Microclimate parameters associated with overwintering monarch butterfly habitats in two State Parks on the central coast of California

Project Report 2007

Winters
2002-03
2003-04
2004-05
2005-06
2006-07

Study Sites:
Andrew Molera State Park
Point Lobos State Reserve

Ventana Wildlife Society
Conservation Ecology Program

Prepared for the California Department of Parks and Recreation, Monterey District

by:

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INTRODUCTION

Microclimate, defined as the set of localized climatic conditions within a habitat (Chen et al 1999), is a critical factor affecting wildlife populations. Microclimate is influenced by the geologic and vegetation characteristics of a habitat, as well as larger-scale climate patterns, and the microclimate of a site can be altered profoundly by apparently minute changes in habitat structure. The sensitivity of wildlife populations to microclimate is well documented (Chen et al. 1999), and thus habitat conservation and management projects should take microclimate into account when developing management plans for species of interest.

Each fall, the western population of monarch butterflies (*Danaus plexippus)* migrates to specific communal roosting sites along the Pacific coast of California to overwinter. Specific structural and microclimate features typically characterize suitable roosting locations. Monarch butterflies roost communally during both their migratory and diapause (suppression of reproductive function during the winter season) periods and an understanding of the habitat characteristics of roost sites selected during each of these portions of the annual cycle is an important component of effective monarch conservation. Current evidence indicates that western monarchs prefer overwintering habitat comprised of a relatively dense grove of trees with some understory, located near water and nectar sources and protected from the wind by topographic landforms or trees (Sakai and Calvert 1991). Because monarchs are sensitive to excessive heat, cold and moisture during their diapause, an overwintering grove should act as a protective "humidity lens" to ameliorate climatic extremes of temperature and moisture occurring outside the grove (Sakai and Calvert 1991).

Effectively managing overwintering monarch butterfly habitat requires an understanding of the microclimate conditions needed by butterflies. Microclimate conditions of habitats supporting monarch butterfly populations along the central coast of California are not well documented. Past studies have reported that monarch butterflies seek trees with exposure to filtered sunlight and shelter from gusty intermittent winds (Leong 1990, Leong et al. 1991, Sakai and Calvert 1991). Monarch butterflies appear to orient themselves to different aspects relative to the trunk of their roost trees during the winter months in response to the direction of winds through the grove (Leong 1990, Hamilton et al. 2002, Frey et al. 2003, Frey et al. 2004, Frey et al. 2005).

Two groves at Andrew Molera State Park and one grove at Point Lobos State Reserve have been recognized as historic monarch butterfly overwintering habitats in Monterey County in the California Natural Diversity Database maintained by the California Department of Fish and Game. Prior to the surveys conducted by Hamilton et al. (2002) beginning in winter 2001-02, monarch butterfly population estimates at these locations had been intermittent and anecdotal.

During the winter seasons in 2002 - 2007 we collected data on microclimate variables in the overwintering habitats at Andrew Molera State Park (Stands A and B) and Point Lobos State Reserve in Monterey County. Our objectives were to monitor microclimate characteristics in monarch butterfly overwintering groves, and to investigate the relationship between microclimate variables and relative numbers of overwintering monarch butterflies within the groves. This report summarizes microclimate data collected during the 2006/07 winter season, and presents analyses of differences in microclimate parameters between groves, and relationships between monarch abundance and microclimate variables using data collected between 2002 and 2007. Finally, we present the conservation implications of these analyses and recommendations for future microclimate monitoring efforts.

METHODS

Study sites.—Beginning in 2002 we installed data-loggers and weather equipment each winter at two locations in Andrew Molera State Park (Appendix A) and at one location in Point Lobos State Reserve (Appendix B). Andrew Molera State Park (Molera) is located 34 km south of the Carmel River, Monterey County. Blue gum eucalyptus (*Eucalyptus globulus*) is the predominant tree species at both Stand A and Stand B, and was the only tree species used as roosting substrate by monarch butterflies. Point Lobos State Reserve (Point Lobos) is located 7 km south of the Carmel River, Monterey County. Monterey pine (*Pinus radiata*) is the predominant tree species at the grove and was the primary tree species used by monarch butterflies.

At each location, we placed a weather station on the northwestern fringe of the "amphitheatre" opening where a significant number of butterflies had clustered in the winter of 2001-02 (Hamilton et al. 2002). However these locations did not exactly match the butterfly roosting sites established in subsequent years. In 2002-03, 2003-04 and 2004-05, butterflies clustered near the Molera Stand A weather station, but in 2005-06 and 2006-07, the butterflies clustered to the south and west of the weather station. Monarchs did not cluster near the Molera Stand B weather station in any survey year. At Point Lobos in 2003-04, the majority of clustering butterflies were about 75 meters west of the weather station (Frey at al. 2004), but in 2002-03, 2004-05, 2005-06 and 2006-07 the majority of butterflies clustered in the vicinity of the weather station (Frey et al. 2005, VWS unpublished data). Each station was elevated off the ground approximately 0.5 to 1.5 m.

