California Fish and Game 101(1):40-50; 2015

Managing monarch butterfly overwintering groves: making room among the eucalyptus

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Proper management and conservation of the coastal California overwintering sites used by western monarch butterflies *(Danaus plexippus L.*) is critical for continued use of these sites by monarchs. Many management efforts are currently concentrating on eucalyptus-only sites because of the prevailing notion that monarchs "prefer" eucalyptus over native tree species. Herein, we test the "eucalyptus preference" hypothesis with data from five overwintering sites comprised of blue gum eucalyptus (*Eucalyptus globulus*) and at least one other native tree species from fall 2009 to spring 2012. We found that when monarchs clustered disproportionately on a tree species relative to its availability, they clustered significantly more than expected on native trees and significantly less than expected on eucalyptus. Also, in years when the overwintering population was highest, monarchs clustered disproportionately on native conifers, and they often switched from clustering on eucalyptus in the early winter to native conifers in the middle or late winter. Our results suggest that overwintering groves should be managed to include a mixture of tree species.

Key words: monarch, *Danaus plexippus*, eucalyptus, habitat preference, overwintering, Monterey cypress, Monterey pine

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Each fall, monarch butterflies (*Danaus plexippus* L.) in western North America migrate long distances to specific groves of trees on the California coast where they gather in large clusters for the winter (Williams et al. 1942, Urquhart and Urquhart 1977). Based on population estimates derived from annual surveys at these sites, it is inferred that the western population has declined by 90% since 1997 (Stevens and Frey 2004, Xerces Society 2013). The two main drivers behind this decline are hypothesized to be the loss of breeding habitat (milkweed patches) in the interior western and southwestern United States, and the loss or degradation of overwintering habitat (tree groves). From 1990 to 1998, there was a 12% decline in available overwintering habitat for monarchs in California (Meade 1999,

Frey and Schaffner 2004). That trend is expected to continue, given that there has been no management policy put in place to stop or reverse the decline. In addition to direct loss, overwintering sites can become unsuitable for monarchs through tree cutting and removal, senescence, tree fall, disease, parasitism, or herbivory (Leong et al. 1991, Weiss et al. 1991, Fallon and Jepsen 2013).

A suitable overwintering site is comprised of a grove of trees that produce a microclimate with a narrow set of values across several parameters. Suitable grove conditions include temperatures that are above freezing (Calvert et al. 1983) but not too warm (Alonso-Mejia et al. 1997), low light intensity and solar radiation with high water vapor pressure (Leong et al. 1991), wind speeds lower than 2 m/s (Leong 1990), and access to fresh water, sometimes via streams or puddles but often in the form of fog drip or morning dew (Tuskes and Brower 1978). The microclimate within an overwintering grove is impacted by landscape-level factors and by the local configuration and characteristics of trees at the site. Canopy height and density, branch configuration, and type of foliage will determine the microclimate and influence if, or where, monarchs cluster. These characteristics may vary considerably depending on tree species. Therefore, monarchs may cluster on different tree species under different climatic conditions.

At California overwintering sites, monarchs have been recorded clustering on a variety of native and non-native trees, primarily blue gum eucalyptus (*Eucalyptus globulus*), Monterey pine (*Pinus radiata*), Monterey cypress (*Hesperocyparis macrocarpa*), and coast redwood (*Sequoia sempervirens*). Historical observations suggest that monarchs clustered primarily on native conifers, particularly Monterey pine (Riley and Bush 1881, 1882; Shepardson 1914). The introduction of eucalyptus in the mid-nineteenth century, however, changed the landscape of coastal California. In southern California, which lacked the coniferous forests of the central and northern coast, eucalyptus became widespread on the landscape as groves were planted for lumber and shade (Groenendaal 1983, Santos 1997). In central California, blue gum eucalyptus was planted extensively while coastal areas forested with Monterey pine were concurrently harvested (Jones and Stokes 1994).

Monarchs currently cluster almost exclusively on eucalyptus in the southern portion of their overwintering range in California (i.e., Santa Barbara, Ventura, Los Angeles, Orange, and San Diego counties). Overall, monarchs use eucalyptus at 75% of California's overwintering sites (Frey and Schaffner 2004), an observation that might lead one to conclude that monarchs "prefer eucalyptus", and in fact, this has become "common knowledge." Some monarch management plans go as far as advocating for conservation and management efforts exclusively at eucalyptus-only overwintering sites (Sakai and Calvert 1991), while others recommend planting more eucalyptus (Oberhauser et al. 2009).

