Monarch Butterfly Population Dynamics in Western North America - Emphasis on Monterey and San Luis Obispo Counties

Winter 2003-2004 Report

Prepared for Helen I. Johnson

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INTRODUCTION

The International Union for Conservation of Nature and Natural Resources classified monarch migration and overwintering as a “threatened phenomenon” due to the alarming rate that wintering habitat was being eliminated or degraded in both Mexico and along the California coast (Wells et al. 1983). This was an important step in monarch conservation because as a relatively abundant and wide-ranging species it was not listed at state or federal levels as endangered or threatened. However, the unique wintering requirements of monarchs and the recurring threat to their winter habitats along with the IUCN designation influenced the California Department of Fish and Game and the California Coastal Commission to preserve monarch wintering habitats. Regulatory and planning levels of government now require surveys for potential monarch wintering habitat for many developments that occur in the coastal zone. Despite this increased concern and policy, monarch habitats in western North America continue to be lost to development or natural causes (Brower et al. 2002; Frey & Schaffner 2004). To implement sound conservation policies for this unique species, knowledge about their migration, natal origins, overwintering phenology, as well as their diverse habitat requirements is still needed. This information should be collected over relatively long periods of time and at several spatial scales. It should also be in a format that allows for hypothesis testing and made readily available to the public.

This funded study has greatly increased our understanding of western monarch population dynamics and patterns of habitat occupancy. We have studied populations at scales ranging from individual habitats to the entire western region. We have also used several approaches including habitat monitoring, tagging, tracking changes in the condition and status of many individual butterflies, and genetic fingerprinting techniques.

This report constitutes a summary of the findings from the third year of a study of western monarch butterfly population dynamics. These findings are discussed in the context of our previous work (Hamilton et al. 2002; Frey et al. 2003). There were six primary objectives for the 2003-2004 season as follows:

1. Document seasonal abundance patterns of monarchs at eight wintering habitats in Monterey and San Luis Obispo counties from site surveys.

2. Document patterns of habitat-use by monarchs at each of the focal wintering habitats.
3. Summarize and analyze the 2003 annual Thanksgiving counts.

4. Correlate seasonal abundance and habitat use with local and regional weather. Also analyze statewide abundance with drought conditions during the past seven years.

5. Summarize tagging activity during the 2002 and 2003 wintering seasons.

6. Provide an update on our analysis of the genetic structure of western monarchs.

**METHODS**

**Study Sites**

Our study included field surveys at eight wintering sites in Monterey County and eight sites in San Luis Obispo County. In Monterey County these sites were Monarch Grove Sanctuary, George Washington Park, Point Lobos State Reserve, Palo Colorado Canyon, Andrew Molera State Park, a site on private property, Prewitt Creek, and Plaskett Creek Campground (Table 1 and Figure 1). In San Luis Obispo County, the sites included: Halcyon Hill, The Pike, Oceano Campground, Pismo North Beach Campground, San Luis Cemetery, Morro Bay State Park Campground, Morro Bay Golf Course, and Monarch Lane (Table 2 and Figure 2). The George Washington Park site was new for this season and the Morro Bay State Park Campground site replaced a site in San Luis Obispo, Bowden Estates, surveyed last season.

**Seasonal Abundance Patterns of Monarchs**

**Site surveys.** We surveyed each of the Monterey sites once each week from 5 November 2003 through the first week of March 2004 and the San Luis Obispo sites every other week during this time. Surveys were conducted in the mornings while temperatures were low (usually below 13°C) and monarch butterflies were still clustered. We did not survey during heavy precipitation and/ or strong winds because of poor visibility and increased chances of the butterflies being scattered and on the ground. We recorded the following data at each site using a standard data form (Appendix 1): date, site, observers, pre-count time start and end, count time start and end, presence of nectar and water sources, and observations of tagged or mating monarch butterflies. Weather data included: sky, percent cloud cover, wind speed and direction, temperature, precipitation, and percent fog. Sky was indexed from 0-8 by the following criteria: (0) Clear or few clouds, (1) Scattered clouds, (2) Mostly cloudy, (3) Overcast, (4) Fog or smoke, (5) Drizzle, (8) Showers. Wind was estimated
using the Beaufort’s wind scale (Appendix 2). For each tree that had roosting monarch butterflies, we recorded the number of monarch butterflies (see below), tree species, and tree identification number.

**Cluster estimations.** At each of the 16 wintering sites, we recorded estimates of the number of butterflies roosting in specific trees. We also estimated the number exhibiting other behaviors, e.g., basking, flying, etc. in the study area. To estimate the number of butterflies in a cluster, we first estimated the number of butterflies in a small area of a cluster and then extrapolated this count to arrive at a total count for the entire cluster. We recorded the average of the total counts of all observers. Total butterflies on each tree were calculated by summing the cluster totals. Prior to the butterflies’ arrival to their wintering sites, we conducted training workshops for project assistants designed to refine our estimating skills. Small clusters of butterflies were estimated by each participant and the cluster was captured and counted. This process was repeated many times. Each biologist gauged his/ her individual accuracy rate, corrected for his/ her individual bias, and calibrated with all observers. We practiced and implemented these techniques throughout the season to ensure that all observers were calibrated in their estimates.

To reduce potential biases inherent in site survey estimates, we periodically computed quantitative counts using Jolly-Seber or Petersen techniques with Krebs Ecological Methodology software. This was possible at habitats where we tagged monarchs during the season. If site survey visual estimates fell outside 95% confidence intervals from the quantitative methods, observers made further adjustments in estimating populations visually.

**Patterns of Habitat-Use by Monarchs**

**Cluster aspect.** We recorded the orientation of clusters of monarchs on each tree by recording the aspect or “outward” facing direction of clusters on each tree. For example, an aspect designation of “S” indicated that monarchs were roosting in the canopy facing south. These ranges were converted to presence or absence of butterflies at eight cardinal directions (N, NE, E, SE, S, SW, W, and NW). For each tree that had butterflies, the number of butterflies present was evenly distributed throughout the range of directions in order to weight aspects for cluster size.

**Cluster height.** For each tree with clustering monarchs we measured the vertical range of heights used. Heights were estimated by measuring a standard known height at the base of the tree below the clusters, such as the height of one of the researchers, then extrapolating that known height to the cluster positions.
**Spatial pattern of cluster trees.** At all San Luis Obispo County sites the location of each tree occupied by clustering monarchs was recorded on each site visit. At the Halcyon Hill, Pismo North Beach Campground, Morro Bay State Park Campground, and Morro Bay Golf Course sites we recorded the latitude and longitude coordinates (GPS) of these trees with a Garmin hand held GPS unit. We created maps of the spatial pattern of these trees for each site survey session with Arc View 3.2 (Figure 3). From these maps we made overlays onto aerial photographs of each site and created polygons that outlined the core area of habitat being used by roosting monarchs. From these polygons we measured several spatial-use features such as changes in size or location from week to week (Figure 4). At the other four SLO sites we recorded the approximate location of cluster trees by indicating them on an aerial photo.

**Analyses of Thanksgiving Counts**

Prior to 2002 the Monarch Program organized the western Thanksgiving counts and took a lead role in disseminating the results. Counts for the past two seasons have been organized and coordinated primarily by Mia Monroe, National Park Service and Xerces Society Monarch Campaign Coordinator, with the assistance of regional coordinators. In the past, summaries of the counts have been provided without analyses of patterns or long-term trends. We organized the Thanksgiving counts for Monterey and San Luis Obispo Counties for 2003. We also enlisted and trained volunteers in both counties to assist with counts but conducted the majority of counts ourselves. Copies of completed data sheets for the western monarch wintering range were supplied to the Cal Poly State University researchers by state-wide coordinator Mia Monroe. This information was added to a Thanksgiving count database for western monarch that we created last season. We used this data to analyze abundance patterns for Monterey and San Luis Obispo Counties as well as to carry out a meta-analysis for the entire western region. Using a variety of statistical procedures, we evaluated each habitat’s status based on its abundance relative to all other habitats. An Excel format data base of system wide counts for the seven year history is available on request.

**Weather and Climate Correlates of Population Dynamics and Space-Use Patterns**

**Sources of weather data.** Weather and climate information on three different spatial scales was recorded or downloaded from public access data bases. The three scales of analyses were: local at specific habitats, regional, and system-wide, i.e., western North America. To record fine-grained local weather we placed Hobo Pro series weather data loggers at two San Luis Obispo habitats,
Pismo and Halcyon Hill. The data loggers were positioned on the north side at a height of 2.5 m on trees where monarchs clustered. They recorded temperature and relative humidity hourly. This data was used to compare local microclimate conditions with changes in (1) the location of where monarchs aggregated and (2) the onset of spring dispersal.