This report summarizes microclimate data collected at Molera and Pt. Lobos from 9 November 2006 to 8 March 2007, compares microclimate parameters between sites, and presents analyses of relationships between microclimate variables and Monarch butterfly abundance at overwintering sites between 2002 and 2007.

Data management.—Using a HOBO shuttle and cable, we routinely transferred weather data from the data loggers to our office desktop computer using Boxcar Pro 4.0 software. From Boxcar, we imported the data into an Excel spreadsheet designed specifically for managing microclimate data. On a regular basis we monitored equipment, downloaded weather data, maintained the database, and ensured that all equipment functioned properly. After March 2007 we removed and safely stored all weather equipment to prevent vandalism.

Sunlight intensity.—We measured light intensity using the HOBO Light Intensity Logger. Every 30 min the HOBO logged light intensity in lumens per square meter.

Temperature, relative humidity, and dew point.—We measured temperature, relative humidity, and dew point using a HOBO Pro Series Weatherproof Logger protected by a rain shield. Temperature was logged every 30 min in degrees Celsius, relative humidity was logged every 30 min in percent, and dew point was logged every 30 min in degrees Celsius.

Precipitation.—We measured precipitation using an Onset RG3-M Data Logging Rain Gauge. The rain gauge collected precipitation using a funnel that dripped water into a "tipping bucket". Each time the bucket tipped, an "event" that equated to 0.02 cm precipitation was logged.

Monarch butterfly censusing.—In addition to recording microclimate data, we conducted a biweekly census of overwintering monarch butterflies at each of the three locations throughout the overwintering period (9 November 2006 to 2 March 2007) in cooperation with Project Monarch Alert at California Polytechnic University. We documented the presence and estimated abundance of clustered monarch butterflies using the standardized counting technique described in Hamilton et al. 2002.

Statistical analyses.—We used one-way ANOVA (Ott 1993) to investigate differences in sunlight intensity, temperature, relative humidity, and dew point at each of the three study sites. We used Pearson Product-moment Correlation (Zar 1998) to test for relationships between microclimate variables and butterfly abundance, and calculated significance values using the formula $t = r/\text{sqrt}[(1-r^2)/(N-2)]$. We assumed statistical significance at a level of $P < 0.05$ for both tests.

RESULTS

2006/07 Summary

Light intensity differed significantly between the three groves (df = 2, $F = 42.9$, $P < 0.001$). Stand B at Molera received the least amount of light, Stand A received moderately higher light levels, and the Stand at Point Lobos received the most light (Table 1).

Temperature differed significantly between the three groves (df = 2, F = 88.47, $P < 0.001$). The stand at Point Lobos had the highest mean temperature, and Molera Stands A and B had similar, lower mean temperatures (Table 1).

Relative humidity was compared only between Point Lobos and Molera Stand A; due to a technical problem with the humidity gauge, no RH data was collected at the Molera Stand B site during the 2006-07 season. Relative humidity was significantly lower at Molera Stand A than at the Point Lobos grove (df = 1, F =1856.92, $P < 0.001$; table 1).

Dew point was compared only between Point Lobos and Molera Stand A; due to a technical problem with the humidity gauge, no dew point data was collected at the Molera Stand B site during the 2006-07 season. Dew point was significantly lower at Molera Stand A than at the Point Lobos grove (df = 1, F = 1498.58, $P < 0.001$; table 1).

Precipitation was not significantly different between sites. Molera Stand B had moderately higher precipitation than Molera Stand A or Point Lobos, and Point Lobos exhibited the least precipitation (Table 1).

Appendix C displays summary data collected for each microclimate parameter at each site for all study years beginning in 2002.

During the overwintering period from 6 November 2006 to 28 February 2007, numbers of overwintering butterflies varied greatly among the three study sites. We regularly observed clusters of overwintering butterflies at Molera Stand A and Point Lobos; weekly population estimates ranged from 8 to 1,070 butterflies at Molera Stand A, and 0 to 390 butterflies at Point Lobos. We never observed butterflies at Molera Stand B. The population counts at Molera Stand A were markedly lower than the previous winter, while the counts at Point Lobos were somewhat higher (Frey et al. 2005; table 2, figure 1).