Monarch preference for tree species has never been formally tested, partially because it is not possible to test for preference at groves comprised only of eucalyptus. It is only possible to establish preference if alternate resources are available, and if utilization is measured relative to resource availability. Our purpose is to examine monarch tree use at sites with multiple available tree species, and determine whether monarchs prefer eucalyptus or if they merely use it in proportion to its availability. If monarchs do not prefer eucalyptus it would suggest that monarchs use eucalyptus at sites that have suitable microclimates regardless of the tree species present: if they are not preferential of the tree, then they must be preferential of the site. Such a paradigm shift would move us from managing and restoring eucalyptus towards managing and restoring overwintering sites.

Materials and Methods

We counted the number of clustering monarchs at five overwintering sites during the overwintering period from fall 2009 to spring 2012. Our weekly monitoring also included information on tree species used, and we examined these data in the context of availability of different species of trees.

Study sites.—All sites were well-known climax overwintering sites, i.e., overwintering sites occupied by monarchs for the entire season (Leong et al. 2004). Monarchs were present throughout the entire overwintering season during every year of the study. Sites were selected from among all known climax sites because the groves contained multiple tree species.

Pacific Grove Monarch Sanctuary (36° 37' N, 121° 55' W) is located in Pacific Grove, California, on the south edge of Monterey Bay, Monterey County. The 1.1-ha site consists of *E. globulus* on the south edge and southeast corner, *P. radiata* and *H. macrocarpa* throughout the rest of the property, coast live oak (*Quercus agrifolia*) in the understory, and several non-native ornamental trees and shrubs. The Big Sur private property site (36° 07' N, 121° 38' W) is located on the Big Sur coast in Monterey County. Monarchs cluster on a 1-ha parcel containing groves of *E. globulus, H. macrocarpa, P. radiata,* and *S. sempervirens*. The site also contains landscaped gardens with plantings of non-native shrubs and flower gardens. Morro Bay Golf Course (35° 21' N, 120° 50' W) is located in Morro Bay, San Luis Obispo County. Total area of the two groves at this site is 4 ha. These groves are comprised mainly of *E. globulus* with *P. radiata* along the outer edges, and little to no understory vegetation. Pismo Beach Monarch Grove (35° 07' N, 120° 37' W) is located adjacent to the Pismo State Beach North Beach Campground in Pismo Beach, San Luis Obispo County. The 1.2-ha overwintering site is comprised of a large *E. globulus* grove with some *P. radiata* and *H. macrocarpa* scattered along the northeast edge. A creek flows along the north edge of the site, which is lined with arroyo willow (*Salix lasiolepis*). There is minimal understory. Oceano Campground (35° 07' N, 120° 37' W) is located within the Pismo State Beach Oceano Campground in Oceano, San Luis Obispo County. The 0.7-ha overwintering site is within the 26-ha campground, and is comprised mainly of *P. radiata* with some cultivated Torrey pine (*Pinus torreyana*), and a small stand of *E. globulus*. There is extensive understory of native and non-native shrubs and forbs.

Monarch overwintering surveys.—Surveys were conducted weekly at each of the five sites from mid-October through mid-March, or until monarchs dispersed from the site in spring. During the 2009–10 season, surveys began in November at all sites except Pacific Grove, which began in October, and ended at all sites in February. During the 2010–11 season, all sites were surveyed from October through March. During the 2011–12 season, all sites were surveyed from October through February. The number of clustered monarchs was estimated using a standardized method (described in Frey et al. 1992). The total number of monarchs estimated clustering on each tree species during each visit was recorded. The average number of monarchs estimated clustering on each tree species per month per site was also calculated, and was used as a metric for tree utilization.

Canopy cover measurements.—Canopy cover was measured at the five sites in summer 2012. All tree species used by monarchs at the sites were evergreens and, thus, were leafed out year-round. At each overwintering site, a polygon that encapsulated all trees that had been used by the monarchs over the last 10 years was mapped, thereby enclosing the

largest area of known use (Hamilton et al. 2002, Frey et al. 2003, Frey et al. 2004, Griffiths and Thorngate 2008, Griffiths 2009). These polygons were overlaid with a 20-m grid, and at the corners of each grid square a densiometer was used to estimate canopy cover. Only canopy above 3 m was considered, as monarchs have rarely been recorded clustering below that height at these sites in the last decade (Hamilton et al. 2002, Frey et al. 2003, Frey et al. 2004, Griffiths and Thorngate 2008, Griffiths 2009). We then used these data to calculate the proportion of total canopy cover of each tree species at each site. The proportion that each tree species contributed to the total canopy cover was used as a metric for tree species availability.

