# Management of Monarch butterfly (*Danaus plexippus*) overwintering habitat: recommendations based on patterns of tree use

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***Executive Summary***

Proper management and conservation of western Monarch butterfly *(Danaus plexippus L.*) coastal California overwintering sites is critical. At many of these overwintering sites, managers currently rely on the "common knowledge" that monarchs "prefer" eucalyptus, and management is often based on that "knowledge". Yet the prevalence of eucalyptus on the landscape is a major confounding factor affecting our interpretation of preference. To show a preference we are required to show that one alternative (e.g.: tree species) is being used, while another alternative is being shunned. By focusing on overwintering sites with multiple tree species, we tested whether monarchs prefer eucalyptus, if they merely use it in proportion to its availability, or if they prefer non-eucalyptus trees when they are available. At five sites across Monterey and San Luis Obispo counties, we conducted weekly counts of overwintering monarchs from fall 2009 through spring 2012, while noting the tree species the monarchs were clustered on. We compared this tree use to the amount of canopy cover contributed by each of the species present (i.e.: the "availability" of each tree species).

When a preference was expressed, overwintering Monarchs more often preferred native conifers than eucalyptus. We found that the number of monarchs clustering on a given tree species varied from site to site and from year to year. Even within a given site and year, monarchs often switched tree species over the course of the winter. In spite of this variability, we found that 1) monarchs clustered disproportionately on native conifers in years when the statewide overwintering population was relatively high, 2) in most years and at most sites, they clustered less than expected on eucalyptus and more than expected on native trees, and 3) in several instances monarchs switched from clustering on eucalyptus at the beginning of the season to clustering on native conifers later in the season. Therefore, we conclude that monarchs do not exhibit any overall tree species preference, though they do sometimes show a preference for one species over another under different circumstances at different sites and in different years.

Based on these findings, we recommend that overwintering groves be managed to include or maintain a mixture of tree species. In groves that are dominated by Eucalyptus, native conifers such as Monterey cypress (*Hesperocyparis macrocarpa*) and pitch canker-resistant Monterey pine (*Pinus radiata*) should be planted around the perimeter, and in any areas where trees have fallen or are likely to fall. Ideally, management will be proactive (anticipate the need for new trees) and not reactive, and will not only consider the trees in the overwintering grove, but also consider the surrounding landscape and its impact on the grove's microclimate. We do not recommend simply planting more eucalyptus.

***Monarch butterflies in decline***

Each fall, adult monarch butterflies (*Danaus plexippus* L.) complete an annual long-distance migration cycle that brings them back to their wintering grounds. Here they gather in large numbers, and form dense clusters that hang from trees. The majority of Western monarchs

overwinter on the California coast from October through March at hundreds of sites from Marin County to San Diego County, though they have been recorded clustering as far north as Mendocino County. There are climax sites, where monarchs persist throughout the winter, or transitional sites, where monarchs cluster only at the beginning of the season and later move to climax sites. Based on population estimates derived from annual surveys at these sites, it is inferred that the Western population has declined by 90% over the last two decades (Stevens & Frey 2004, Xerces 2012) (Figure 1).

One of the main drivers behind the decline in the monarch population is hypothesized to be the loss of breeding habitat (milkweed) in the continental U.S. due to changing agricultural practices and increased herbicide use (Oberhauser et al. 2001, Hartzler 2010, Pleasants and Oberhauser 2012). In the West and Southwest this loss of habitat is likely exacerbated by annual variability in the abundance and distribution of the remaining milkweed habitat caused by variation in precipitation (Stevens and Frey 2010). An additional driver of population decline may be the loss and degradation of overwintering habitat. Therefore, the International Union for Conservation of Nature and Natural Resources has classified the monarch migration and overwintering locations as a "threatened phenomenon" (Wells et al. 1983) and the World Wildlife Fund has classified monarch butterflies as "near threatened". The years 1990-1998 demonstrate the trend. Over that 9 year period there was a 12% decline in available overwintering habitat for California monarchs (Meade 1999, Frey and Schaffner 2004). That trend is expected to continue, given that approximately 30% of the California overwintering sites are privately owned, and have minimal protection. In addition to direct loss, overwintering sites can become unsuitable for monarchs through tree cutting and removal, senescence, tree fall, and/or defoliation due to leaf beetle herbivory (Fallon and Jepsen 2013) or pitch canker (Correll

et al. 1991). Therefore, the engagement and participation of landowners and land managers in the conservation and management of the remaining overwintering sites is vital to the continued survival of the western monarch butterfly and the California overwintering phenomenon.