Associations Between Monarch Abundance and Microclimate Parameters

At the Point Lobos site, monarch numbers were positively correlated with weekly average light intensity ($n = 65$, $r = 0.579$, $P < 0.001$) (figure 2) and previous day average light intensity ($n = 65$, $r = 0.458$, $P < 0.001$) (figure 3). Monarch abundance was negatively correlated with previous day minimum temperature ($n = 65$, $r = -0.260$, $P = 0.05$) (figure 4), previous day maximum dew point ($n = 65$, $r = -0.299$, $P = 0.03$) (figure 5) and previous day average dew point ($n = 65$, $r = -0.256$, $P = 0.05$) (figure 6), and was not correlated with humidity or precipitation.

Associations between monarch butterfly abundance and microclimate variables at Point Lobos	
Microclimate Variable	Direction of Association
Weekly average light intensity	+
Previous day average light intensity	+
Previous day minimum temperature	-
Previous day maximum dew point	-
Previous day average dew point	-

At Andrew Molera Stand A, monarch numbers were negatively correlated with weekly minimum dew point ($n = 62$, $r = -0.356$, $P = 0.001$) (figure 7), weekly maximum dew point ($n = 62$, $r = -0.296$, $P = 0.025$) (figure 8), weekly average dew point ($n = 62$, $r = -0.403$, $P = 0.001$) (figure 9), weekly maximum RH ($n = 38$, $r = -0.509$, $P = 0.001$) (figure 10) and weekly average RH ($n = 38$, $r = -0.494$, $P = 0.001$) (figure 11). Monarch abundance was not correlated with light intensity, temperature, or precipitation at Molera Stand A.

Associations between monarch butterfly abundance and microclimate variables at Andrew Molera Stand A	
Microclimate Variable	Direction of Association
Weekly minimum dew point	-
Weekly maximum dew point	-
Weekly average dew point	-
Weekly maximum RH	-
Weekly average RH	-

DISCUSSION

Most microclimate parameters measured from 9 November 2006 to 8 March 2007 varied significantly among the three study sites. Point Lobos averaged the highest light intensity, temperature, relative humidity, and dew point (Table 1). In contrast, Stand A at Molera averaged the lowest light intensity, temperature, relative humidity, and dew point (Table 1). The lack of difference in precipitation between sites may have been the result of a particularly dry winter; continued collection of consistent weather data will elucidate the patterns of rainfall and other microclimate parameters within monarch overwintering sites. These and other microclimate conditions likely influenced the abundance of overwintering butterflies roosting at the sites- Molera Stand A had consistently higher abundance of monarchs than did Point Lobos; however, refined long-term monitoring of microclimate parameters and overwintering butterflies is necessary in order to clearly understand relationships between microclimate conditions and their effect on overwintering butterflies.

Monarch numbers were positively correlated with weekly and previous day light intensity at the Point Lobos site but not at the Molera Stand A site. The overwintering season, which begins in October and ends in March, is characterized by light intensity that wanes continuously as days get shorter, the angle of the sun gets lower, and weather fronts become more prevalent. After December, light intensity begins to increase again due to increasing daylight time and angle of the sun. During the overwintering period, monarch numbers at roost sites tend to increase steadily over the first portion of the season, as more butterflies arrive from their breeding grounds and from ephemeral roosting sites. Towards the end of the season, monarch numbers begin to decrease as they enter the breeding and dispersal portion of their life cycle. Thus, the pattern of light intensity through the overwintering season and the behavior of the butterflies during this portion of their annual cycle should result in a negative correlation between light intensity and monarch numbers if the correlation is an artifact of seasonality rather than light intensity per se. However, we see the opposite pattern at Pt. Lobos, suggesting that, at that site, light intensity is an important microclimate parameter influencing monarch numbers. Past studies have reported that overwintering butterflies did not cluster on trees subjected to sun exposure and bright illumination (Brower et al. 1998, Leong 1990, Leong et al. 1991). Frey et al (1992), found that on any given day, approximately 80% of the clusters were found in the shaded or indirectly lighted parts of a tree. According to Chaplin and Wells (1982), the monarch metabolic rate is a function of body temperature, and thus prolonged exposure to direct light could result in suboptimal rate of body fat utilization. Lower light intensity at Molera A as compared to Point Lobos, may in part, explain why Molera A consistently shelters more overwintering monarchs annually than does brighter and hotter Point Lobos. However, the butterflies function within a complex interrelationship of microclimate and habitat parameters, and it is possible that sites with greater light intensity provide enough solar radiation to maintain their bodies above the flight threshold of 13.8° C, while other microclimate variables such as dew point act to balance the warming effects of light intensity.