Statistical analyses.—Tree use was analyzed using chi-square tests, which tested whether monarchs were using trees in proportion to their availability (Sokal and Rohlf 1995). The predicted use reflective of availability (expected cluster values referenced below), was calculated by taking the total observed counts and distributing them across tree species based on the relative canopy cover of each tree species. We used R 2.15.3 (R Core Team 2013) to conduct three chi-squared goodness-of-fit tests and compared (1) the average monthly observed vs. expected monarchs clustering on eucalyptus or native conifers; (2) observed vs. expected monarch numbers during maximum occupancy (highest population size) of that site during that overwintering season; and (3) observed vs. expected monarch numbers for mid-season (closest to December 31) surveys. A sign test of the significant chi-square results was used to determine if monarchs clustered significantly more than expected on eucalyptus or on native trees (Sokal and Rohlf 1995). Because multiple counts were done at each site in the same seasons, we used a repeated measures ANOVA (Gotelli and Ellison 2004) using JMP 10.0 (SAS Institute Inc. 2012) to test for effects of tree species, site, month, and year on the number of clustering monarchs. Monthly monarch cluster averages were cube-root transformed to more closely approximate normality.

Results

Canopy cover varied greatly between sites (Table 1). Only *E. globulus* and *P. radiata* were present at every site we sampled. *E. globulus* canopy cover ranged from 15.3% at Oceano Campground to 97.4% at Morro Bay Golf Course. *P. radiata* canopy cover ranged from 1.1% canopy cover at Big Sur private property to 84.2% at Oceano Campground.

Table 1.— Canopy cover proportions by tree species at five monarch butterfly *(Danaus plexippus)* overwintering sites from 2009 – 2012 in Monterey and San Luis Obispo counties, California.

	Tree Species				
Site	Blue gum eucalyptus	Monterey pine	Monterey cypress	Coast redwood	Other
Pacific Grove Monarch Sanctuary	0.425	0.345	0.220	-	0.010
Big Sur private property	0.449	0.011	0.447	0.091	0.002
Morro Bay Golf Course	0.974	0.026	-	-	-
Pismo Beach Campground	0.762	0.035	0.108	-	0.095
Oceano Campground	0.153	0.842	-	-	0.005

Monarch abundance varied widely among sites and among years (Figure 1). The fewest monarchs were present in 2009–2010. At all sites except Big Sur, there were more monarchs present during 2010–2011 than during 2009–2010. There were more monarchs present at all sites during 2011–2012 than in any other overwintering season of our study. Likewise, the proportion of monarchs clustering on eucalyptus vs. native trees varied among sites and among years (Figure 1). In most years and at most sites, monarchs did not even cluster in the same proportions on eucalyptus throughout one season, indicating that some monarchs moved, or that monarchs switched tree species. At three sites in at least one year 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 (Figure 1).