***The "Goldilocks" zone: monarch microclimate preferences***

A suitable overwintering site is comprised of a grove of trees that produce a microclimate with a narrow set of values for several parameters. In general the trees are in an amphitheater formation surrounding a clearing or opening in the canopy. Temperature is a primary parameter, as monarchs cannot survive prolonged exposure to freezing (Calvert et al. 1983). Research into additional parameters at California overwintering sites reveals that monarchs preferentially cluster in areas with relatively low light intensity (< 550 foot-candle), low solar radiation (< 0.08 cm $cal^{-2}$ $m^{-1}$), high moisture in the air ( VPD of < 0.20 mmHg) ( Leong et al. 1991), and low wind speeds (< 0.84 m/s), with site abandonment at wind speeds > 2 m/s Leong (1990). Monarchs that cluster under canopy cover have higher body temperatures than those that are exposed to the night sky (Anderson and Brower 1996), meaning that monarchs form clusters under denser canopy with fewer openings. In addition, monarchs must have access to water in the form of fog drip or morning dew (Tuskes and Brower 1978).

The microclimate at an overwintering site is impacted on a large scale by landscape-level factors and on a small scale by the configuration and characteristics of the trees at the site. The canopy height and density, configuration of branches, and type of tree foliage will determine the microclimate and influence where monarchs cluster, or if they cluster at all. All of these characteristics may vary considerably depending on tree species. Therefore, monarchs will potentially cluster on different tree species under different climatic conditions.

***Monarchs and eucalyptus***

At California overwintering sites monarchs have been recorded clustering on a wide variety of native and non-native trees. Primary cluster trees include blue gum eucalyptus (*Eucalyptus globulus*), Monterey pine (*Pinus radiata*), Monterey cypress (*Hesperocyparis macrocarpa*), coast redwood (*Sequoia sempervirens*), and trees that are used to a lesser extent include Western sycamore (*Platanus racemosa*), coast live oak (*Quercus agrifolia*), and river red gum (*Eucalyptus camaldulensis*) (Leong et al. 1991, Sakai and Calvert 1991, Frey and Schaffner 2004). Historical observations suggest that prior to the widespread introduction of eucalyptus from Australia, monarchs clustered primarily on native conifers, particularly Monterey pine (Riley & Bush 1881, Riley & Bush 1882, Shepardson 1914).

The introduction of eucalyptus in the mid-nineteenth century drastically changed the landscape of coastal California. In southern California, which had been largely a treeless landscape dominated by coastal scrub and chaparral, groves of eucalyptus were planted for lumber and shade (Santos 1997). Harvesting was common in coastal areas of central California that were originally forested with Monterey pine (Jones & Stokes 1994). Eucalyptus supplanted native trees in many areas on the coast where it is now the dominant tree on the landscape. This occurred via direct planting of eucalyptus, and its expansion by naturalization into mesic sites where available.

We postulate that some stands of eucalyptus, once they became large enough, eventually generated the microclimate conditions required by monarchs, leading to the pattern of tree use we see today. For example, monarchs cluster almost exclusively on eucalyptus in the southern portion of the overwintering range (i.e. Santa Barbara, Ventura, Los Angeles, Orange, and San

Diego counties). Likewise, Frey and Schaffner (2004) found that monarchs use eucalyptus at 75% of California's overwintering sites. So, with only a modern eye, one might conclude that monarchs prefer eucalyptus, and in fact, this has become "common knowledge." Some monarch management plans go as far as 1) advocating for conservation and management efforts exclusively at eucalyptus-only overwintering sites (Sakai and Calvert 1991) effectively abandoning non-eucalyptus site, or 2) recommend planting more eucalyptus (Oberhauser et al. 2009).

Yet the eucalyptus preference hypothesis has *never* been tested. At groves that only have eucalyptus, it is not possible to test for preference if no alternative tree species is available. Preference is a behavior that shows a choice – choice is demonstrated by measuring utilization relative to resource availability. So, in order to access choice and preference, we must examine monarch tree use at sites with multiple tree species. If one could show that more monarchs use eucalyptus, or use it more often, or use it to the exclusion of other tree species that are present, *then* one could show preference. Likewise, if monarchs cluster more, more often, or exclusively on other tree species that are present, *then* one could show a preference for *non-eucalyptus*. Only in this manner can we determine if monarchs actually prefer eucalyptus, or if they simply use eucalyptus in proportion to its availability. A lack of preference for eucalyptus would suggest that monarchs use eucalyptus because it grows at sites that might have suitable microclimates regardless of the tree species present. Such a paradigm shift would change our focus from managing eucalyptus towards managing overwintering sites.

***Do monarchs prefer eucalyptus?***

In order to study monarch tree choice, we analyzed data from five climax sites collected during the overwintering seasons of 2009-2010, 2010-2011 and 2011- 2012. Every site contained at least one native tree species in addition to non-native Blue Gum Eucalyptus. Native species were Monterey pine, Monterey cypress, and coast redwood. Two sites were located in Monterey County (Pacific Grove Monarch Sanctuary and a private property site in Big Sur) and three were located in San Luis Obispo County (Pismo Beach North Campground, Oceano Campground, and Morro Bay Golf Course).

Monarch clusters were counted weekly at each site during the entire overwintering season, using methods described in Frey et al. (1992). The total number of monarchs clustering on each tree species during each visit was recorded, and the average number of monarchs clustering on each tree species per month per site was calculated. This was used as a metric of tree utilization. Canopy cover was measured in the field at each site in 2012, using a spherical crown densiometer. The proportion that each tree species contributed to the total canopy cover was used as a metric availability canopy cover for each species.