At Point Lobos, monarch abundance was negatively correlated with previous day minimum temperature, an expected pattern given the temperature sensitivity of monarchs during their overwintering period, when they must find roosts cool enough to keep their bodies in diapause, but well above freezing so that they maintain mobility. We hypothesize that low minimum temperatures may cause the butterflies to relocate throughout the winter season to areas that are more buffered against low temperatures, resulting in lowered census numbers. The lack of association between temperature and monarch numbers at Molera Stand A suggests that the temperature remains within the preferred parameters for the butterflies throughout the overwintering season.

Monarch abundance was also negatively correlated with dew point at both Point Lobos and Molera Stand A, suggesting that monarchs prefer drier microclimates, and may respond to increases in ambient dampness by relocating to other roost sites. Additionally, monarch numbers were negatively correlated with relative humidity at Molera Stand A, again suggesting that the butterflies seek out roosting habitats that remain relatively dry throughout the season, and may be responding to increases in humidity by shifting to alternative roost sites. Monarch numbers were not correlated with precipitation at either site, but the previous lack of strong precipitation data in the dataset precludes robust analyses of interactions between precipitation levels and monarch numbers at this juncture. As monitoring continues and a continuous precipitation dataset is built up for each site, we will be able to discern patterns of monarch response, if any, to precipitation.

RECOMMENDATIONS

- We recommend continued microclimate monitoring at both the Point Lobos and Andrew Molera overwintering sites. Interannual and decadal fluctuations in monarch numbers, as well as an increasingly changeable climate, are well documented in the literature. Continued study will discern critical changes in microclimate and track long-term shifts in microclimate parameters due to alteration of global weather patterns, as well as assessing how microclimate patterns and trends affect monarch populations.

- We recommend placing microclimate sensors in monarch roost trees in order to further elucidate the relationship between microclimate parameters and monarch abundance. Studies indicate that microclimate data are critically sensitive to topography, habitat structure and vegetation characteristics, suggesting that microclimate variables should be collected as close to monarch roost sites as possible in order to accurately assess the microclimate variables that the butterflies are responding to.

- We recommend the placement of permanent microclimate stations at standardized heights at each of the currently known stable monarch overwintering sites in Monterey County. Understanding the complex interactions between microclimate parameters and monarch abundance and movement requires a broad sample of roost locations encompassing different habitat types, management regimes, anthropogenic influences and landscape features.

- We recommend drafting a Monarch Habitat Management Plan for Point Lobos Reserve that considers canopy structure, tree health, long-term grove management and restoration. Because Point Lobos supports monarchs even in low numbers, it is possible that with proper management and restoration it could shelter more monarchs given appropriate protections in the grove from cold temperatures, wind and wet conditions.

- We recommend an immediate reassessment of the monarch grove at Andrew Molera State Park following the original template created by Weiss and Luth (2002), to be followed by continued reassessments at five-year intervals. Additionally, we recommend comprehensive vegetation structure assessments at the beginning and end of each overwintering season, to determine the effects of changes in midstory, understory, and ground cover structure on microclimate and monarch numbers. Given the sensitivity of monarchs to microclimate, it is essential to periodically track changes in habitat structure that may influence microclimate variables and monarch behavior.

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Table 1. Microclimate parameters compared during winter 2006-07 between three microclimate monitoring sites at Andrew Molera State Park (Stand A and Stand B) and Point Lobos State Reserve, Monterey County, California.

Stand	Light intensity (Lumens/sq. m)		Temperature[c] (°C)		Relative humidity[c] (%)		Dew point[c] (°C)		Precipitation[c] (cm)	
	µ[a]	SE[b]	µ	SE	µ	SE	µ	SE	µ	SE
Molera A	0.24	0.04	10.22	0.05	67.75	0.35	2.11	0.15	3.93	0.22
Molera B	-0.09	0.03	10.45	0.05	N/A	N/A	N/A	N/A	8.42	0.12
Point Lobos	0.37	0.04	11.25	0.07	87.10	0.28	8.20	0.05	9.36	0.08

[a] Mean
[b] Standard error of the mean

Table 2. Weekly monarch butterfly abundance during winter 2006-2007 near three microclimate monitoring sites at Andrew Molera State Park (Stand A and Stand B) and Point Lobos State Reserve, Monterey County, California.

