles are permanently occupied sites; squares are transient sites; open circles are unoccupied or formerly occupied sites. Note that permanently occupied and transient sites exhibit relatively narrow ISF and annual DSF ranges (2a). Winter DSF at occupied sites exhibits a larger range than yearly DSF (2b).

ble 2). The largest increases in ISF and DSF are at a site (12G) with a substantial understory, and the smallest increases are at the site with the least understory (Center).

Monthly DSF appears to be more sensitive to height g. 4). Monthly DSF showed a regular pattern at subsite −2P, with values consistently higher at 6.5 m than at 1.75 m (Fig. 4a). The Ellwood center subsite showed

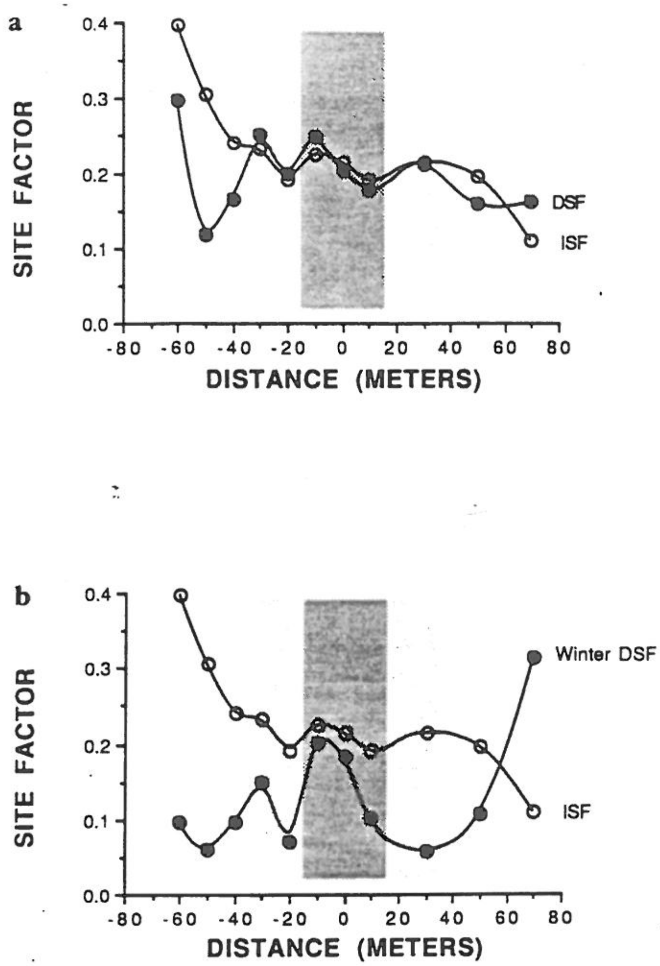


Figure 3. ISF and DSF along a transect from the forest edge on the ocean side through the center to the opposite forest edge at Ellwood Main aggregation site. Butterfly occupancy status along the transect is indicated by dark gray for permanent occupancy and light gray for transient occupancy. Much of the central portion of the transect exhibits similar ISF and yearly DSF (3a). Winter DSF significantly increases toward the center of the aggregation (3b), the result of a large canopy gap along winter sunpaths.

a more irregular pattern of vertical variation (Fig. 4b). In some months, DSF at 1.75 m was higher than at 6.5 m, but DSF in other months showed the opposite pattern. DSF in December is much lower at 1.75 m than at 6.5 m,

Table 2. ISF and DSF at different heights at four sites within the Ellwood Main grove.