Tree species preference was tested by comparing the proportion of monarchs that clustered on each tree species to the proportion of available canopy cover of each tree species. It was possible to test for preferential use of eucalyptus over other species because 1) eucalyptus and at least one other species of tree were present at every site, 2) preference could be shown if monarch proportional utilization of eucalyptus exceeded its proportional availability canopy cover, 3) a lack of preference could be shown if monarch proportional utilization of eucalyptus was lower than its proportional availability canopy cover, and 4) no preference could be shown if utilization was directly proportional to canopy cover availability.

Tree use was analyzed via a chi-squared test, which tested whether monarchs were using trees in proportion to their availability. A sign test was used to test whether cases of disproportional use shown by the chi-square were due to monarchs clustering significantly more than expected on eucalyptus, or on native species, or if there was no overall preference. We used a repeated measures ANOVA to test for any significant effects of tree species, site, month, and year, as well as interactions between terms, on the number of clustering monarchs.

***Results***

Monarchs did not utilize tree species relative to their canopy availability. In all three years and at all five sites, monarchs used some species disproportionately more and some disproportionately less than what was expected based on available canopy cover. Therefore, in all cases, some preference was shown; however, monarchs did not show an overall preference for any single species. At some times of year at some sites, monarchs did cluster significantly more than expected on eucalyptus but that was the exception since more than 50% of the time they clustered significantly more than expected on native conifers (Table 1) (Appendices A-E). Repeated measures ANOVA showed that both the average number of monarchs present and the average number clustering on native trees were significantly higher across all sites in 2011.

**Table 1.** Test of overall preference for *Eucalyptus* across three years and five California overwintering sites. Sign test of chi-squared results comparing monarch butterfly's utilization of trees relative to their available canopy cover. Site-year cases where monarchs clustered significantly more than expected on eucalyptus are labeled as "+", and as "-" when monarchs clustered significantly less than expected on eucalyptus. One analysis was done over the course of the whole season using monthly count averages, one analysis was done on population counts at their seasonal maximum, and a third was done on mid-season population counts (December 31). P-values for all three tests were non-significant, indicating no overall tree species preference.

| Site | Year | Whole season | Seasonal Maximum | Mid-season (Dec 31st) |
|---|---|---|---|---|
| Pacific Grove | 2009-10 | + | + | - |
| | 2010-11 | - | - | - |
| | 2011-12 | - | - | - |
| Big Sur | 2009-10 | - | - | - |
| | 2010-11 | + | + | - |
| | 2011-12 | - | - | - |
| Pismo Beach | 2009-10 | - | - | - |
| | 2010-11 | + | + | + |
| | 2011-12 | - | - | - |
| Oceano | 2009-10 | + | + | + |
| | 2010-11 | + | + | - |
| | 2011-12 | - | - | - |
| Morro Bay | 2009-10 | - | - | + |
| | 2010-11 | + | + | + |
| | 2011-12 | + | + | + |
| | **Total +** | 7 | 7 | 5 |
| | **Total -** | 8 | 8 | 10 |
| | **p-value** | 1.00 | 1.00 | 0.30 |

These results indicate that the monarchs are not exhibiting an *overall* preference for eucalyptus across sites and years either during the overwintering season as a whole, at peak population sizes, or during the middle of the season. One criticism of the results is that they are an average across all of the conditions that monarchs experience at a site within one year. It is plausible that monarchs truly only "need" to express a preference when microhabitat conditions are the least favorable (when "goldilocks" conditions only occur in a portion of the

overwintering grove). The least favorable conditions would likely be mid-season, when winter storms are more common, temperatures are lower, and wind speeds are higher. Interestingly, the mid-season counts showed a different pattern of monarch clustering from the whole-season and maximum-population-size counts. At mid-season (around December 31), monarchs clustered significantly more than expected on native trees in a majority of years at all sites except Morro Bay Golf Course. Interestingly Morro Bay is comprised of 97% eucalyptus (versus 15-76% at other sites), whereby Morro Bay would provide the lowest potential for us to detect a preference (choice) if one existed.

The patterns that we observed are that 1) in years when the overall overwintering population was the highest, monarchs clustered disproportionately on native trees, 2) the number and proportion of monarchs clustering on native conifers versus non-native eucalyptus varies considerably from site to site, from year to year, and even within year, 3) in most years at most sites, monarchs clustered more than expected on native tree species and less than expected on eucalyptus, 4) monarchs at a site switch tree species over the course of the season, and 5) in several instances monarchs clustered on eucalyptus near the beginning of the season but switched to native conifers in the middle or at the end of the season (Appendix B, Appendix D). Thus, while monarchs do not exhibit an overall tree species preference, we can say that under different circumstances, at different sites and in different years, they do not use all tree species in proportion to their available canopy cover, though the cases that show a eucalyptus preference are more restrictive (or fewer and limited) than cases where preference for native conifers is demonstrated.