Date	Point Lobos	Andrew Molera A	Andrew Molera B
11/6/06	116	3555	0
11/21/06	1430	2858	0
12/4/06	1355	2180	0
12/18/06	1024	no count	0
1/3/07	1055	4046	0
1/15/07	522	3792	0
1/29/07	215	4504	0
2/12/07	111	2559	0
2/26/07	2	192	0

Figure 1. Mean monarch butterfly population counts during the overwintering period at Point Lobos and Andrew Molera Stand A, Monterey County, California from the winter of 2002-03 to the winter of 2006-07.

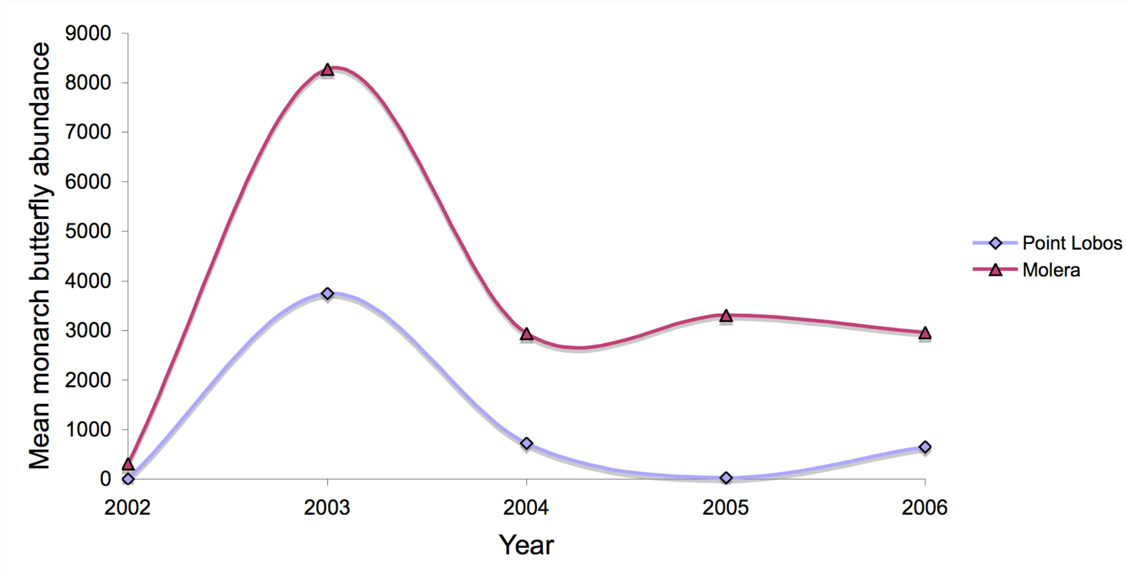


Figure 2. Correlation between weekly average light intensity (lumens/m^2) and monarch abundance at Point Lobos (r=0.579, P < 0.001).

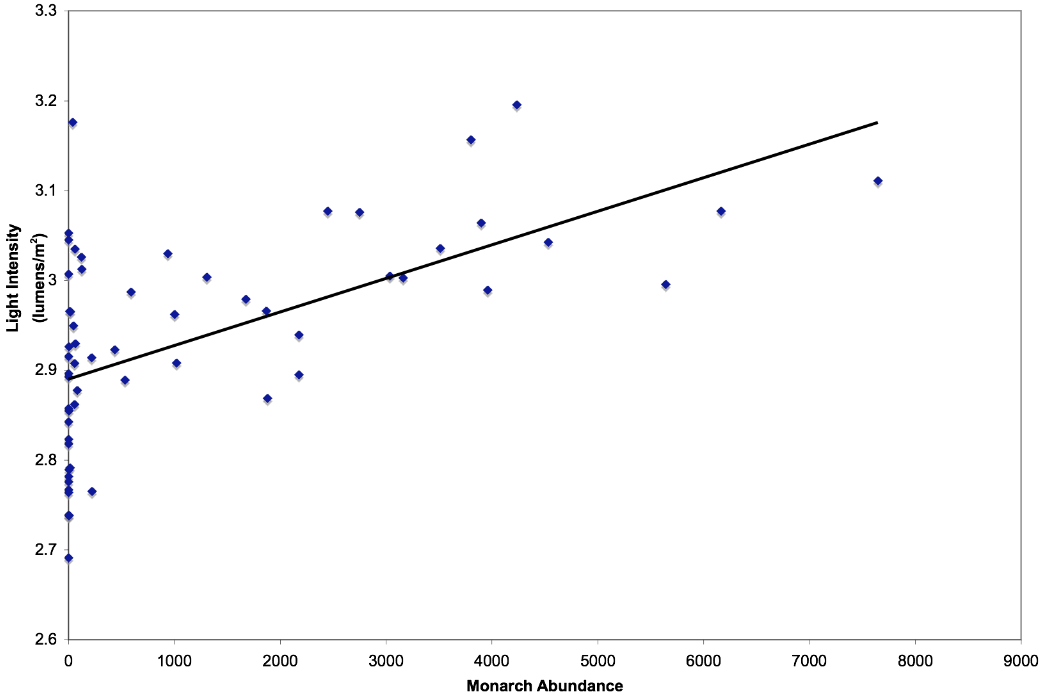


Figure 3. Correlation between previous day average light intensity (lumens/m2) and monarch abundance at Point Lobos (r = 0.458, P < 0.001).