We obtained regional scale weather data for Monterey County from a California Department of Water California Irrigation Management Information System weather station (CIMIS station #19) located near Castroville, California. Comparable data for San Luis Obispo County were downloaded from CIMIS station # 52 located on the Cal Poly State University campus, San Luis Obispo, California (Figure 5). These data were used to determine whether regional conditions such as precipitation, temperature, evapotranspiration, and wind velocity, differed between Monterey and San Luis Obispo Counties and whether the weather during the current season differed from the 2002-2003 season. In addition we used it to identify unseasonably hot dry periods and test whether they were associated with the timing of spring dispersal or changes in habitat-use patterns such as “tree switching” or movement in the location of core roosting areas.

We needed large scale weather conditions to conduct a meta-analysis of the relationship between drought status and population dynamics throughout western North America during the past seven years. We downloaded data for a meteorological drought index for the period 1997 through 2003 from the National Climatic Data Center from stations in four western states – Arizona, California, Nevada, and Oregon. These states were considered as the most likely breeding grounds for the majority of western migratory monarchs based on (1) their proximity to coastal wintering sites, (2) availability of host plant (Woodson 1954), and (3) the literature (Frey & Schaffner 2004). The Palmer Drought Severity Index, PDSI, is a widely used meteorological drought index that responds to weather conditions that have been abnormally dry or abnormally wet. The PDSI is calculated based on precipitation and temperature data, as well as the local available water in the soil. Human impacts on the water balance, such as irrigation, are not considered (Palmer 1965). Monthly PDSI values were available for each of the 27 geographical divisions of these four states (Figure 6). We averaged these values for each year to correlate with Thanksgiving count data. A second drought data set was created using only the PDSI information for the seven California divisions.

Defining hot/dry periods. Hot dry periods were operationally defined for the local scale Hobo data as days on which, for at least two hours, temperature was greater than 1.5 standard deviations (s.d.) above the seasonal average, i.e., trend line of a quadratic regression, and relative humidity was 1.5 s.d. below average. Similarly, hot dry periods based on regional CIMIS data were
determined by examining the residuals from a regression of daily maximum temperature and daily evapotranspiration (ETo) against Julian days. Days with residuals in excess of 1.5 s.d. were categorized as hot and dry.

**Tagging Program**

**Tags and tagging protocols.** We used tags from our previous year’s study that were similar to those used by Monarch Watch. The press-on tags were preprinted with 5-digit identification number, a toll-free telephone number, the name of the project (Monarch Alert), and the words “Free Call” (Figure 7). Tagging was planned for both Monterey and San Luis Obispo Counties, but permits or permission issues prevented our tagging efforts for Monterey County. Tagging took place at the Pismo wintering habitat during the 2003-2004 season. In addition to marking butterflies with these tags, we also marked nearly 3,000 individuals with a Sharpie pen in one of the marginal cells of the right hindwing. This was done by undergraduate students from a Cal Poly Animal Behavior class conducted by Dennis Frey on five sessions in November and December 2003. These butterflies were part of those necessary to make quantitative estimates of population abundance using Petersen or Jolly methods prior to our more formal tagging. Tagging was done on four sessions in January through March 2004. Details of the tagging sessions is given in Table 3. One thousand five hundred and fifty monarchs were tagged and 800 of that group were sampled for the protozoan parasite Ophryocystis elektroscirrha.

We captured butterflies early in the morning when temperatures were below flight threshold (10-14°C) to increase sample size and to reduce chances of injuring any butterflies. To capture clustered butterflies, we used long-reach adjustable poles with an attached soft mesh net. We collected butterflies from several locations, where possible, to ensure random samples. Butterflies were placed in large paper bags in groups of 50-100 and stored in an ice chest until processing. Cold temperature storage helped reduce movement and the chances for injury, accidental loss of tags, and horizontal transfer of O. elektroscirrha spores among individuals. Butterflies were drawn from bags and a tag carefully applied to the underside of the right hindwing over the discal cell (Figure 7). The identification number and information about the butterfly were recorded and the butterfly released.

**Assessment Protocols.** We recorded body condition measurements immediately after tag application using protocols similar to those used in the previous season. We visually assessed each tagged butterfly for wing damage, wing condition, and adiposity, and palpated females to determine mated status. Wing damage was a simple quantitative measurement of the number of wings on the
butterfly that had existing tears or portions missing with scores ranging from 0-4. A score of 0 indicated no obvious wing damage on any of the wings, whereas a score of 4 indicated that each of the four wings exhibited either tears or missing portions. A second, qualitative wing measurement was the wing condition score, which assessed amount of net scale loss from all four wings on a scale ranging from 1-5. A score of 1 was reserved for butterflies with no scale loss and wings in pristine condition. A score of 5 was given to butterflies exhibiting extreme scale loss coupled with highly visible wing membranes (Figure 8).

We scored adiposity from 1-3, using both lateral and ventral observations of the abdomen. By observing the ventral view of the abdomen, we assessed relative distension of the two white ventral abdominal stripes. Category 1 individuals often had black abdominal scales visible beyond the thin white ventral stripes, while category 3 individuals had highly distended ventral stripes with no visible black scales beyond the stripes (Figure 8). Thin, pencil-like abdomens were assigned a score of 1, with plump, ovoid-shaped abdomens assigned a score of 3.

Mated status conditions for females were determined by gently palpating the abdomen for the presence of a spermatophore. Scores ranged from 0 to 2, with 0 indicating a non-mated female, and a score of 2 indicating the definite presence of a spermatophore. The condition was difficult to measure, and a score of 1 was used if presence of a spermatophore was uncertain.

To collect samples for determining infection levels of the protozoan parasite, Ophryocystis elektroscirrha, we removed a few scales from a butterfly’s body by touching the abdomen with a small piece of transparent tape held with forceps. We then placed the tape on a white 3x5 card for inspection under the microscope. We categorized infection levels from 0 to 5. Categories 0, 1, and 2 are characterized by spore loads of 0, 1, and 2-20 spores, respectively, while category 3 depicts spore loads of 21-100. These are relatively low infection levels compared to category 4 with spore loads from 100-1000 and category 5 spore loads that exceed 1000 spores per sample (Figure 9).

**RESULTS**

**Seasonal Abundance Patterns of Monarchs**

**Overwintering Sites in Monterey County**

**Monarch Grove Sanctuary.** An estimated 15,563 monarch butterflies were present at Monarch Grove Sanctuary on the initial survey date of 6 November 2004 (Figure 10). Weekly estimates averaged 21,377 monarch butterflies during the months of November 2003 and December 2003. The maximum weekly estimate was 25,094 monarch butterflies recorded on 18 December.
2003. Weekly estimates declined only slightly during January 2004 (weekly average 19,239 butterflies), but declined more steadily in February 2004 (weekly average 13,477 butterflies). By March 2004, most of the monarch butterflies had dispersed. The final estimate, which was recorded on 4 March 2004, was 2,500 monarch butterflies.

Blue gum eucalyptus, Monterey cypress, and Monterey pine were the predominant tree species at Monarch Grove Sanctuary. Monarch butterflies clustered mainly on blue gum eucalyptus throughout most of the winter, but continued to consistently use Monterey pine. However, at the end of January, the monarch butterflies shifted to Monterey cypress and Monterey pine (Figure 11). This behavior is referred to as tree switching. Tree switching most likely occurs due to small abiotic changes in the roosting environment, or the habitat’s microclimate. Microclimate changes, such as humidity and temperature fluctuations, can occur independently of local weather patterns due to tree shading or site aspect. However, these changes are also often driven by larger-scale regional weather patterns. Through 30 January 2004, 64% of the total estimated number of butterflies were observed clustering on blue gum eucalyptus while 33% clustered on Monterey pine and 3% on Monterey cypress. In contrast, during February 2004, 42% of the total estimated number of butterflies were observed clustering on Monterey cypress, 33% on Monterey pine, and only 24% on blue gum eucalyptus.

**Private Property Site.** An estimated 11,078 monarch butterflies were present at the private property site on the initial survey date of 5 November 2003 (Figure 10). Weekly estimates averaged 17,809 monarch butterflies during the months of November 2003 and December 2003. The maximum weekly estimate was 21,918 monarch butterflies recorded on 24 November 2003. Weekly estimates increased during January 2004 (weekly average 18,371 monarch butterflies) and decreased in February 2004 (weekly average 14,306). By March 2004, most of the monarch butterflies had dispersed and the final estimate, which was recorded on 4 March 2004, was 3,242 monarch butterflies.

Coast redwood, blue gum eucalyptus, Monterey cypress, and Monterey pine were the predominant tree species at the private property site. Most of the monarch butterflies at the private property site clustered on a single coast redwood tree through February 2004 (Figure 12). From 5 November 2003 through 17 February 2004, 92% of the total estimated number of butterflies clustered on a single redwood, while 8% clustered on blue gum Eucalyptus. After the butterflies began dispersing at the end of February, they clustered primarily on Monterey pine (51% of the
total), with the remaining butterflies clustering on blue gum eucalyptus (19% of the total), Monterey cypress (16% of the total), and coast redwood (14% of the total).