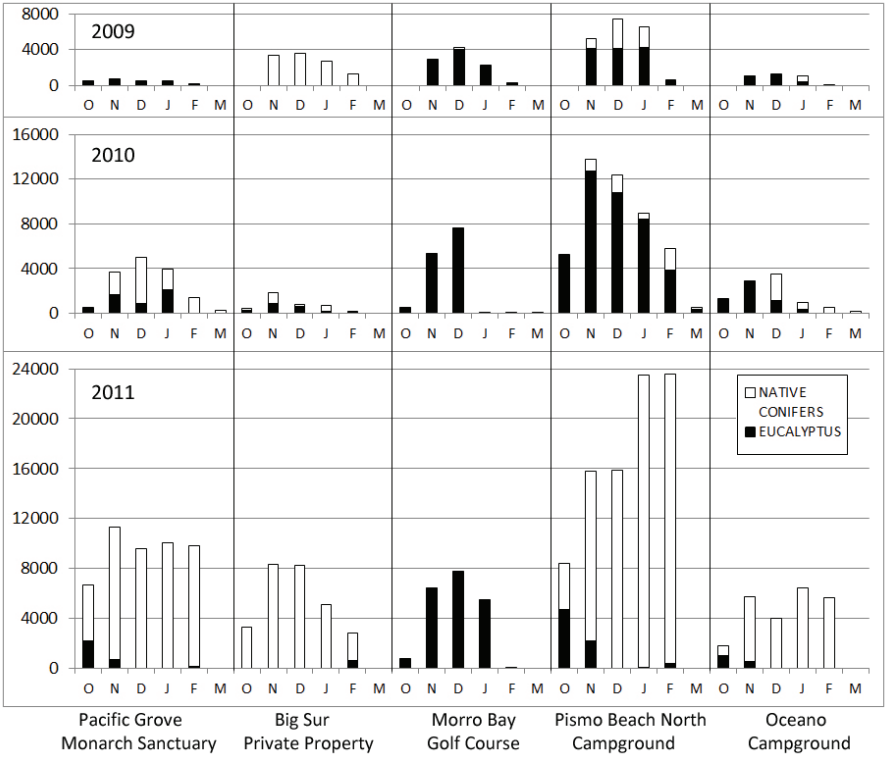

Figure 1.—Number of monarch butterflies *(Danaus plexippus)* present and tree usage at five overwintering sites in Monterey and San Luis Obispo counties, California, during three winters from 2009 to 2012. Site names are listed across the bottom. Each vertical bar represents the total number of monarchs estimated to be present at that site in that month (starting in October and ending in March of each year). Each bar is colored according to the number of monarchs clustering on blue gum eucalyptus (filled) or native conifers (un-filled) such as Monterey pine, Monterey cypress, and coast redwood.

In all three years and at all five sites, the chi-square values were significant (X^2 values ranged from 13.27–233530.72, $P < 0.001$ in all cases), indicating that monarchs were not clustering on tree species in proportion to canopy availability over the course of a season, during maximum site occupancy, or during the middle of the overwintering season. Sign tests for each of the three years were not significant, indicating that monarchs did not show

Table 2.—Sign test results for tree species utilization by monarch butterflies *(Danaus plexippus*) relative to tree species availability across three years and five California overwintering sites in Monterey and San Luis Obispo counties, California, 2009 – 2012. Site-year cases where a chi-square test showed that monarchs clustered significantly more than expected on eucalyptus are labeled as "+". They are labeled as "-" when a chi-square test indicated that 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 maximum seasonal occupancy, and the third was done on population counts closest to the middle of the season (31 December). *P*-values for all three tests were non-significant, indicating no overall tree species preference even though the chi-squared test showed that trees species were not used relative to their availability.

Site	Year	Whole season	Max Occupancy	Mid-season
Pacific Grove Monarch Sanctuary	2009–10	+	+	-
	2010–11	-	-	-
	2011–12	-	-	-
Big Sur private property	2009–10	-	-	-
	2010–11	+	+	-
	2011–12	-	-	-
Morro Bay Golf Course	2009–10	-	-	+
	2010–11	+	+	+
	2011–12	+	+	+
Pismo Beach Campground	2009–10	-	-	-
	2010–11	+	+	+
	2011–12	-	-	-
Oceano Campground	2009–10	+	+	+
	2010–11	+	+	-
	2011–12	-	-	-
	Total +	7	7	5
	Total -	8	8	10
	P-value	1.00	1.00	0.30

a preference for eucalyptus or native conifers (Table 2). Nevertheless, monarchs clustered more than expected on native trees more than 50% of the time (8 out of 15 times on a seasonal level, 8 out of 15 times at peak occupancy, and 10 out of 15 times during mid-season).

Repeated measures ANOVA showed that the average number of monarchs present at all sites was significantly higher during 2011–12 ($F_{2,12} = 4.73$, $P = 0.013$). The average number clustering on native trees was also significantly higher during 2011–12 ($F_{2,12} = 9.24$, $P < 0.001$). During the 2011–12 season, monarchs clustered significantly more than expected on conifers in every month of the winter (October through February) at three of five sites (Pacific Grove Monarch Sanctuary, Big Sur Private Property, and Pismo Beach North Campground), and clustered significantly more than expected on conifers at Oceano

Campground from November through February (Figure 1). Therefore monarchs clustered disproportionately more on native conifers in 2011–12 earlier and for more consecutive months than during 2009–10 and 2010–11.

Discussion

Among our study areas, monarchs did not exhibit an overall preference for eucalyptus across sites and years during the middle of the season, at maximum site occupancy, or during the overwintering season as a whole. These results force us to reject the "eucalyptus tree preference" hypothesis. Additionally, monarchs exhibited tree switching, moving from clustering predominantly on eucalyptus to clustering predominantly on native trees over the course of the season. They also clustered significantly more than expected on native trees at mid-winter in 10 out of 15 site-year combinations. This indicates that monarchs may prefer different tree species under different microclimate conditions.