***Monarchs use a variety of tree species***

Monarchs select overwintering sites based on specific microclimate conditions such as temperature, wind speed, humidity, and sunlight intensity (Leong 1990). The structure of a tree impacts how much shelter it provides, how tightly the monarchs can cluster, and how much sunlight can penetrate to lower branches. Different tree species result in different microclimates. In spite of this, our analysis shows that monarchs utilize multiple tree species within seasons, suggesting that monarchs shift tree utilization in response to the different microclimates they experience over the winter. Our results indicate that monarchs cluster on native tree species when the overall annual overwintering populations are relatively high. Regardless of the size of the wintering population, they tend to shift to native trees during the middle and end of the season when microclimate conditions at the site are likely to be least favorable. More research is needed to determine exactly when and under what conditions monarchs switch to native tree species, and whether they use native trees at critical times to the exclusion of eucalyptus. Our results suggest that groves comprised entirely of eucalyptus may be sub-optimal for monarchs when compared with mixed-species groves, because single-species groves would not allow monarchs the ability to express a choice among different tree species. Analyses of correlates between tree species diversity, monarch overwinter survival, status as climax versus transitional grove, and tree utilization during most intense storms should be done in order to inform our currently *Eucalyptus* centric management of overwintering groves.

***Management recommendations***

Based on these data and analyses, we propose the following recommendations for landowners wishing to manage for monarch butterflies.

- Maintain a diversity of tree species in the grove.

- If your grove is entirely eucalyptus, consider planting native conifers.
- Plant trees to provide a wind screen, especially where trees have fallen/been removed, or are likely to fall/be removed.
- If pitch canker-resistant Monterey Pine becomes available, this would also be a good alternative.
- We do not recommend planting eucalyptus. While some biologists do, this is usually because it is very fast-growing, perceived to be useful at filling gaps in the canopy, or creating an emergency windbreak. This would be a signature of management that is *reactive*, and only *responding* to a decline in habitat quality or the number of overwintering monarchs.
- Management must be long-term and far-sighted. Planted trees will probably not be large enough to provide clustering habitat for at least 10 years. Therefore it is best to anticipate where future trees will be needed and manage *proactively rather than reactively.* Native conifers such as Monterey cypress are relatively slow-growing, but could be important for longer term grove management.
- The surrounding landscape is important and contributes to the grove microclimate. Overwintering groves should be sheltered from the prevailing southeast winter storm winds. Before removing trees surrounding a grove, consider how that action may impact the overwintering grove. Native conifers may be planted around the outside of the grove to enhance wind protection.

In order to successfully manage overwintering sites, it is imperative that we create and maintain the habitat characteristics that make a site suitable for monarchs. Since we know what climatic parameters monarchs need (filtered sunlight, wind speeds below 2 m/s, temperatures

above freezing, available water), we must manage overwintering groves in a manner that provides for all these requirements. While monarchs utilize both eucalyptus and native trees, they do not exhibit a preference for eucalyptus, and most years and at most sites they cluster more than expected on native conifers when they are available. We must ask: *What are the most challenging conditions that monarchs experience in an overwintering cluster and what trees and microhabitats do they use then?* Only by using evidence-based habitat assessments to craft management practices can biologists, landowners, land managers, and concerned citizens act to conserve and protect the overwintering habitat that is so crucial to the continued survival of the monarch butterfly.