**Andrew Molera State Park.** An estimated 16,133 monarch butterflies were present at Andrew Molera State Park on the initial survey date of 5 November 2003, which was the maximum weekly estimate at that site (Figure 10). Weekly estimates averaged 12,789 monarch butterflies during the months of November and December 2003. In January 2004, following a major storm, weekly estimates dropped considerably to an average of 5,425 and remained low throughout the month of February 2004 (weekly average 2,113). The final estimate, which was recorded on 26 February 2004, was 290 monarch butterflies.

Blue gum eucalyptus was the predominant tree species at the grove at Andrew Molera State Park and was the only tree species used by monarch butterflies.

**Plaskett Creek Campground.** An estimated 2,605 monarch butterflies were present at Plaskett Creek on the initial survey date of 5 November 2003 (Figure 13). Weekly estimates averaged 2,897 monarch butterflies during the month of November 2003. During the month of December 2003, the weekly average rose to 4,047, and the maximum weekly estimate was 4,383 monarch butterflies recorded on 10 December 2003. Weekly estimates declined during January 2004 (weekly average 2,377 butterflies) and by February 2004 the butterflies began dispersing (weekly average 1,495 butterflies). The final estimate, which was recorded on 26 February 2004, was 426 monarch butterflies.

Blue gum eucalyptus, Monterey cypress, and Monterey pine were the predominant tree species at Plaskett Creek. Monarch butterfly presence on these trees shifted over the course of the winter from Monterey pine to Monterey cypress (Figure 14). In November 2003, 91% of the butterflies clustered on Monterey pine while the remaining 9% clustered on blue gum eucalyptus, and in December 2003 100% of the butterflies preferred Monterey pine. However, from 15 January 2004 until the last estimate on 26 February 2004, 84% of the butterflies clustered on Monterey cypress while 16% clustered on Monterey pine.

**Point Lobos State Reserve.** An estimated 1,460 monarch butterflies were present at Point Lobos State Reserve on the initial survey date of 6 November 2003 (Figure 13). Weekly estimates averaged 3,021 monarch butterflies during the month of November, and doubled to 6,089 monarch butterflies during the month of December 2003. The maximum weekly estimate was 7,661 monarch butterflies recorded on 3 December 2003. In January 2004, weekly estimates declined to 4,103 butterflies, and declined further as the butterflies dispersed in February (weekly average 1,790
butterflies). The final estimate, which was recorded on 26 February 2004, was 158 monarch butterflies.

Monterey pine was the predominant tree species at the grove at Point Lobos State Reserve and was the only tree species used by monarch butterflies.

**George Washington Park.** An estimated 332 monarch butterflies were present at George Washington Park on the initial survey date of 6 November 2003 (Figure 13). Weekly estimates averaged 1,775 monarch butterflies during the month of November 2003. During the months of December 2003 and January 2004, weekly estimates rose to an average of 3,287. The maximum weekly estimate was 3,841 monarch butterflies recorded on 29 January 2004. The butterflies began dispersing mid-February, and weekly estimates declined to an average of 1,447 during February 2004. Most of the butterflies had dispersed by March 2004, and the final estimate, which was recorded on 4 March 2004, was 527 monarch butterflies.

Monterey pine was the predominant tree species at the grove at George Washington Park and was the only tree species used by monarch butterflies.

**Autumnal Sites in Monterey County**

**Palo Colorado Canyon.** An estimated 159 monarch butterflies were present at Palo Colorado Canyon on the initial survey date of 13 November 2003 (Figure 15). Weekly estimates averaged 88 monarch butterflies during November 2003 and rose to an average of 110 monarch butterflies during the month of December 2003. The maximum weekly estimate was 225 monarch butterflies recorded on 3 December 2003. Weekly estimates declined steadily into January 2004 (weekly average 62 butterflies), and February 2004 (weekly average 6 butterflies). The butterflies had dispersed entirely by 26 February 2004, when zero butterflies were detected at the site.

Blue gum eucalyptus was the predominant tree species at the grove at Palo Colorado Canyon and was the only tree species used by monarch butterflies.

**Prewitt Creek.** An estimated 131 monarch butterflies were present at Prewitt Creek on the initial survey date of 5 November 2003 (Figure 15). Weekly estimates averaged 166 monarch butterflies during November 2003, and the maximum weekly estimate was 199 monarch butterflies recorded on 24 November 2003. In December 2003, the average weekly estimate was 78 monarch butterflies, declining to 27 monarch butterflies during the month of January 2004 and 17 monarch butterflies during the month of February. The final estimate, which was recorded on 26 February 2004, was 12 monarch butterflies.
Blue gum eucalyptus was the predominant tree species present at the grove at Prewitt Creek and was the only tree species used by monarch butterflies.

**Overwintering Sites in San Luis Obispo County**

**Pismo North Beach Campground.** The Pismo North Beach Campground site had higher overall counts this season than the 2002-03 season. More butterflies were also present earlier in the season this year. On the initial survey date of 14 November 2003, an estimated 14,830 butterflies were present (Figure 16). This number rose to 38,438 butterflies by the next population estimate on 26 November 2003. The population estimate declined between early December and January, but rose to the maximum population estimate of 47,031 on 23 January 2004. This was the largest monarch butterfly overwintering site in San Luis Obispo County this season, and has been the largest site in San Luis Obispo County every year since 1991. By the following biweekly estimate on 6 February 2004, the population had drastically declined to a population estimate of 6,075 butterflies. The final estimate, recorded on 5 March 2004, was 1,751 butterflies.

In addition to visual estimates, mark-release-recapture methods were also used to determine population abundance and assess our visual estimates at the Pismo North Beach Campground. The Jolly-Seber and Peterson techniques were used for the mark-release-recapture method. Monarch butterflies were tagged or marked, and then released. Recapture of these tagged or marked monarchs at subsequent site visits allowed use of this alternative method for population estimates. Our visual population estimate was 38,425 butterflies on 5 December 2003. The mark-release-recapture method returned a population range of 12,755-128,105 butterflies with 95% confidence limits. On 11 December 2003, 23,100 butterflies were estimated visually, while the mark-release-recapture method returned a population range of 15,797-29,225 butterflies with 95% confidence limits.

Blue gum eucalyptus, Monterey pine, and Monterey cypress are the predominant tree species found at Pismo North Beach Campground. Butterfly clusters were found on all three of these tree species at different points throughout the season (Figure 17). While Monterey cypress and blue gum eucalyptus were the most consistently used tree species, Monterey pine also sporadically supported many butterfly clusters. Early in the season, November through mid-December, approximately 18% of the butterflies were roosting in Monterey pine with the remaining 82% roosting in the blue gum eucalyptus and Monterey cypress. By January, approximately 26% of the butterflies were roosting in Monterey pine followed by a significant decline to 0% by early February. From this date until the end of the season, butterflies clustered exclusively on blue gum eucalyptus and Monterey cypress.
**Oceano Campground.** Population estimates at Oceano Campground were uncharacteristically low this season. The initial estimate on 14 November 2003 of 14,865 butterflies was also the maximum estimate for the entire season (Figure 16). Within one month, the population declined to 2,375 butterflies on 11 December 2003, less than 25% of the population maximum. Numbers continued declining throughout the remainder of the season with only 6 butterflies recorded on the final survey date of 5 March 2004.

Monterey pine was the predominant tree species at Oceano Campground and was the only tree species used by butterflies. In previous years monarchs also clustered on Torrey pines at this same site.

**Halcyon Hill.** An estimated 5,420 butterflies were present at Halcyon Hill on the initial survey date of 14 November 2003 (Figure 16). The maximum population estimate was 6,400 monarch butterflies recorded the following survey on 26 November 2003. Biweekly estimates declined during the months of December 2003 and January 2004 with a biweekly average of 3,900 butterflies. The final estimate, recorded 20 February 2004, was 1,250 monarch butterflies with zero butterflies present on 5 March 2004.

Blue gum eucalyptus was the predominant tree species at Halcyon Hill and was the only tree species used by butterflies. The site is located on private property with the eucalyptus trees planted in a plantation-like pattern. The habitat occurs on sloping terrain which is unlike the majority of the San Luis Obispo sites which are predominantly flat. Some natural gaps have developed within this stand (Figure 18).

**Morro Bay Golf Course.** The Morro Bay Golf Course supported higher population counts this season, with an initial population estimate of 2,110 butterflies on 13 November 2003 (Figure 19). By 12 December 2003, the population had increased to an estimate of 5,548 butterflies. After a noticeable decline to 1,985 butterflies in early January, the population rose to a maximum estimate of 6,675 butterflies on 24 January 2004. Between 21 February 2004 and the final survey date on 5 March 2004, the population dropped drastically from 6,480 butterflies to 720 butterflies.

Blue gum eucalyptus was the predominant tree species at Morro Bay Golf Course and was the only tree species used by butterflies.

**Morro Bay Campground.** Site surveys were not conducted at this habitat last year, so year-to-year comparisons cannot be made. On the initial survey date of 13 November 2003, an estimated 2,700 butterflies were present (Figure 19). While the population rose to 10,050 on 27 December 2003, it declined down to 6,425 by the end of January. On 8 February 2004, the population
increased to a maximum estimate of 10,100 butterflies. This was the largest maximum population estimate recorded for the Morro Bay region of San Luis Obispo County. The final estimate, recorded 6 March 2004, was 1,652 butterflies.