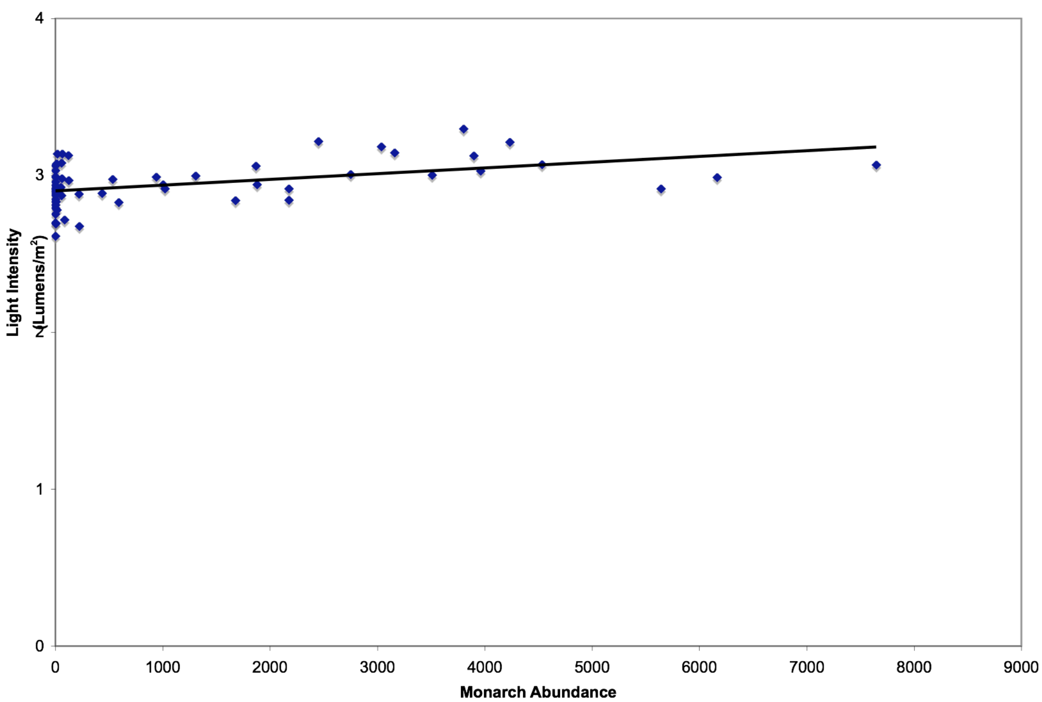


Figure 4. Correlation between previous day minimum temperature (°C) and monarch abundance at Point Lobos (r = 0.260, P = 0.05).