	ISF		*DSF*		*Winter DSF*	
Site	*1.75 m*	*7 m*	*1.75 m*	*7 m*	*1.75 m*	*7 m*
Center	.21	.23	.20	.20	.18	.19
−2P	.19	.19	.18	.22	.05	.09
12G	.18	.23	.19	.28	.13	.18
10D	.14	.17	.18	.21	.09	.11

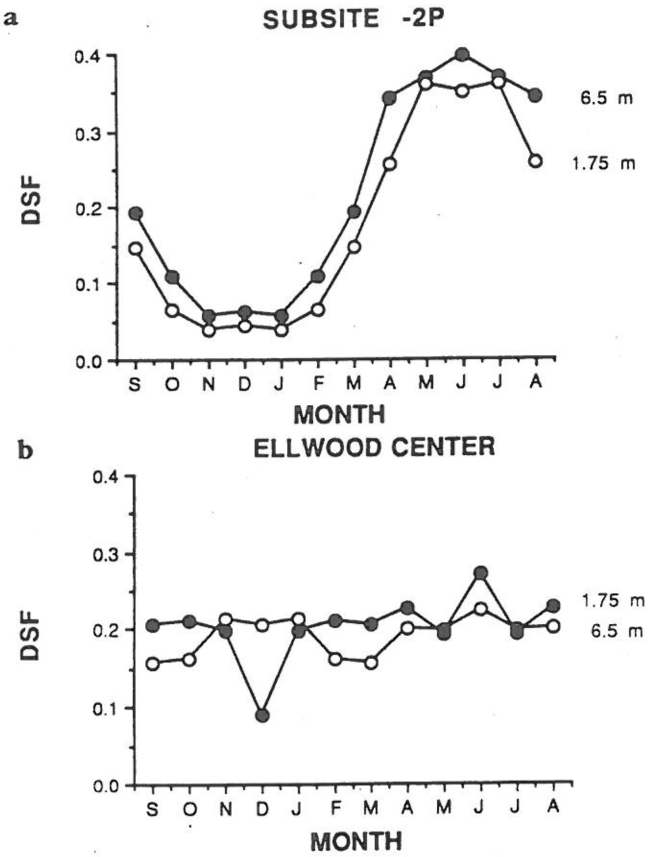


Figure 4. Vertical variation in monthly DSF at two sites, the center of Ellwood Main (same as 0 meters in Fig. 3) and a transient site (−2P) just east of the main aggregation. Note the regular increase in monthly DSF with height at subsite −2P compared with the more irregular pattern at Ellwood Main center.

due to the presence of branches and foliage that block the low December sunpath (see Fig. 1c).

The inconsistent relationship between ground- and mid-level site factors suggests that we cannot reliably extrapolate from monthly DSF at 1.75 m to monthly DSF at the level of butterfly clusters. Without such extrapolation or photographs at exact cluster locations, the utility of this and other finer scale measurements is reduced, especially related to the use of specific locations within a grove by monarch butterflies.

Effects of Forest Changes

Large numbers of monarchs previously aggregated in trees around the Music Academy of the West, approximately 10 km east of the large Ellwood Main colony. Following severe storm damage a decade ago, many trees were removed from this site and the canopy was dramatically opened, which apparently destroyed the suitability of the site. ISF and DSF are now suitable for monarchs at only one site around the Music Academy (Music Academy Interior, Table 1); however, this grove of trees does not attract butterflies, perhaps because of its limited area. While ISF at one site west of the Music Academy (Music Center S, Table 1) is still within the proper range (.26), DSF at this site (.41) is well above that found in any currently occupied sites. In a third area near the Music Academy, a grove of *Eucalyptus* that was recently thinned exhibits the highest ISF and DSF of any grove photographed (Thinned Grove, Table 1 and Fig. 1f).

In one grove, Coronado, several trees were removed in an attempt to increase suitability for monarchs (A. Wenner, personal communication). ISF and DSF at this site currently appear to be too high for either a permanent or a transient aggregation. Tree growth within and around the edges of the grove, however, may decrease both ISF and DSF so that the site may become more suitable for monarchs in the future. Importantly, this photograph (Fig. 1e) provides a baseline from which future changes in this grove may be assessed.