Blue gum eucalyptus and Monterey cypress were the predominant tree species used at Morro Bay Campground (Figure 20). The butterflies clustered on eucalyptus only until early December. By 12 December 2003, 13% of the total estimated numbers of butterflies were roosting on Monterey cypress. This number dropped down to 1.5% the following survey and by 10 January 2004, had risen back to 11% of the total estimated number of butterflies. From this date onwards, clusters recorded in eucalyptus steadily declined, and Monterey cypress use increased. On 8 February 2004, 79% of the total estimated numbers of butterflies were roosting on Monterey cypress and only 21% of roosting butterflies were found on eucalyptus. This site is in California State Parks jurisdiction and the habitat is maintained as a mixed stand of several tree species arranged in a natural grove (Figure 21).

Autumnal Sites in San Luis Obispo County

**The Pike.** An initial population estimate of 1300 butterflies was recorded on 14 November 2003 (Figure 19). The final estimate of 473 butterflies was recorded on only the second survey, 26 November 2003. By early December, all the butterflies had dispersed.

Blue gum eucalyptus was the predominant tree species at the Pike and was the only tree species used by butterflies.

**Monarch Lane.** An initial population estimate on 13 November 2003 recorded 510 butterflies present. On the following survey date, 25 November 2003, the population had risen to a maximum estimate of 1,160 butterflies. By the last week of December, all of the butterflies had dispersed. The final estimate, recorded on 12 December 2003, was 144 butterflies.

Blue gum eucalyptus was the predominant tree species and the only tree species used by butterflies at Monarch Lane. This habitat has been highly modified in efforts to enhance its quality and status as a monarch wintering site (Leong 1999). The open area in the photo represents trees that were cut down as part of the habitat modification (Figure 22).

**San Luis Cemetery.** San Luis Cemetery supported more butterflies this season than last season and the butterflies persisted longer, until the last week of February. The initial population estimate on 13 November 2003 was 415 butterflies. The population continued to rise until 10 January 2004, with a maximum estimate of 920 butterflies. The final estimate, recorded on 21
February 2004, was 225 butterflies. By the following survey period, all of the butterflies had dispersed.

Blue gum eucalyptus, Monterey pine, and other Pinus species were the predominant tree species found at San Luis Cemetery. Pinus sp. was the tree most consistently used by the butterflies throughout the season, with two notable exceptions (Figure 23). On 27 November 2003, all butterflies clustered exclusively on Monterey cypress and on 23 February 2004, all clustered butterflies were found exclusively on eucalyptus.

Habitat-Use Patterns by Monarchs

Cluster aspect and height. In Monterey County monarch butterfly clusters were observed at all cardinal directions (N, NE, E, SE, S, SW, W, NW), with the majority of clustering monarch butterflies (54%) observed at NE, E, or SE aspects (Figure 24 a). All overwintering sites were roughly similar. At Andrew Molera State Park, most of the clustering butterflies (55%) were observed on SE to SW aspects. At the private property site, the majority of butterflies (69%) were observed clustering on NE and E aspects of roost trees. At three of the sites, the majority of clustering butterflies were observed on E, SE, and S aspects: George Washington Park (82%), Point Lobos (60%), and Plaskett Creek (70%). Only one autumnal site did not have a clear dominant aspect: Monarch Grove Sanctuary had butterflies clustered relatively evenly on all aspects except W and NW. Averaged across all sites, monarch butterflies clustered at heights between 8 meters and 10 meters from ground level. Wind direction was highly variable throughout the season, blowing predominantly from the NE, E, SW, and NW (collectively accounting for 61% of the wind direction) (Figure 24 a).

In San Luis Obispo County cluster aspects also occurred in all cardinal directions but 66% of measured cluster aspects were oriented SE, S, or SW (Figure 24 b). Two autumnal sites, Monarch Lane and the Pike, deviated most from this pattern with many of their clusters facing eastward. The average height of monarch clusters at the eight SLO habitats ranged from 8 to 13 meters. The cluster heights were greatest at Monarch Lane (autumnal site) and Morro Bay Campground (wintering site).

Spatial pattern of cluster trees. The week-by-week locations of the core area used by roosting monarchs at four San Luis Obispo County sites are shown on Figures 25 & 26. The trees on which monarchs roosted sometimes changed significantly between consecutive survey dates. For example between week 1 and week 3 at Halcyon Hill, there were no overlapping trees between the
two weeks (Figure 25 a). Similarly, Morro Bay Campground had this same non-overlapping shift between weeks 15 and 17 (Figure 26 b). The median size of the core-use areas were as follows: Halcyon Hill (84 m$^2$), Pismo (496 m$^2$), Morro Bay Campground (492 m$^2$), and Morro Bay Golf Course (676 m$^2$). The large size of the Morro Golf Course core area was somewhat distorted by an unusually large area reported for the 15th week of the survey (see Figure 26 b) during which extreme overcast conditions made it difficult for the GPS unit to lock on to satellites. However, even after disregarding the week 15 reading the median area was still larger than the other habitats (654 m$^2$). Occasionally there was a very large difference in the size of core areas between weeks when a group of monarchs either spread very far apart or condensed tightly as illustrated at the Pismo habitat between week 7 and week 9 (Figure 25 b).

Another feature of the core areas used by monarchs that we were able to measure with our Arc View analysis was the primary direction or orientation of the grouping of cluster-trees within the overall stand of trees making up the habitat. The Morro Bay Campground’s clustering trees were predominantly oriented in an east-west pattern while trees used at the Halcyon Hill site were strongly oriented in a north-south manner the majority of time. Orientations at the other two sites had much less directionality (Figures 25 & 26).

### 2003 Annual Thanksgiving Count

Abundance at California winter habitats was once again collected as part of the annual Monarch Program Thanksgiving Count (MPTC) for 2003, marking the eighth year since the program’s inception. While data was collected statewide by many volunteers, Ventana Wilderness Society researchers provided data for eight Monterey County habitats and Cal Poly researchers collected data for 23 San Luis Obispo County habitats.

This season’s collecting efforts increased substantially over the 2002 season, with an additional 32 sites surveyed statewide (Table 5). While Thanksgiving Counts have recorded the rise and fall of monarch populations over the last eight years, it is important to realize that the number of sites surveyed can play a large, influential role in determining statewide abundance. In 1997, the year of the first MPTC, 101 monarch habitats were surveyed. As additional volunteers were recruited and the program became more widely known, the number of sites surveyed each season continually increased, reaching a maximum of 140 sites in 2000. The next few years revealed a decline in the number of sites surveyed, following a management shift of the MPTC. The 2003 season showed a 36% increase in the number of monarch habitats surveyed over last season, the
first such increase since 2000. Hopefully this trend will continue as once again, more volunteers are recruited in this data collection effort for the western monarch population. In addition to increased collecting efforts, the Cal Poly team has compiled the collected data for 2003 into a database that will be made available to the public.

Statewide monarch abundance for the 2003 season is almost 1½ times larger than the 2002 season with 254,359 monarch butterflies counted in all counties (Table 5). Once again, this also represents an increase in survey effort. To account for the differences in survey effort between the 2002 and 2003 season, it is more valid to compare the median values. The median (or midpoint) population values are another good measure of abundance patterns. The median value is the middle value of a list of measurements, or in our case, a list of population numbers at many different habitats. While the overall total number of butterflies increased this season, this is supported by the increase in the median value from 13.5 individuals per site in 2002 to 30 individuals in 2003.

There were population increases for the 2003 season for all nine counties that reported data for both the 2002 and the 2003 seasons. Monterey County reported 68,978 butterflies this year, a substantial increase over the 11,593 butterflies recorded for 2002. San Luis Obispo County reported 92,752 butterflies compared to the 2002 season abundance of 50,487 butterflies. Accordingly, San Luis Obispo County comprised the largest overwintering butterfly populations statewide, with Monterey County comprising the 2nd largest overwintering populations. Santa Barbara County fell to 3rd ranking this year with a reported county total of 35,324 butterflies. Together, Monterey County and San Luis Obispo County account for 64% of the total number of butterflies counted statewide in 2003.

Marin County’s population doubled this year with 12,763 butterflies reported. Santa Cruz County’s population also increased substantially over last year, and this increase was almost entirely due to increased numbers at two sites- Lighthouse Field and Moran Lake. Santa Barbara County also showed increased numbers, which is noteworthy since only about half as many habitats were surveyed this season compared to the 2002 season. Sonoma County’s population of 160 butterflies represents only one habitat out of the four known county habitats. While the increase in monarch population is comparatively smaller than to those sites discussed above, Alameda County, Los Angeles County and San Diego County also showed increased monarch abundance.
Weather and Climate Correlates of Population Dynamics and Space-Use Patterns

Seasonal Abundance and Habitat Use Patterns. Weather differed markedly between the 2002 and 2003 monarch wintering seasons in both counties based on regional-level comparisons of temperature and dryness (ETo) from CIMIS weather stations. Conditions were 11% warmer for both counties during last season, 2002-2003, and dryer by over 15%. The timing of brief periods of unseasonably hot, dry conditions also differed between the two years. We assessed the influence that extreme hot, dry weather may have had on monarch population dynamics during the dispersal phase of the wintering season.