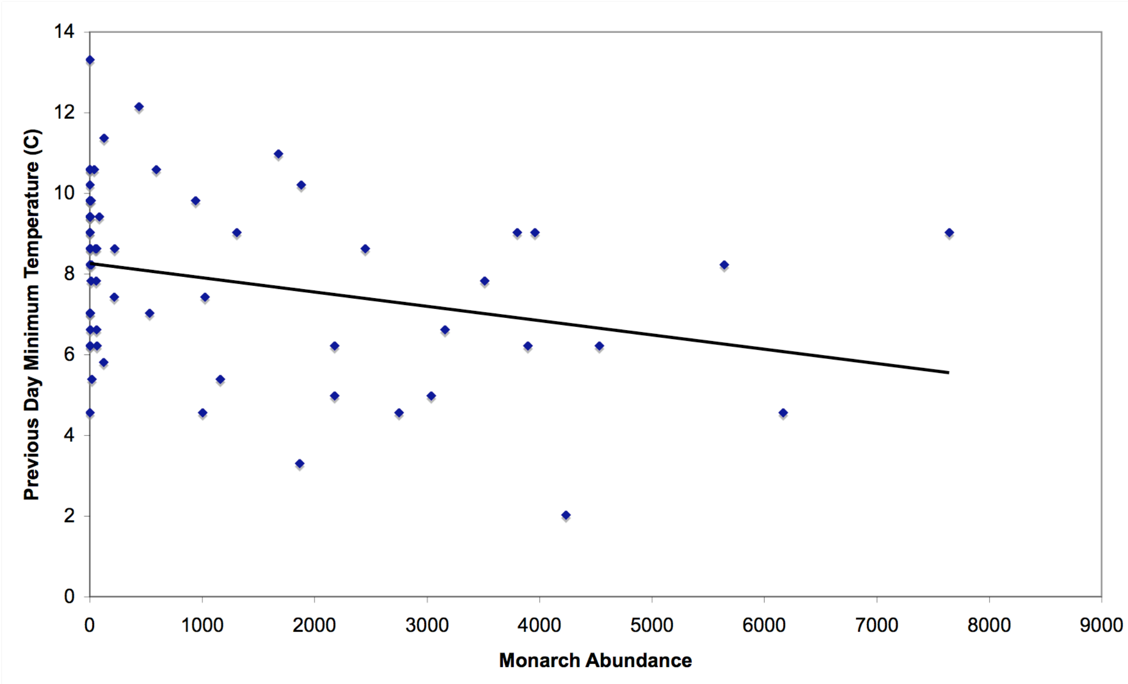


Figure 5. Correlation between previous day maximum dew point (°C) and monarch abundance at Point Lobos (r = -0.299, P = 0.03).

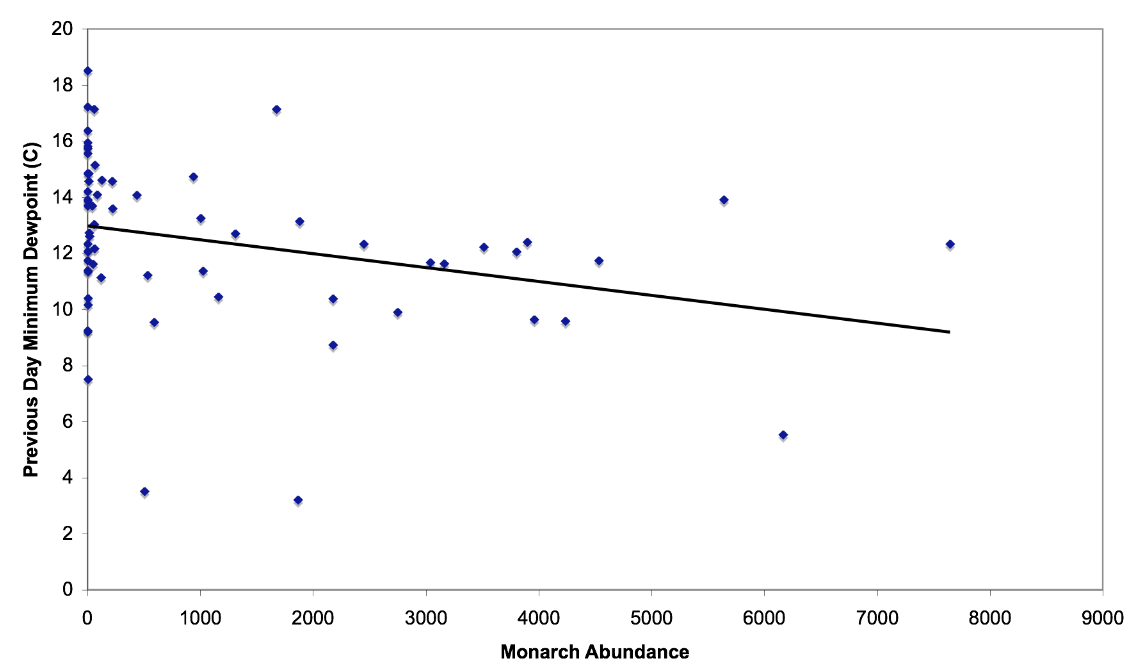


Figure 6. Correlation between previous day average dew point (°C) and monarch abundance at Point Lobos (r = -0.256, P = 0.05).