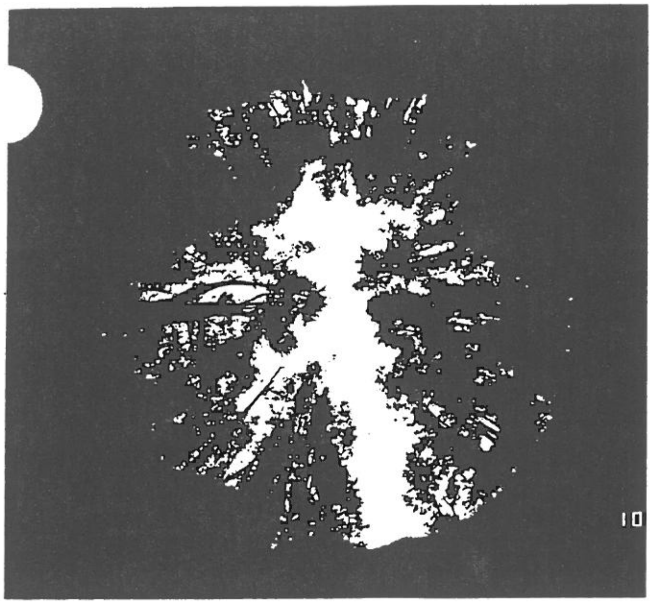
Predicting the Effects of Tree Removals

The above observations on the effects of tree removals on ISF and DSF do not facilitate rigorous comparisons of "before" and "after" site factors. The program CANOPY, however, allows us to edit digitized images to simulate the effects of tree removals, tree growth, and building construction on ISF and DSF. The canopies of particular trees were removed from images of two sites, Tecolote and Butterfly Lane, to predict changes in site factors that may be brought by proposed real estate developments.

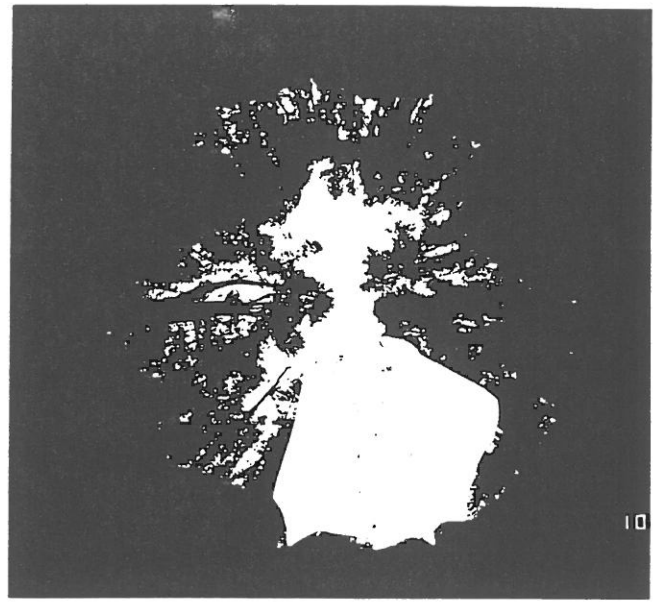
The Tecolote site lies in an arroyo and supports a permanent aggregation. Tree removal at Tecolote along the path of a proposed road would greatly open the site toward the south (Fig. 5a) and increase ISF and DSF substantially (Table 3). Two scenarios are considered: (1) minimal tree removal (with north as 0°, trees that fall between 194° and 239° azimuth), and (2) virtually complete tree removal along the road (between 179° and 257° azimuth). Both scenarios widen the existing canopy gap along the stream bed. The minimal removal scenario increases ISF to .22 and annual DSF to .27, at the upper end of the DSF range of occupied sites. The maximal removal scenario increases ISF to .28 and annual DSF to .37, both out of the range observed for occupied sites.