For Monterey County habitats we considered how these events may have influenced two population measures - the onset of population decline and tree switching (see above). At Monarch Grove Sanctuary the onset of significant population decline was identified as occurring just prior to the 26 January survey along with substantial tree switching, i.e., many monarchs began roosting on cypress trees instead of eucalyptus (Figures 10 & 11). These population changes were preceded by hot, dry weather on 21-23 January. Similarly, the private property site had significant population decline and tree switching (redwood to eucalyptus) between 9 February and 16 February (Figures 10 & 12). Regional hot, dry weather occurred on 2 February 9, 10, and 11 based on CIMIS records.

In San Luis Obispo County we used the above two measures of population change, as well as the occurrence of any shifts in the location of core clustering areas based on the GIS component of the study. Dispersal at the Pismo site began following the 23 January survey and was accompanied by tree switching, but not a shift in the core-area location (Figures 16, 17). Hot, dry weather extremes, indicated from the on-site data logger, occurred on January 21, 22, & 25. A similar regional weather extreme occurred on February 9, 10, and 11 and was congruent with the population decline at the Morro Bay Campground site. Tree switching also occurred there at this time (cypress to eucalyptus) but there were not changes in core-area use at the site.

Statewide Abundance and Drought. Our meta-analysis combines data between drought status and population dynamics throughout western North America during the past six years. The year 1998, an El Nino year, was the last year of abundant soil moisture and precipitation in the western United States. The Palmer Drought Severity Index (PDSI) has dropped steadily through 2002, as shown by declining drought index values on Figure 27a. During the current year, higher levels of precipitation and less extreme temperatures have resulted in a lessening of drought conditions. As shown in Figure 27a, the yearly population median follows the same decline as
drought index values through 2002. This past season, the population increase seems to have occurred in response to the increasingly favorable moisture conditions.

To test this hypothesis we conducted analyses at two different spatial scales. First, we looked at the variation between population size and PDSI for the following four states - Arizona, California, Nevada, and Oregon. Next we did the same analysis, but instead only used the PDSI values from California. While both statistical models showed that drought variation did account for abundance variation, the model using all four states accounted for more of the variation. Nearly 99% of the statewide variation in abundance is explained by the variation in drought averaged over all four states. This is represented by all solid circles falling close to the predicted regression line in Figure 27b.

A more detailed analysis of the statewide population increase in 2003 relative to drought conditions was made by looking at population abundance at the county level. We did this by analyzing the relative change in abundance between the 2002 and 2003 seasons for all Thanksgiving Count habitats. The results indicated that many habitats did not increase comparably across the coastal range of western wintering grounds, and some showed population declines. Position of a point relative to the horizontal line shown on Figure 28 represents the degree to which population abundance either increased or decreased at individual habitats compared to the previous season. Points, or habitats, at the far right of the figure represent sites predominantly from San Diego County. Points located on the far left of the figure represent sites in Marin County. Sites located in the southern extreme of the wintering range responded less favorably to the increasingly cooler, wetter conditions in the western region. While four of the seven Marin County sites had patterns similar to San Diego County, the northern half of the wintering range showed overall positive growth patterns.

**Tagging Program**

**Tagging Sessions.** From 19 November 2003 to 7 March 2004 we tagged or marked 4,230 monarch butterflies during nine sessions at the San Luis Obispo Pismo site. Table 3 gives details of the tagging sessions. Thirty four of the tagged individuals were recaptured during the last two sessions along with comparable numbers of monarchs marked with the Sharpie method. Tagged and marked butterflies were spotted at the nearby Oceano site by members of the site-survey crews, but not at any of the other habitats. There were numerous reports of tagged monarchs being found on-site at the Pismo habitat, but only one long-distance “call back” has been logged as of the date of
this report. As with the previous season, reports may occur as dead monarch are discovered during the next few months. Data summarizing the current and previous two seasons for tagging is shown in Table 4. The migrant monarch (#23895) reported for this year was found in San Mateo, California on May 15, 2004 which is a later reporting date than any during previous years. The butterfly was a male that had one damaged wing and fatty index 2 at the time of tagging. Its straight-line flight distance of 307 km makes it the 5th longest recovery in our three year program. Its northward flight path was typical of the majority of our long distance reports.

**Monarch Butterfly Condition.** As the database from the 2002-03 season nears completion, we've been able to start analyzing small portions of the tagging data from almost 20,000 tagged butterflies. All butterflies that were tagged as part of the tagging component of the study were also assessed for several body condition measurements (as described in Tagging Methods). These measures included wing damage, wing condition, adiposity and the mated status of females. While these measurements can help elucidate factors involved in spring dispersal, they can also answer interesting questions regarding differences between our eight habitats in four counties.

Ordinal regression techniques combined with cross tabulation queries of our tagging database revealed interesting associations between fat index, the adiposity measurement, and county. For this test, we focused on butterflies tagged during Session 1, in November. Santa Cruz and Marin Counties had relatively more butterflies that scored a fat index measurement of 3, meaning that they had more fat butterflies than San Luis Obispo and Monterey Counties. While Santa Cruz and Marin County had more fat butterflies, they accordingly had fewer skinny butterflies, or butterflies with a fat index score of 1. Our two southern counties, San Luis Obispo and Monterey Counties, showed the opposite trend; these counties had fewer fat butterflies and many more skinny butterflies. Using the same statistical techniques against tagging session, which is essentially looking at changes in fat load over the course of the season, showed that fat levels decreased.

We performed the same statistical techniques using wing condition as our body condition measurement of interest. Wing condition assesses the overall wear of the butterfly wings, along with scale loss on a scale of 1 to 5, with 5 being the most heavily worn or damaged wings. Results of this test showed that Marin had the fewest number of butterflies with heavily worn wings (wing condition score of 5) and also had the fewest number of butterflies that scored a wing condition measurement of 4, which is still considerably worn wing condition. Santa Cruz County, like Marin County, also had fewer butterflies that scored 4’s and 5’s. The county that had the highest number of 5’s, butterflies with heavily damaged wings, was Monterey County. San Luis Obispo had relatively
more butterflies with a wing condition score of 4. These results show a slight north-south trend in wing condition, with the more southern counties having somewhat more butterflies with heavily worn wings, while the northern counties had fewer butterflies with heavily worn wings. Looking over all three tagging sessions, there are differences in wing condition as the season progresses.

**Ophryocystis elektroscirrha.** We compared the incidence of heavy infection of monarchs with *O. elektroscirrha* between counties and over the tagging sessions from the 2002-2003 samples. We defined heavy infection as categories 4 and 5 using Altizer’s criteria (100 or more spores mm$^2$; Altizer & Oberhauser 1999, Altizer et al. 2000). Using binary logistic regression and cross tabulation, the incidence of heavily infected butterflies did not differ between counties (range: 21.63% to 23.46% for San Luis Obispo and Santa Cruz counties respectively). In addition the incidence of heavily infected individuals remained constant over the three sessions.

**Genetic Analysis**

Analysis of the regional population genetic structure of western monarchs is essential for the conservation and management of this species. As part of the project Monarch Alert, genetic analysis of the northern half of the western monarch population is underway to look for genetic relatedness among individuals at eight different habitats. Along with our tagging results, this information will help test two important hypotheses regarding monarch migration: the local recruitment hypothesis and the mixing bowl hypothesis. The local recruitment hypothesis suggests that most wintering populations originate from localized, nearby breeding ranges (Wenner and Harris 1993). In contrast, the mixing bowl hypothesis suggests that wintering populations originate from a large, distant panmictic population, hence the name “mixing bowl.” Genetic structure of monarch populations will be tested with the isolation by distance model, which predicts genetic variation should increase with distance. According to this model, localized breeding monarch populations under the local recruitment hypothesis should be more distantly related to other populations along the coast, especially among more distant habitats in different counties. However, if there is very little or no genetic variation among different populations along the coast, that supports the mixing bowl hypothesis. While this is the ultimate goal of the genomics portion of our project, there are no laboratory results to present as yet. Therefore, this section constitutes a brief progress report.

Amplified fragment length polymorphisms (AFLPs) is a DNA fingerprinting technique that we are using to analyze western monarch population structure. In order to learn how to use this technique, Shawna Stevens and Dennis Frey traveled to the University of El Paso, Texas (UTEP) in
July 2003 to study under Dr. Sandra Perez, a leading authority on the use of AFLPs in analyzing monarch genomics. She is currently doing research on a worldwide population genetic study of monarch butterflies. We spent one week in her lab at UTEP, working long hours to practice the technique and become familiar with the equipment (Figure 29). The end product of this technique is a gel with the DNA fragments of several different individuals. Each individual’s unique array of DNA fragments constitutes their “fingerprint.” We will then compare fingerprints between different individuals, and different populations to determine genetic variation. Due to differences in lab equipment between Cal Poly and UTEP, we are transitioning to the equipment here at Cal Poly. We will use a different sequencer, the piece of equipment that allows us to visualize these DNA fragment patterns. Instead of a gel, we will have a computer generated image that will indicate the presence of DNA fragments by a colored peak (Figure 30). The computer will then transform this data into a binary coding system for computer analysis. This switch to a new piece of equipment is a time-consuming task, as it requires troubleshooting numerous small problems to make the transition successful. We have conducted several test runs with sample DNA and the results look very promising. The next few months should be exciting as we start processing and analyzing our DNA results.