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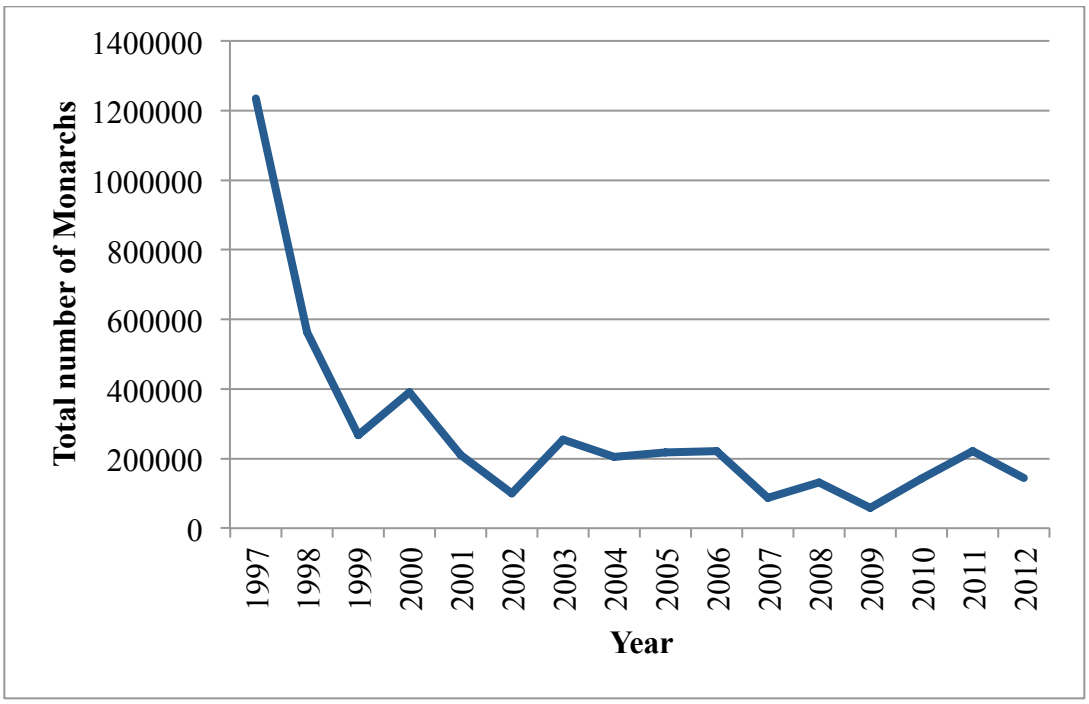
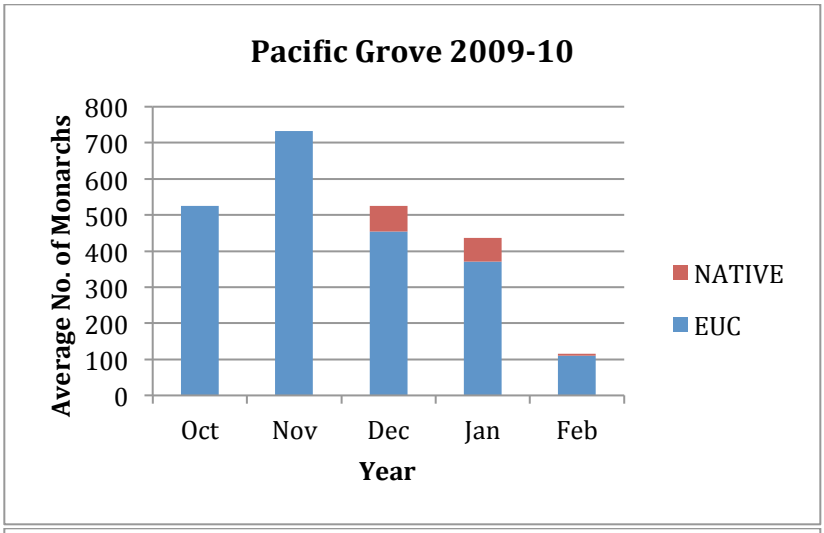
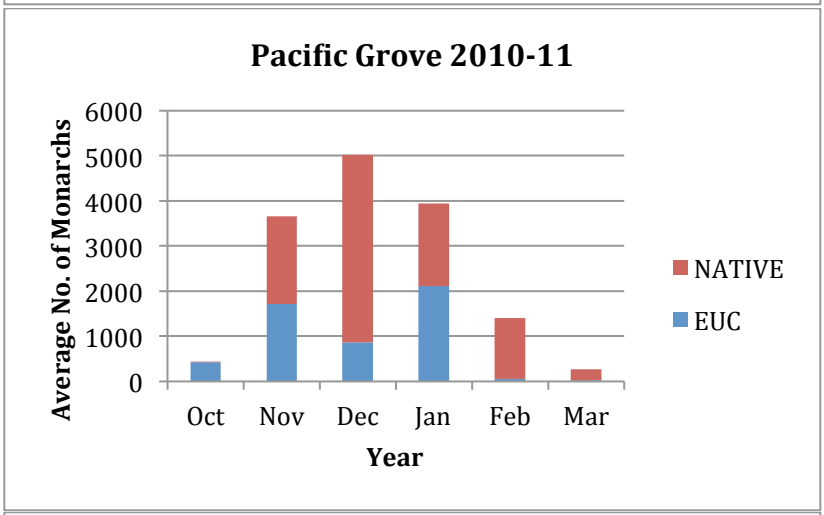
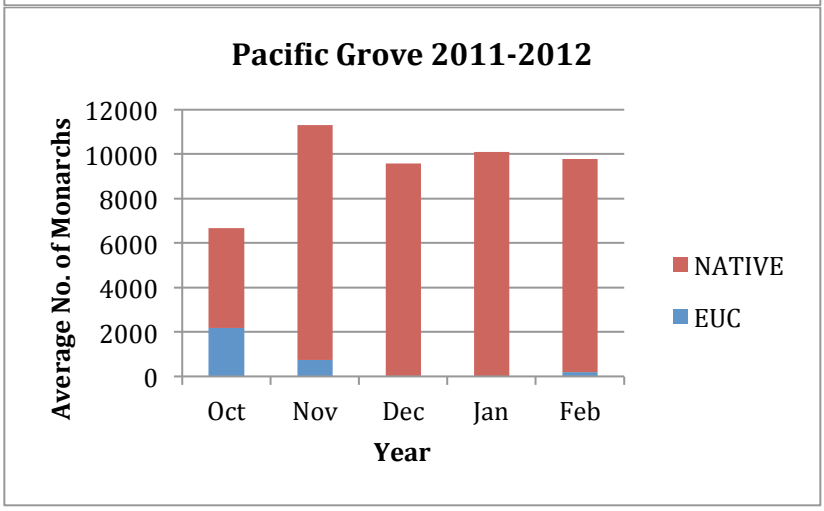



**Figure 1.** The decline in population size of Western monarch butterflies as measured by the annual Thanksgiving Count, a California-wide estimation of the monarch population size at overwintering sites (Xerces 2012).