A weakness when examining tree use across an entire season is that such an approach includes all of the conditions that monarchs experienced at a site within one winter and ignores fine-scale weather variations. Previous studies have shown that monarchs move between trees in response to changing microclimate (Leong et al. 1991, Frey et al. 1992); therefore it is important to record clustering behavior in a variety of weather conditions. It is possible that monarchs show a different tree species preference when microclimate conditions are the least favorable, and this is the reason that we examined tree use during mid-season, when winter storms are more frequent, temperatures are lower, and wind speeds are higher (NCDC 2012). Indeed, monarchs clustered in a different pattern during the mid-season counts than during the whole-season and maximum occupancy counts: they clustered significantly more than expected on native trees in a majority of years at all sites except one. It should be noted, however, that this site (Morro Bay Golf Course) is our weakest test of the preference hypothesis because it is 97% eucalyptus; the other four sites range from 15–76% eucalyptus.

Monarchs select overwintering sites based on a narrow set of microclimate parameters (Tuskes and Brower 1978, Calvert et al. 1983, Leong 1990, Leong et al. 1991, Anderson and Brower 1996). Our results show that monarchs utilize multiple tree species during a single season and within single groves. We propose that different trees result in different microclimates because they have varying heights, foliage density, and structure, and suggest that it is possible that monarchs shift among tree species in response to changes in ambient conditions. At three of the five sites, and at one or more sites in all three years, monarchs switched from clustering predominantly on eucalyptus to clustering predominantly on native trees in the middle of the season. In most site-year cases where monarchs exhibited tree switching, they clustered more than expected on eucalyptus at the beginning of the season (except in 2011–12, see below), and then clustered more than expected on native trees during mid- and late season. We hypothesize that when the weather is most inclement, monarchs will shift from eucalyptus to native conifers. This could be tested by carefully measuring microclimate conditions in overwintering groves and correlating monarch movement with shifting weather. More study is needed to determine exactly what conditions prompt monarchs to switch tree species, and whether there are circumstances under which they will use native trees to the exclusion of eucalyptus.

Interestingly, when the annual overwintering population was at its highest (in 2011–12) during the three years of this study, monarchs clustered significantly more on native trees, and did so earlier in the season and for a greater length of time. Tree switching occurred in 2011–12 at only two sites (Pismo North Beach Campground and Oceano Campground), whereas at the other three sites monarchs clustered predominantly on native trees from the start of that season. Only at Oceano Campground did monarchs cluster disproportionately on eucalyptus at the start of that season; at Pismo North Beach Campground they clustered on eucalyptus in proportion to its availability. It seems that the size of the overwintering population may influence how and where monarchs cluster. Our results indicate that when more monarchs are present, they may cluster preferentially on conifers.

Groves comprised entirely of eucalyptus may not be optimal for monarchs when compared with mixed-species groves because monarchs would not be able to respond to local conditions available across different tree species. Our data show that monarchs moved off of eucalyptus and on to conifers in December and January, and that monarchs clustered disproportionately more on conifers during the mid-winter (December 31) when the climate is most unstable. At a eucalyptus-only site, monarchs would not be able to take advantage of the more favorable microclimate offered by conifers. This could cause monarchs to leave eucalyptus-only sites, or could even result in increased mortality from winter storms.

Our data lead us to recommend that land managers with eucalyptus-only overwintering groves on their properties manage for monarch butterflies by creating and maintaining appropriate tree species diversity within the overwintering grove. At overwintering sites located on the central coast of California north of Santa Barbara County, planting native conifers such as *P. radiata* and *H. macrocarpa* would be appropriate where trees have fallen or have been removed, or are likely to be removed. This recommendation would not be appropriate for Southern California since we have not evaluated data from that region and because the native conifers are not suited to that climatic region. Management must be long-term and far-sighted. Newly 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 desirable and manage proactively rather than reactively. If we are to successfully manage overwintering sites, we must do so in a manner that provides the proper climactic parameters that monarchs need, such as filtered sunlight, available water, and wind speeds below 2 m/s. We must determine the most challenging conditions that monarchs experience while overwintering, and what microhabitats and trees they use under those circumstances. Only then can we craft management practices that will conserve and protect the habitat that is so critical to the monarch's continued survival.

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Received 25 November 2013
Accepted 7 July 2014
Associate Editor was S. Osborn