The effect of both scenarios on monthly DSF, particularly in winter, is striking (Fig. 5b). Trees that would be removed include those that block substantial portions of October through February sunpaths; thus, wintertime light levels would increase substantially. The probable result of tree removal is that the site will become less acceptable overwintering habitat for monarch butterflies. At best, minimal removal would drive the monarch clusters deeper into the forest surrounding the drainage.

a



b



c

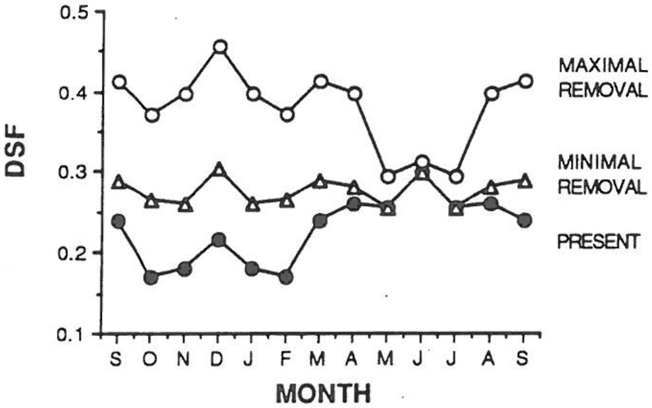


Figure 5. (a) Hemispherical photograph at Tecolote showing present canopy structure. (b) Maximum tree removal scenario at Tecolote. The white areas represent that portion of the canopy removed under the maximal removal scenario (trees removed between 179° to 257°). (c) Effect of tree removal scenarios on monthly DSF. The minimal removal scenario increases DSF during overwintering months from between 0.15 and 0.20 to between 0.25 to 0.30. The maximal removal scenario increases DSF during the same months to well above 0.35.

Maximal tree removal would probably cause monarchs to abandon the site.

The second site for which development is proposed, Butterfly Lane, supports a transient monarch aggregation early in the overwintering season. The trees proposed for removal are in the SE quadrant of the canopy, so their removal may increase DSF. However, the proportion of the total canopy removed is relatively small. Digital removal of these trees increases ISF from .23 to .26, and annual DSF from .23 to .28 (Table 3), at the upper end of the range observed at other occupied sites. Construction of a 8 m in height house decreases ISF slightly, but has no predicted effect on DSF because the elevation angle of the house from the photograph site (15°) does not intercept sunpaths. Tree removal at Butterfly Lane is expected to increase DSF the most during months surrounding the equinoxes (September–October and February–March; Fig. 6). Such changes in ISF and DSF could drive the transient aggregation away from this site, but the impacts are less obvious and the conclusion less clear than at Tecolote.

Discussion

In this preliminary study, hemispherical photography has proven to be a valuable tool for quantification of canopy structure for conservation research. Prior to this study, only anecdotal observations and other qualitative

Table 3. Effects of tree removals on ISF and DSF at two sites. Present ISF and DSF are taken from Table 1. The first row of projected site factors at Tecolote is for the minimal tree removal scenario (trees removed between 194° and 239° azimuth); the second row is for the maximal removal scenario (179° to 257°). At Butterfly Lane, the first row is for tree removal only; the second row is for tree removals plus the addition of an 8-m-tall house.

	Present		*Projected*	
Site	*ISF*	*DSF*	*ISF*	*DSF*
Tecolote	.198	.227	.221 .278	.275 .375
Butterfly Lane	.225	.225	.249 .243	.261 .261

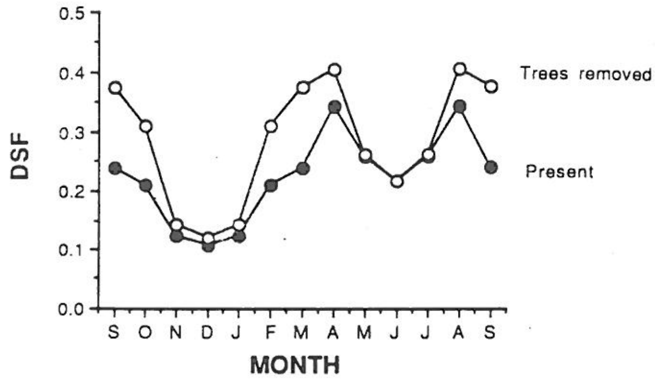


Figure 6. Effect of tree removal scenario on monthly DSF at Butterfly Lane. In contrast with Tecolote, DSF changes little in November, December, and January; note that the greatest changes occur around the equinoxes (September-October and February-March). Addition of the house does not affect DSF in any month.