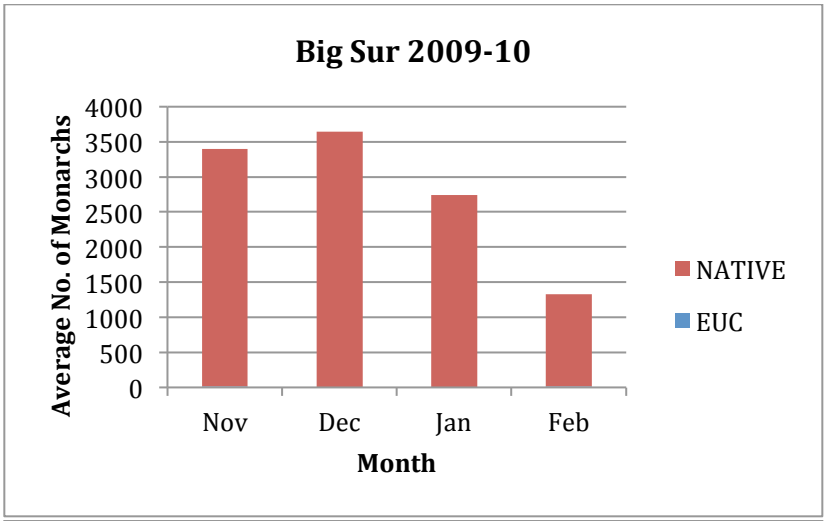
APPENDIX A. Overwintering monarch butterfly populations and tree usage at Pacific Grove Monarch Sanctuary in Pacific Grove, CA during the three winters from 2009-2012. EUC represents Blue Gum Eucalyptus, while NATIVE represents Monterey Pine and Monterey Cypress. Of the total available canopy, 42.6% was eucalyptus, and 57.4% was native conifer.