DISCUSSION

Over the past three years, this project has ranged in scope from studies of individual habitats to system-wide population dynamics. We took this broad approach because the wintering range of western monarchs spans approximately 700 km with great differences in topography, vegetation, and microclimate between habitats. This contrasts drastically with the homogeneous overwintering habitats in Mexico, which occur in close proximity to one another and are subject to less variable conditions. Field studies were done at many varied habitats throughout the northern half of the monarchs wintering range. Sites included those with traditionally large numbers (e.g., Pismo, Natural Bridges), those with mixed stands of the three signature tree species of western habitats (e.g., Morro Bay Campground, Figure 21), and those with definite anthropogenic character (e.g., Halcyon Hill, Figure 18; Monarch Lane, Figure 22). To accomplish our goals, we used a variety of techniques ranging from field work to molecular genetics, tagging studies to GPS spatial patterns, and descriptive observations to statistical analyses.

While the overall scope of the project has evolved over the past three years, conservation of western monarch butterflies has been the primary goal of Helen I. Johnson, the project’s founder.
With the notoriety of the eastern monarch population, it is hard to remember that the western monarch population is not well studied and their presence here on the west coast is not well documented. This project was only possible due to her vision and desire for increased public awareness of western monarch populations and threats to their habitats. What follows are discussions of significant findings from the 2003 season, with comparisons to results from the previous two years.

The most notable finding was a significant increase in monarch abundance in western North America this year over last year’s record low. This was verified by our site surveys at focal habitats in San Luis Obispo and Monterey Counties and data from the 2003 Thanksgiving Count. This follows a consistent and significant decline in monarch abundance from the previous five years. Monterey County reported increased abundance at all 8 habitats, while San Luis Obispo County reported increased abundance at all but one habitat, Oceano Campground. These two counties make up more than 50% of the statewide abundance of monarch butterflies.

The proximate factors that cause monarchs to switch from sedentary summer breeding butterflies to the migrating wintering generation are fairly well known. They include shortening day length, declining temperatures, and changes in chemical composition of milkweed (Goehring & Oberhauser 2004). However, the causative factors that initiate the onset of dispersal from coastal overwintering sites are not known. It is generally believed that periods of hot, dry weather may influence spring dispersal. The timing of tree switching and changes in core roosting areas this season were related to extreme weather events in both San Luis Obispo and Monterey Counties. Tree switching and changes in core roosting areas occurred during both the first half and the second half of the season, but tree switching often occurred simultaneously with the onset of dispersal. Periods of hot dry weather recorded at habitat and county levels were also associated with both tree switching behavior and the onset of dispersal. This was similar to a finding of last season, but dispersal occurred one month earlier. A variety of factors might have caused last season’s early dispersal, but it may have been related to last year’s weather conditions being warmer and drier in both counties.

Another major finding for this season is the effect of western North American climatic conditions on statewide monarch abundance. Since the last El Nino conditions in 1998, abundance has declined from over a half million butterflies to a low of less than a hundred thousand butterflies. This dramatic decline occurred statewide and is congruent with increasing drought conditions in the west. This year’s increase in monarch abundance occurred simultaneously with the lessening of
drought conditions, suggesting a causal relationship between them. Increasing drought conditions lead to overall declines in milkweed biomass at monarch breeding grounds, which in turn leads to lower monarch recruitment to the migratory population. This concept is commonly referred to as the bottom-up approach to population dynamics in contrast to top-down control by predators and parasites.

We used a statistical regression technique with the Thanksgiving Count data, and found that population abundance at winter habitats was strongly correlated between successive years. This was true for all habitats in the Thanksgiving Count database and each pair of successive years beginning with 1998 and ending with 2003. These findings also support our hypothesis that a large proportion of the population decline of monarchs during the past six years has resulted from system-wide influences. From this technique, there were a number of individual habitats that had abundance patterns that were consistently above or below those predicted by the model. Drought conditions would be expected to have a larger effect on sites located in the southern extreme of the range, such as sites located in San Diego County. Under lessening drought conditions, such as this past season, it is expected that these southern sites would recover more slowly than sites located elsewhere in the range. This pattern is evident and shown in Figure 28.

The findings from our three year tagging program have revealed much about monarch population dynamics. For all three years, monarchs rarely transferred beyond nearby, neighboring sites during the wintering period. Butterflies tagged in one county never transferred to a site in another county. Most of the butterflies reported by calls to the toll free number had estimated distances of less than 15 kilometers. Additionally, most of these butterflies had a non-random flight path orientation that was predominantly northward. A significant finding from the tagging portion of our study was a recovered butterfly from Pueblo, Colorado, a town located on the eastern side of the Rockies. The general view is that western and eastern monarch populations do not mix and are kept isolated by large geographical barriers, such as the Rocky Mountains.

The tagging component of the study allowed us to identify individual butterflies and monitor changes in these butterflies over time as they were recaptured or recovered. We compared the fat index and wing condition among the four counties over time. Butterflies from the two northern counties (Santa Cruz and Marin Co.) tended to be fatter. This apparent difference in fat load between our two northern counties and our two southern counties (San Luis Obispo and Monterey Co.) can be due to a number of different factors, such as weather for example. Perhaps the cooler temperatures in the north allow the butterflies to metabolize less and hold on to their fat store.
Another finding was that the fat levels declined over the course of the season. This is expected, as fat stores are used without replacement for energy and survival over most of the winter months.

There was also a north-south trend in wing condition. Monterey and San Luis Obispo Counties had somewhat more butterflies with more worn wings, while the northern counties had fewer butterflies with heavily worn wings. There was also increasing wing wear as the season progressed. The cross tabulation test that looked at changes in fat index and wing condition among counties was performed only for Session 1 butterflies, or those butterflies tagged in November. Since these were butterflies arriving at the overwintering sites in November, and the southern butterflies were skinny with worn wings, this leads to interesting questions about the length and difficulty of travel to respective overwintering sites.

In contrast to the body condition tests, we did not find any differences between counties for the prevalence of *O. elektroscirrha*. We also tested the hypothesis that females with greater levels of infection would gain weight seasonally. This association was predicted on the basis of a study of captive butterflies under summer conditions (Altizer & Oberhauser 1999). We found no association between these two variables in the context of our field study of wintering monarchs.

The way that monarchs used our focal habitats was similar to the previous year. No differences were detected in cluster height or aspect between this year and last year. Clustering typically occurs in mid-level tree canopy and was similar to other studies of western monarchs (Frey et al. 1992). Cluster aspects did differ between the two counties, with Monterey County monarch clusters generally facing eastward while San Luis Obispo County butterflies generally faced southward. This unexplained difference requires further investigation, but is most likely due to unique local topography and/ or weather. At four of the eight habitats in San Luis Obispo County, we mapped the location of all trees that contained roosting monarchs throughout the season. The core areas used by monarchs did not change greatly from one survey period to the next. At Pismo North Beach Campground, core areas overlapped for six consecutive weeks. Halcyon Hill differed most from the other three habitats. It had the smallest core area, cluster trees had a north-south axis, and its core-area was spatially separated at least once during the season.

**Conclusion.** The monarch has been referred to as a butterfly without borders because its breeding grounds are sometimes distantly located in Canada from its wintering grounds in Mexico. This can be true not only for the more familiar eastern populations but also for those in western North America. The monarch also transcends typical borders between science and the arts and there
is still much about it that remains a mystery. However, a great deal of what we know about
monarchs in general, and specifically for this study, is the result of tireless efforts of citizen scientists
like Helen Johnson who frequently are at the vanguard of helping bridge borders. The findings from
this three year study is evidence that one persons dedication can help greatly increase our
understanding of the causative factors that influence the population dynamics of monarchs in
western North America.