data were available to biologists concerned with canopy structure and light conditions. The key finding of this study is that monarch aggregation sites fall into a narrow range of canopy structure as expressed by ISF and DSF. The apparent lower limits of ISF and DSF suggest that sites must allow sufficient insolation to allow butterflies to thermoregulate by basking in sunlight. The apparent upper limits on ISF and DSF indicate that forest groves must also be dense enough to moderate temperature, humidity, and wind.

Forest canopy structure that falls within the observed narrow ranges of ISF and DSF appears to be a necessary condition for forests to support aggregations of monarchs. These site factors alone, however, are not sufficient to assure that a grove will serve as an overwintering site. Among the other important features that determine habitat suitability are cool moist air pools in depressions or drainages within forest groves (Calvert et al., unpublished). Drainages also provide standing water that allow monarchs to rehydrate themselves during extremely dry Santa Ana weather conditions. Nearby nectar resources allow monarchs to replenish energy reserves during sunny weather; *Eucalyptus globulus* itself provides abundant nectar during the overwintering period.

Large disturbances to canopy structure, such as the removal of understory or overstory trees (particularly those blocking southern exposures), are likely to have drastic effects on habitat suitability. Our tree removal simulations suggest that individual trees can greatly affect ISF and DSF, particularly in small groves. Nonetheless, certain small changes in canopy structure may not necessarily reduce the suitability of an aggregation site. It is not surprising that human disturbances have disrupted and eliminated aggregation sites all at certain locations along the California coast, while monarch butterflies continue to aggregate in other disturbed sites in the midst of urban areas (Sakai et al. 1989).

Forest structure and its effects on interior microclimate is perhaps the only component of monarch habitat suitability that can be managed effectively. Individual trees can be planted or removed to manipulate ISF and DSF in central areas of forest groves. In fact, some silvicultural management appears to be a necessity if monarch aggregations are to persist in increasingly modified coastal environments. The editing capability of the CANOPY program can be used to predict the effects of such manipulation. Initial photographs create permanent records of existing canopy conditions, and photographs taken through time document long-term structural changes.

While this study has documented the use of hemispherical photography and digital image analysis, it constitutes only a preliminary application of the technique to investigation of overwintering monarch aggregations in a limited geographic area and in a single forest type. Logical extensions of this study include sampling over broader geographic areas, examining monarch sites dominated by different tree species (Monterey pine, Monterey cypress, native riparian, and Mexican fir), and more thorough sampling of microsite variation within aggregation sites. For example, a vertical hoist could be used to take photographs at monarch cluster heights within the canopy to investigate the importance of direct light in determining the exact locations of butterfly clusters. A vertical, as well as horizontal, sampling scheme could allow three-dimensional mapping of ISF and DSF within forest groves. Concurrently, relationships between canopy structure and microclimate conditions (temperature, wind, and relative humidity) could be investigated with standard micrometeorological equipment (e.g., Leong 1990; Calvert et al. 1983).

Overwintering monarch aggregations continue to diminish incrementally as both natural changes and human impacts affect forest grove habitats, but protection of overwintering monarch butterflies in California poses a paradoxical conservation challenge. Few aggregation sites appear to be "natural." Unlike the well-known groves in native Monterey pine forests (*Pinus radiata*) in Pacific Grove, the majority of present aggregation sites are in groves dominated by nonnative *Eucalyptus globulus*. The proximity of urban and agricultural areas to overwintering habitat also provides abundant nonnative nectar resources. Indeed, the large numbers of monarchs found in overwintering areas in California appear at least in part to be a consequence of widespread human disturbance across western North America that has favored the spread of milkweeds (*Asclepias* species), the larval host plants of the monarch butterfly (Vane-Wright, in press). The contradictions inherent in the preservation of an unusual ecological phenomenon in a far from pristine setting, coupled with the highly rged political atmosphere surrounding coastal land velopments, have caused disagreement and confusion over proper conservation measures.