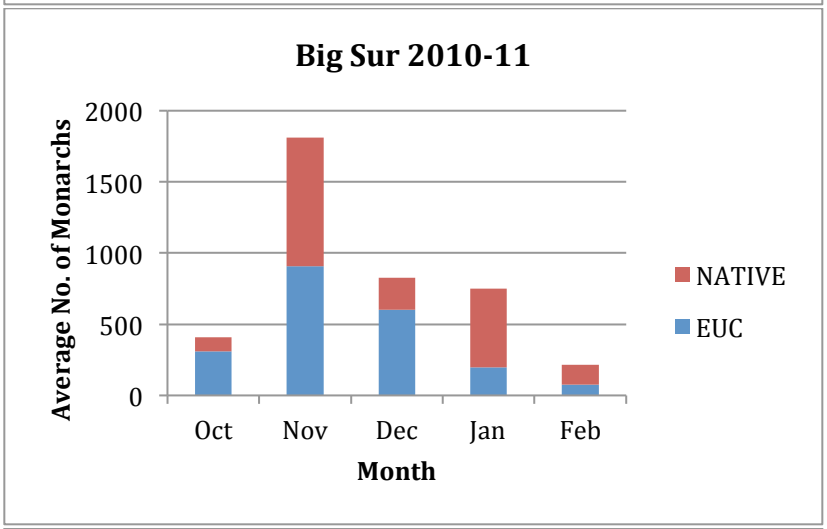


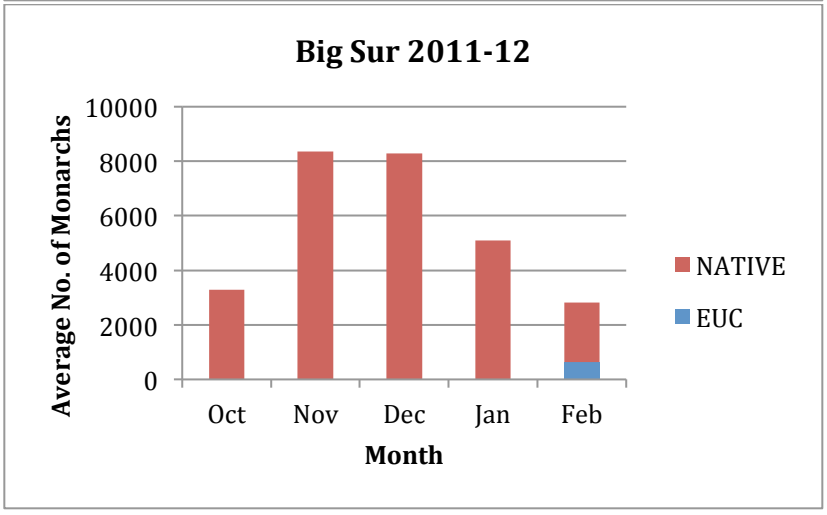



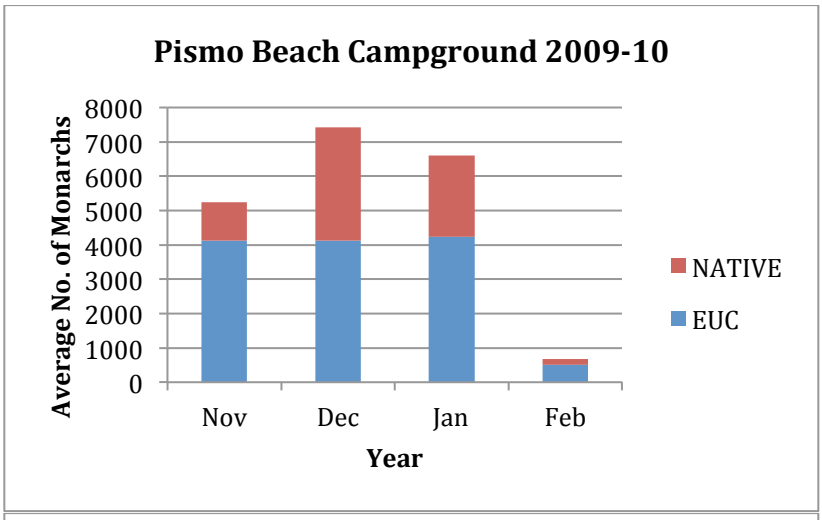
APPENDIX B. Overwintering monarch butterfly populations and tree usage at a private property site in Big Sur, CA during the three winters from 2009-2012. EUC represents Blue Gum Eucalyptus, while NATIVE represents Coast Redwood, Monterey Pine and Monterey Cypress. Of the total available canopy, 44.9% was eucalyptus, and 55.1% was native conifer.