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Table 1. Study sites and surveys on the coast of Monterey County, California during winter 2003-2004.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Site Location</th>
<th>Predominant Tree Species</th>
<th>Survey Period</th>
<th>Number of Surveys</th>
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<td>Pacific Grove Monarch Sanctuary</td>
<td>3.0 km N&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Blue Gum Eucalyptus Monterey Cypress Monterey Pine</td>
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<td>Private Property</td>
<td>50.0 – 60.0 km S</td>
<td>Blue Gum Eucalyptus Monterey Cypress Monterey Pine</td>
<td>11/5/03 - 3/4/04</td>
<td>17</td>
</tr>
<tr>
<td>Prewitt Creek</td>
<td>60.0 km S</td>
<td>Blue Gum Eucalyptus</td>
<td>11/5/03 - 2/26/04</td>
<td>16</td>
</tr>
<tr>
<td>Plaskett Creek Campground</td>
<td>60.5 km S</td>
<td>Blue Gum Eucalyptus Monterey Cypress Monterey Pine</td>
<td>11/5/03 - 2/26/04</td>
<td>16</td>
</tr>
</tbody>
</table>

<sup>a</sup> North of Carmel River  
<sup>b</sup> South of Carmel River
Table 2. Study sites and surveys on the coast of San Luis Obispo County, California during winter 2003-2004.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Site Location</th>
<th>Predominant Tree Species</th>
<th>Survey Period</th>
<th>Number of Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halcyon Hill</td>
<td>Halcyon</td>
<td>Monterey pine</td>
<td>11/14/03 – 3/5/04</td>
<td>9</td>
</tr>
<tr>
<td>The Pike</td>
<td>Grover</td>
<td>Blue gum eucalyptus</td>
<td>11/14/03 – 3/5/04</td>
<td>9</td>
</tr>
<tr>
<td>Oceano Campground</td>
<td>Oceano</td>
<td>Monterey pine</td>
<td>11/14/03 – 3/5/04</td>
<td>9</td>
</tr>
<tr>
<td>Pismo North Beach Campground</td>
<td>Pismo</td>
<td>Blue gum eucalyptus</td>
<td>11/14/03 – 3/5/04</td>
<td>9</td>
</tr>
<tr>
<td>Morro Bay State Park Campground</td>
<td>Morro Bay</td>
<td>Blue gum eucalyptus</td>
<td>11/13/03 – 3/6/04</td>
<td>9</td>
</tr>
<tr>
<td>Morro Bay Golf Course</td>
<td>Morro Bay</td>
<td>Monterey pine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monarch Lane</td>
<td>Los Osos</td>
<td>Blue gum eucalyptus</td>
<td>11/13/03 – 3/6/04</td>
<td>9</td>
</tr>
<tr>
<td>San Luis Cemetery</td>
<td>San Luis Obispo</td>
<td>Blue gum eucalyptus</td>
<td>11/13/03 – 3/6/04</td>
<td>9</td>
</tr>
</tbody>
</table>
**Table 3.** Tagging/ marking sessions in San Luis Obispo County during winter 2003-2004

<table>
<thead>
<tr>
<th>Date</th>
<th>Number marked with Sharpie</th>
<th>Number tagged</th>
<th>Number sampled for <em>Ophryocystis elektroscirrha</em></th>
<th>Tagged individuals recaptured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 19 &amp; 21, 2003</td>
<td>500</td>
<td>None</td>
<td>None</td>
<td>0</td>
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<tr>
<td>Dec. 3 &amp; 5, 2003</td>
<td>1,000</td>
<td>None</td>
<td>None</td>
<td>0</td>
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<tr>
<td>Dec. 11, 2003</td>
<td>1,180</td>
<td>None</td>
<td>None</td>
<td>0</td>
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<tr>
<td>Jan. 16, 2004</td>
<td>0</td>
<td>500</td>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>Jan. 31, 2004</td>
<td>0</td>
<td>450&lt;sup&gt;a&lt;/sup&gt;</td>
<td>300</td>
<td>16</td>
</tr>
<tr>
<td>Feb. 14, 2004</td>
<td>0</td>
<td>350&lt;sup&gt;b&lt;/sup&gt;</td>
<td>200</td>
<td>18</td>
</tr>
<tr>
<td>Mar. 7, 2004</td>
<td>0</td>
<td>250</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,680</td>
<td>1,550</td>
<td>800</td>
<td>41</td>
</tr>
</tbody>
</table>

<sup>a</sup> Captured and checked 1,675 total  
<sup>b</sup> Captured and checked 995 total  
<sup>c</sup> Total monarchs processed (both “tagging” methods) was 4,230
Table 4. Tagged monarchs reported from distances greater than 15 km.

<table>
<thead>
<tr>
<th>Tag #</th>
<th>General location found</th>
<th>Origin</th>
<th>Date found</th>
<th>Distance traveled (km)</th>
<th>Flight direction</th>
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</thead>
<tbody>
<tr>
<td><strong>2001 Callbacks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5372</td>
<td>Pozo - SLO</td>
<td>PISM</td>
<td>3/20/2002</td>
<td>33</td>
<td>NE</td>
</tr>
<tr>
<td>5651</td>
<td>River Pine</td>
<td>PISM</td>
<td>3/27/2002</td>
<td>379</td>
<td>N</td>
</tr>
<tr>
<td>5005</td>
<td>American Canyon-Napa</td>
<td>PISM</td>
<td>3/24/2002</td>
<td>350</td>
<td>N</td>
</tr>
<tr>
<td><strong>2002 Callbacks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7073</td>
<td>San Luis Obispo</td>
<td>PISM</td>
<td>2/14/2003</td>
<td>15</td>
<td>N</td>
</tr>
<tr>
<td>3975</td>
<td>Gonzales</td>
<td>PRIVPROP</td>
<td>2/20/2003</td>
<td>42</td>
<td>NE</td>
</tr>
<tr>
<td>3107</td>
<td>Carmel</td>
<td>PRIVPROP</td>
<td>2/25/2003</td>
<td>33</td>
<td>NE</td>
</tr>
<tr>
<td>19891</td>
<td>Cambria</td>
<td>PISM</td>
<td>3/15/2003</td>
<td>58</td>
<td>N</td>
</tr>
<tr>
<td>na</td>
<td>San Jose</td>
<td>na</td>
<td>3/31/2003</td>
<td>115</td>
<td>N</td>
</tr>
<tr>
<td>na</td>
<td>Springdale, Utah</td>
<td>na</td>
<td>3/31/2004</td>
<td>793</td>
<td>E</td>
</tr>
<tr>
<td>na</td>
<td>West Hollywood</td>
<td>na</td>
<td>3/31/2003</td>
<td>244</td>
<td>SE</td>
</tr>
<tr>
<td>14171</td>
<td>Bakersfield</td>
<td>PISM</td>
<td>4/5/2003</td>
<td>154</td>
<td>E</td>
</tr>
<tr>
<td>16472</td>
<td>Red Bluff</td>
<td>PUGA</td>
<td>4/7/2003</td>
<td>255</td>
<td>N</td>
</tr>
<tr>
<td>10375</td>
<td>Santa Maria</td>
<td>OCEA</td>
<td>4/8/2003</td>
<td>31</td>
<td>S</td>
</tr>
<tr>
<td>12378</td>
<td>Rocklin</td>
<td>LIHO</td>
<td>4/10/2003</td>
<td>215</td>
<td>N-NE</td>
</tr>
<tr>
<td>21820</td>
<td>Goleta</td>
<td>PISM</td>
<td>4/10/2003</td>
<td>110</td>
<td>S</td>
</tr>
<tr>
<td>1934</td>
<td>Pueblo, Co.</td>
<td>ANMO</td>
<td>4/28/2003</td>
<td>1451</td>
<td>E-NE</td>
</tr>
<tr>
<td><strong>2003 Callbacks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23895</td>
<td>San Mateo</td>
<td>PISM</td>
<td>5/15/2004</td>
<td>307</td>
<td>N</td>
</tr>
</tbody>
</table>

na - tag number not available
1 Origin estimated at Big Sur vicinity
3 Origin estimated at Pismo/Oceano vicinity
Table 5. County-level abundance for annual monarch butterfly Thanksgiving counts compared among years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendocino</td>
<td>3,310</td>
<td>50</td>
<td>0</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Sonoma</td>
<td>6,660</td>
<td>1,600</td>
<td>750</td>
<td>3,206</td>
<td>7</td>
<td>NR</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Marin</td>
<td>32,150</td>
<td>16,200</td>
<td>6,200</td>
<td>31,315</td>
<td>1,018</td>
<td>6,335</td>
<td>12,763</td>
<td></td>
</tr>
<tr>
<td>San Francisco</td>
<td>850</td>
<td>110</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Solano</td>
<td>NR</td>
<td>110</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Contra Costa</td>
<td>8,000</td>
<td>12</td>
<td>1,000</td>
<td>600</td>
<td>153</td>
<td>0</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Alameda</td>
<td>53,700</td>
<td>27,085</td>
<td>7,348</td>
<td>9,680</td>
<td>6,350</td>
<td>4,000</td>
<td>5,050</td>
<td></td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>260,000</td>
<td>119,898</td>
<td>31,958</td>
<td>62,961</td>
<td>6,123</td>
<td>7,034</td>
<td>22,700</td>
<td></td>
</tr>
<tr>
<td>Monterey</td>
<td>45,000</td>
<td>41,000</td>
<td>25,000</td>
<td>20,000</td>
<td>31,199</td>
<td>11,593</td>
<td>68,978</td>
<td></td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>249,800</td>
<td>182,050</td>
<td>83,050</td>
<td>103,050</td>
<td>70,783</td>
<td>50,487</td>
<td>92,752</td>
<td></td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>354,300</td>
<td>84,312</td>
<td>87,138</td>
<td>131,266</td>
<td>66,278</td>
<td>22,429</td>
<td>35,324</td>
<td></td>
</tr>
<tr>
<td>Ventura</td>
<td>188,000</td>
<td>65,100</td>
<td>22,815</td>
<td>18,710</td>
<td>28,465</td>
<td>4,965</td>
<td>15,305</td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>34,775</td>
<td>18,180</td>
<td>2,022</td>
<td>9,701</td>
<td>1,536</td>
<td>127</td>
<td>1,188</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>13,650</td>
<td>4,358</td>
<td>43</td>
<td>43</td>
<td>86</td>
<td>NR</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>San Diego</td>
<td>25,615</td>
<td>2,590</td>
<td>100</td>
<td>348</td>
<td>78</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Baja California</td>
<td>4,680</td>
<td>1,757</td>
<td>150</td>
<td>198</td>
<td>NR</td>
<td>NR</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>