In this arena, as in others, repeatable quantitative techniques are needed to direct conservation planning. Hemispherical photography and digital image processing provide a valuable method (perhaps the best available) of quantifying canopy structure in forests such as those used by overwintering monarchs. The strengths of the technique include a number of key features: (1) it is relatively easy to use and labor efficient; (2) it creates a permanent photographic record; (3) it facilitates quantitative comparisons between sites; (4) it is based on geometry and allows assessment of seasonal changes in light penetration from a single measurement; (5) it estimates site factors that correlate with microclimatic conditions, such as wind penetration; and (6) it allows prediction of structural changes in forest canopies. We strongly recommend use of this technique (and an appreciation of its limits) in habitats where canopy structure appears to be a primary factor to be addressed in conservation planning.

Acknowledgments

want to thank Kathy Rehm Switky for her always .pful comments and assistance in the preparation of this manuscript. Jack Baughman provided a critical reading of a late draft. Harold A. Mooney provided the use of his image-processing system and offered enthusiastic encouragement. Douglas Freund expertly machined the camera gimbals on short notice. We are particularly grateful to Anne Moore and Richard Garlinghouse of Southwest Diversified, Inc., for their support of much of this and associated research at Ellwood Main in Goleta, California. Additional support for this work has been provided by the William and Flora Hewlett Foundation, the New Land Foundation, the National Science Foundation (BSR 87-00102, BSR 89-18185, BSR 86-14769), Santa Barbara County, and Los Alamos National Laboratory Environmental Research Park.

Literature Cited

Anderson, M. C. 1964. Studies of the woodland light climate. I. The photographic computation of light condition. Journal of Ecology **52**:27–41.

Becker, P., D. W. Erhart, and A. P. Smith. 1989. Analysis of forest light conditions. Part I. Computerized estimation of solar radiation from hemispherical canopy photographs. Agricul- l and Forest Meteorology **44**:217–232.

Brower, L. P., W. H. Calvert, L. E. Hedrick, and J. Christian. 1977. Biological observations on an overwintering colony of monarch butterflies (*Danaus plexippus*: Danaidae) in Mexico. Journal of the Lepidopterists' Society **31**:232–242.

Brower, L. P., and S. B. Malcolm. 1989. Endangered phenomena. Wings 14(2):3–9.

Bunnell, F. L., and D. J. Vales. 1990. Comparison of methods for estimating forest overstory cover: differences among techniques. Canadian Journal of Forest Research **20**:101–107.

Burger, J. 1972. The use of a fisheye lens to study nest placement in Franklin's gull. Ecology **53**:362–364.

Calvert, W. H., W. Zuchowski, and L. P. Brower. 1983. The effect of rain, snow, and freezing temperatures on overwintering monarch butterflies, *Danaus plexippus* L. in Mexico. Biotropica **15**:42–47.

Chan, S. S., R. W. McCreight, J. D. Walstad, and T. A. Spies. 1986. Evaluating forest cover with computerized analysis of fisheye photographs. Forest Science **32**:1085–1091.

Chaplin, S. B., and P. Wells. 1982. Energy reserves and metabolic expenditures of monarch butterflies overwintering in southern California. Ecological Entomology **7**:249–256.

Chazdon, R. L., and C. B. Field. 1987*a*. Determinants of photosynthetic capacity in six rainforest *Piper* species. Oecologia **73**:222–230.

Chazdon, R. L., and C. B. Field. 1987*b*. Photographic estimation of photosynthetically active radiation: evaluation of a computerized technique. Oecologia **73**:525–532.

Lane, J. Overwintering monarch butterflies in California: past and present. In Biology and conservation of the monarch butterfly. Los Angeles County Museum of Natural History, Los Angeles, California. In press.