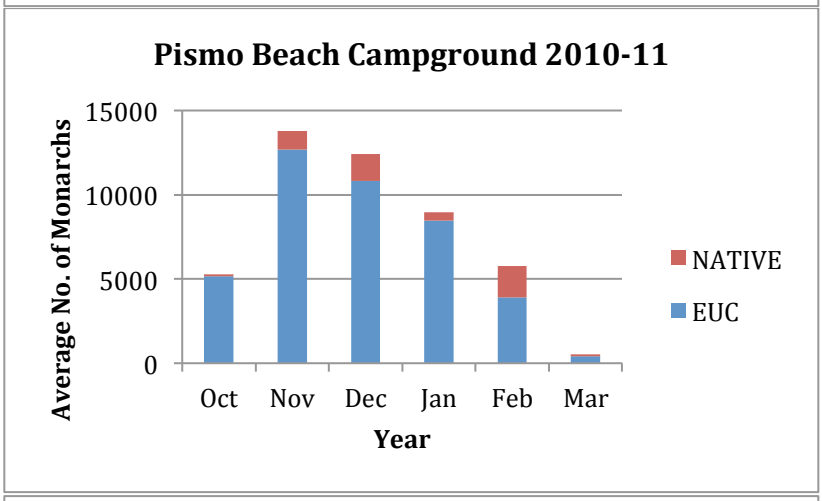


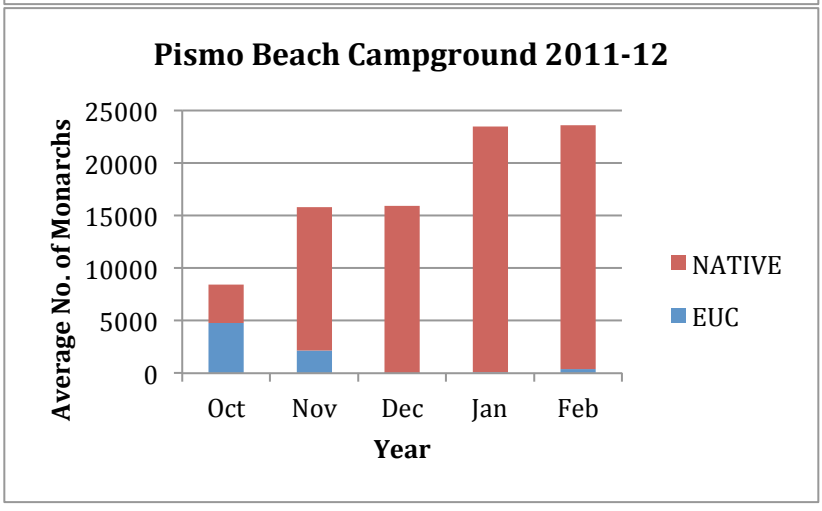



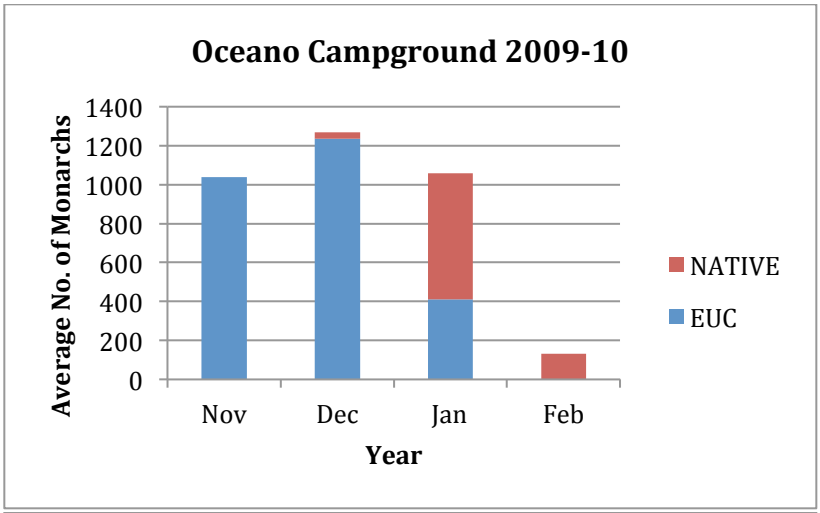
APPENDIX C. Overwintering monarch butterfly populations and tree usage at Pismo Beach North Campground in Pismo Beach, CA during the three winters from 2009-2012. EUC represents Blue Gum Eucalyptus, while NATIVE represents Monterey Pine and Monterey Cypress. Of the total available canopy, 76.2% was eucalyptus, and 23.8% was native conifer.

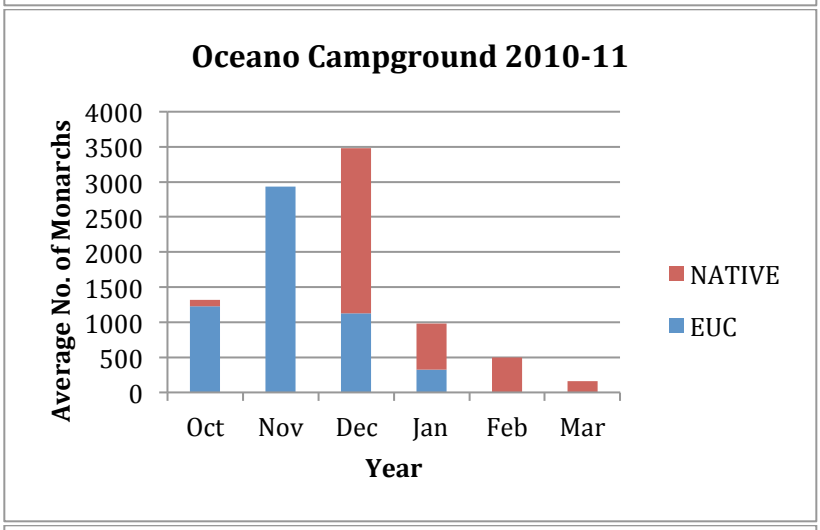


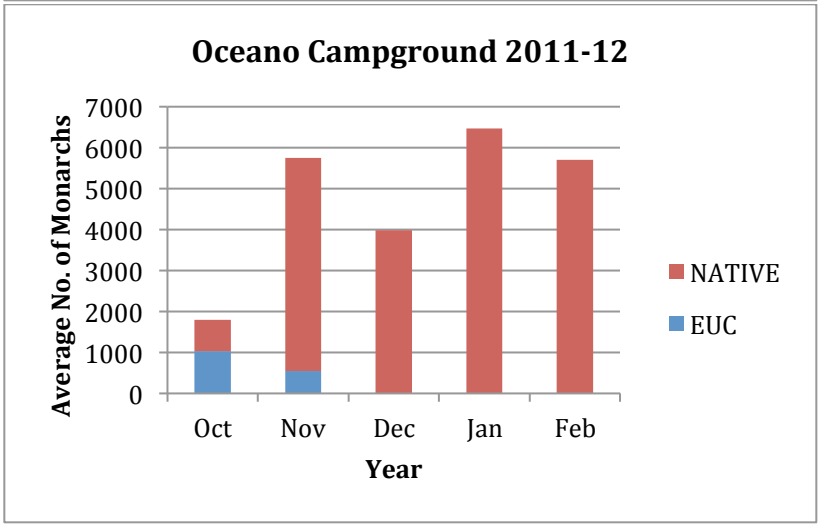



APPENDIX D. Overwintering monarch butterfly populations and tree usage at Oceano Campground in Oceano, CA during the three winters from 2009-2012. EUC represents Blue Gum Eucalyptus, while NATIVE represents Monterey Pine. Of the total available canopy, 15.3% was eucalyptus, and 84.7% was native conifer.



APPENDIX E. Overwintering monarch butterfly populations and tree usage at Morro Bay Golf Course in Morro Bay, CA during the three winters from 2009-2012. EUC represents Blue Gum Eucalyptus, while NATIVE represents Monterey Pine. Of the total available canopy, 97.4% was eucalyptus, and 2.6% was native conifer.