Total          | 1,280,490| 564,412| 267,574| 391,078| 212,076| 107,010| 254,363|

Median         | 2000    | 250    | 100    | 25.5  | 25     | 13.5   | 30    |

Sites Surveyed | 101     | 111    | 118    | 140   | 126    | 90     | 122   |

Data source: Monarch Program Thanksgiving counts; NR - not reported
Figure 1. Locations of eight study sites on the coast of Monterey County, California surveyed winter 2003-2004.
Figure 2. Locations of eight study sites on the coast of San Luis Obispo County, California surveyed winter 2003-2004.
Figure 3. Spatial analyses of cluster trees at San Luis Obispo wintering sites. (a) Holly Tretten (left) records GPS coordinates of a cluster-tree while Andrea Barron (middle) and Shawna Stevens (right) record data and estimate monarch abundance. (b) Shawna, Holly, and Andrea converting field data into spatial maps for analyses.
**Figure 4.** The location of trees with clusters of monarchs from field GPS coordinates at the Morro Bay Campground habitat during the 1st week of the study.
Figure 5. California Irrigation Management Information Stations – source data for regional weather. (a) Weather station #19, (b) approximate locations of CIMIS station #19 (Castroville) and CIMIS station #52 (San Luis Obispo).
Figure 6. National Climatic Data Center climate divisions in four western states from which Palmer Drought Severity Index data were used in analyses of climate effects on monarch butterfly population trends.
(Source: http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/statelist.html)
Figure 7. Monarch tagging. (a) Cal Poly State University undergraduate assistants (left) and a member of the “parasite club” with a tagged monarch resting on her hat (right). (b) Schematic of tag showing the location on typical placement on the underside of the right hindwing.
Figure 8. Scoring methods for monarch wing and body condition. (a) Examples of two of the five categories used to score monarch butterfly wing condition. (b) Ventral view of monarch butterflies to illustrate one of the criteria to score adiposity. A fat, category 3 butterfly is shown on the left.
Figure 9. Screening monarchs for spore loads of the parasite Ophryocystis elektroschirra. (a) Shawna Stevens and Chelsie Romulo counting monarchs in a Cal Poly State University lab. (b) Microscopic view of an uninfected monarch (left) and a heavily infected butterfly (Category 5).
Figure 10. Weekly estimates of overwintering monarch butterflies at three overwintering sites in Monterey County, California during winter 2003-2004.
Figure 11. Estimated number of monarch butterflies using different tree species at Monarch Grove Sanctuary during winter 2003-2004.
Figure 12. Estimated number of monarch butterflies using different tree species at private property site during winter 2003-2004.
Figure 13. Weekly estimates of monarch butterflies at three overwintering sites in Monterey County, California during winter 2003-2004.
Figure 14. Estimated number of monarch butterflies using different tree species at Plaskett Creek Campground during winter 2003-2004.
**Figure 15.** Weekly estimates of overwintering monarch butterflies at two transitional sites in Monterey County, California during winter 2003-2004.
Figure 16. Estimates of monarch butterflies at four wintering sites in southern San Luis Obispo County, California during winter 2003-2004. Stars indicate when the population was one forth the size at its peak abundance.
Figure 17. Estimated number of monarch butterflies using different tree species at Pismo North Beach Campground during winter 2003-2004.
Figure 18. Photograph taken at the Halcyon Hill habitat showing the sloping terrain and plantation-like tree plantings.
Figure 19. Estimates of monarch butterflies at four wintering sites in northern San Luis Obispo County, California during winter 2003-2004. Stars indicate when the population was one forth the size at its peak abundance.
Figure 20. Estimated number of monarch butterflies using different tree species at Morro Bay Campground during winter 2003-2004
Figure 21. Photograph taken at the Morro Bay State Park Campground habitat showing the mixed stand nature of the site.
Figure 22. Photograph taken at the Monarch Lane habitat showing interior clearing created as part of restoration modifications (Leong 1999).
Figure 23. Estimated number of monarch butterflies using different tree species at San Luis Cemetery during winter 2003-2004.
Figure 24. Distribution of clustering monarch butterflies in roost trees during winter 2003-2004 (a) relative to aspect and wind direction at eight overwintering sites combined in Monterey County (b) relative to aspect at eight sites combined in San Luis Obispo County.
Figure 25. Spatial pattern of the core clustering areas at two wintering habitats in San Luis Obispo County during the study. (a) Halcyon Hill (b) Pismo State Beach.
Figure 26. Spatial pattern of the core clustering areas at two wintering habitats in San Luis Obispo County during the study. (a) Morro Bay Campground (b) Morro Bay Golf Course.
Figure 27. Association between western North America drought conditions and monarch abundance. (a) Palmer drought severity index and median monarch abundance at western sites from Thanksgiving counts. (b) Regression of median monarch abundance against PDSI for that year.
Figure 28. Deviations in abundance from the average population trend between the 2002 and the 2003 seasons. Circles represent monarch habitats surveyed in 2003 in order from north to south. Positive values indicate that a site’s abundance increased relatively more than the state-wide average while negative values indicate lesser recovery from the previous year or a decline.
Figure 29. Dr. Sandra Perez and Shawna Stevens working in Sandra’s molecular lab at the University of El Paso, Texas.
Figure 30. AFLP sequencer output showing a range of DNA fragment sizes of a female butterfly from Lighthouse Field in Santa Cruz County. Each peak represents the presence of specific sized DNA fragment.
APPENDIX 1 - MONARCH BUTTERFLY SITE SPECIFIC DATA SHEET

**Overwintering Monarch Butterfly Project**

DATE ___________   SITE NAME ________________________________

<table>
<thead>
<tr>
<th># Observers</th>
<th>Observers</th>
<th>Precount Time Span</th>
<th>Total Precount (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>to</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Count Time Span</th>
<th>Total Count (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weather: Sky _______ Cloud Cover _______% Wind _______ Wind Dir _______
Temp _______ Fog _______% Precip: none, drizzle, rain, downpour

<table>
<thead>
<tr>
<th># Monarchs</th>
<th>Tree Species</th>
<th>Aspect</th>
<th>Cluster Height</th>
</tr>
</thead>
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<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
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</tbody>
</table>

Total:  

<table>
<thead>
<tr>
<th># of Fliers:</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Grounders:</td>
</tr>
<tr>
<td>Grand Total:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nectar Source</td>
<td></td>
<td></td>
</tr>
<tr>
<td># Tagged Monarchs</td>
<td></td>
<td></td>
</tr>
<tr>
<td># Observed Matings</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional Notes:
APPENDIX 2 - WEATHER AND TREE CODES

**Temp**: in Celsius degrees

**Sky**: 
0 = Clear, few clouds
1 = Partly cloudy, scattered
2 = Mostly cloudy, broken
3 = Overcast
4 = Fog or smoke
5 = Drizzle
8 = Showers

**Wind (Beaufort Scale)**:

<table>
<thead>
<tr>
<th>Beaufort #</th>
<th>mph</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt; 1</td>
<td>Smoke rises vertically</td>
</tr>
<tr>
<td>1</td>
<td>1 - 3</td>
<td>Smoke drifts</td>
</tr>
<tr>
<td>2</td>
<td>4 - 7</td>
<td>Wind felt on face, leaves rustle intermittently</td>
</tr>
<tr>
<td>3</td>
<td>8 - 12</td>
<td>Leaves in constant motion</td>
</tr>
<tr>
<td>4</td>
<td>13 - 18</td>
<td>Dust raised, branches moving</td>
</tr>
<tr>
<td>5</td>
<td>19 - 24</td>
<td>Small trees sway</td>
</tr>
<tr>
<td>6</td>
<td>&gt;25</td>
<td>Large branches sway</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Whole trees sway</td>
</tr>
</tbody>
</table>

**Tree Species Codes**:

- **EUSP** Blue Gum Eucalyptus
- **PIRA** Monterey Pine
- **SESE** Coast Redwood
- **CYMA** Monterey Cypress
- **QUAG** Coast Live Oak

Eucalyptus spp.
Pinus radiata
Sequoia sempervirens
Cypressus macrocarpa
Quercus agrifolia