Leong, K. L. H. 1990. Microenvironmental factors associated with the winter habitats of the monarch butterfly (Lepidoptera: Danaidae) in central California. Annals of the Entomological Society of America **83**:906–910.

Lincoln, D. E., and H. A. Mooney. 1984. Herbivory on *Diplacus aurantiacus* shrubs in sun and shade. Oecologia **64**:173–176.

Masters, A. R., S. B. Malcolm, and L. P. Brower. 1988. Monarch butterfly (*Danaus plexippus*) thermoregulatory behavior and adaptations for overwintering in Mexico. Ecology **69**:458–467.

Neumann, H. H., G. den Hartog, and R. H. Shaw. 1989. Leaf area measurements based on hemispherical photographs and leaf-litter collection in a deciduous forest during autumn leaf fall. Agricultural and Forest Meteorology **45**:325–345.

Pearcy, R. W. 1983. The light environment and growth of C_3 and C_4 tree species in the understory of a Hawaiian forest. Oecologia **58**:19–25.

Pearcy, R. W. 1989. Radiation and light measurements. Pages 95–116 in R. W. Pearcy, J. Ehrlinger, H. A. Mooney, and P. W. Rundel, editors. Plant physiological ecology: field methods and instrumentation. Chapman and Hall, New York.

Rich, P. M. 1988. Video image analysis of hemispherical canopy photography. Pages 84–95 in P. W. Mausel, editor: First Special Workshop on Videography, Terra Haute, Indiana, May 19–20, 1988. American Society for Photogrammetry and Remote Sensing.

Rich, P. M. 1989. A manual for analysis of hemispherical canopy photography. Los Alamos National Laboratory Report LA-11733-M.

Rich, P. M. 1990. Characterizing plant canopies with hemispherical photographs. In: Instrumentation for studying vegetation canopies for remote sensing in optical and thermal infrared regions. Remote Sensing Reviews.

Rich, P. M., D. M. Ranken, and J. S. George. 1989. A manual for microcomputer image analysis. Los Alamos National Laboratory Report LA-11732-M.

Sakai, W., C. Nagano, A. V. Evans, J. Schrumpf, J. Lane, and M. Monroe. 1989. The wintering colonies of the monarch butterfly (*Danaus plexippus* L.: Nymphalidae: Lepidoptera) in the state of California, USA. California Department of Fish and Game, Sacramento, California.

Tuskes, P. M., and L. P. Brower. 1978. Overwintering ecology of the monarch butterfly (*Danaus plexippus* L.) in California. Ecological Entomology 3:141–153.

Urquhart, F. A., and N. R. Urquhart. 1976. The overwintering site of the eastern population of the monarch butterfly (*Danaus plexippus:* Danaidae) in southern Mexico. Journal of the Lepidopterists' Society 30:153–158.

Urquhart, F. A., and N. R. Urquhart. 1977. Overwintering area and migratory routes of the monarch butterfly (*Danaus plexippus;* Lepidoptera: Danaidae) in North America with special reference to the western population. Canadian Entomologist 109:1583–1589.

Urquhart, F. A., and N. R. Urquhart. 1978. Autumn migration routes of the eastern population of the monarch butterfly (*Danaus p. plexippus* L.: Danaidae: Lepidoptera) in North America to the overwintering site in the Neovolcanic Plateau of Mexico. Canadian Journal of Zoology 56:1759–1764.

Vane-Wright, R. I. The Columbus hypothesis: an explanation for the dramatic 19th century range expansion of the monarch butterfly. In: Biology and conservation of the monarch butterfly. Los Angeles County Museum of Natural History, Los Angeles, California. In press.

Walsh, J. W. T. 1961. The science of daylight. London, England.

Warren. M. S. 1985. The influence of shade on butterfly numbers in woodland rides, with special reference to the wood white, *Leptidea sinapsis.* Biological Conservation 33:147–164.