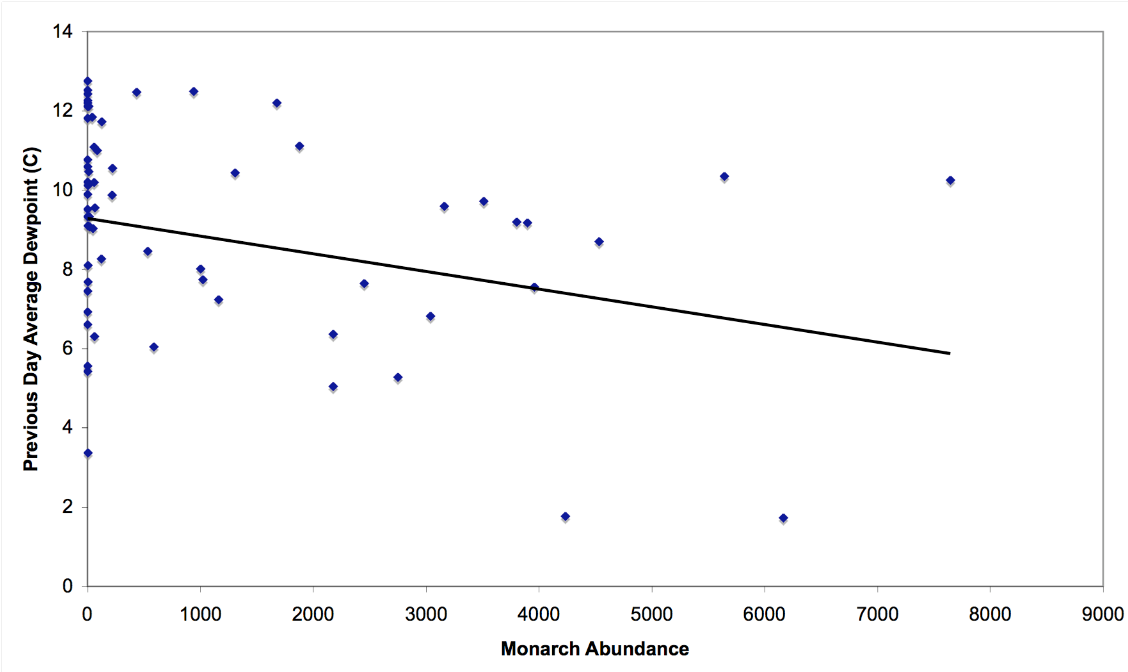


Figure 7. Correlation between weekly minimum dew point (°C) and monarch abundance at Molera Stand A (r = -0.356, P = 0.001).

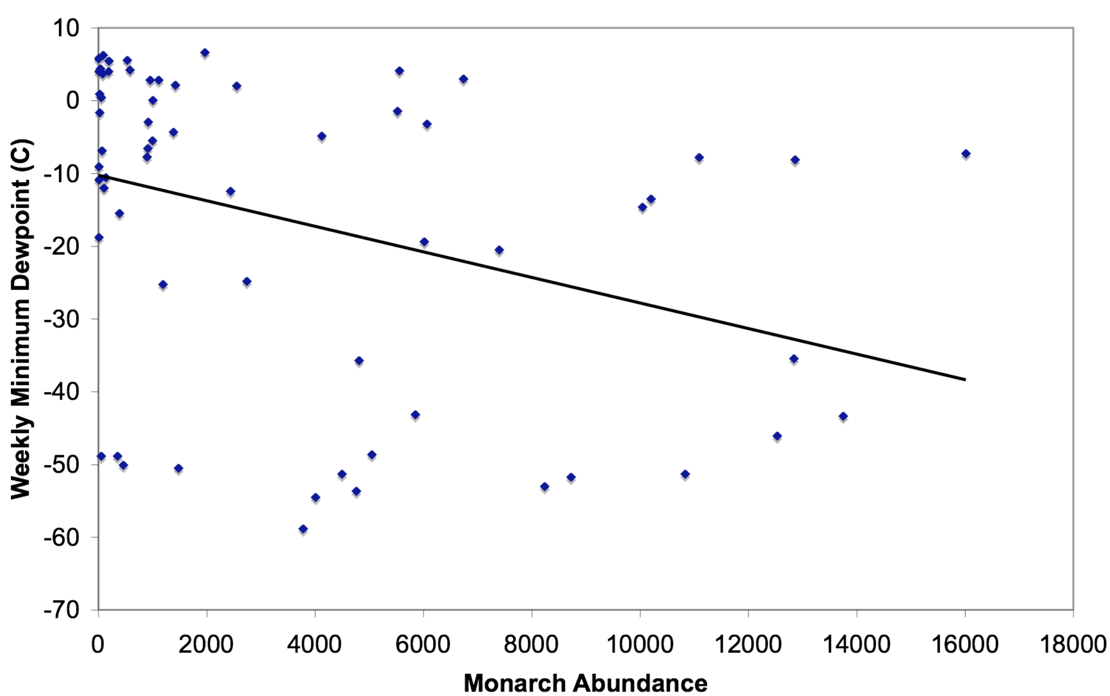


Figure 8. Correlation between weekly maximum dew point (°C) and monarch abundance at Molera Stand A (r = -0.296, P = 0.025).

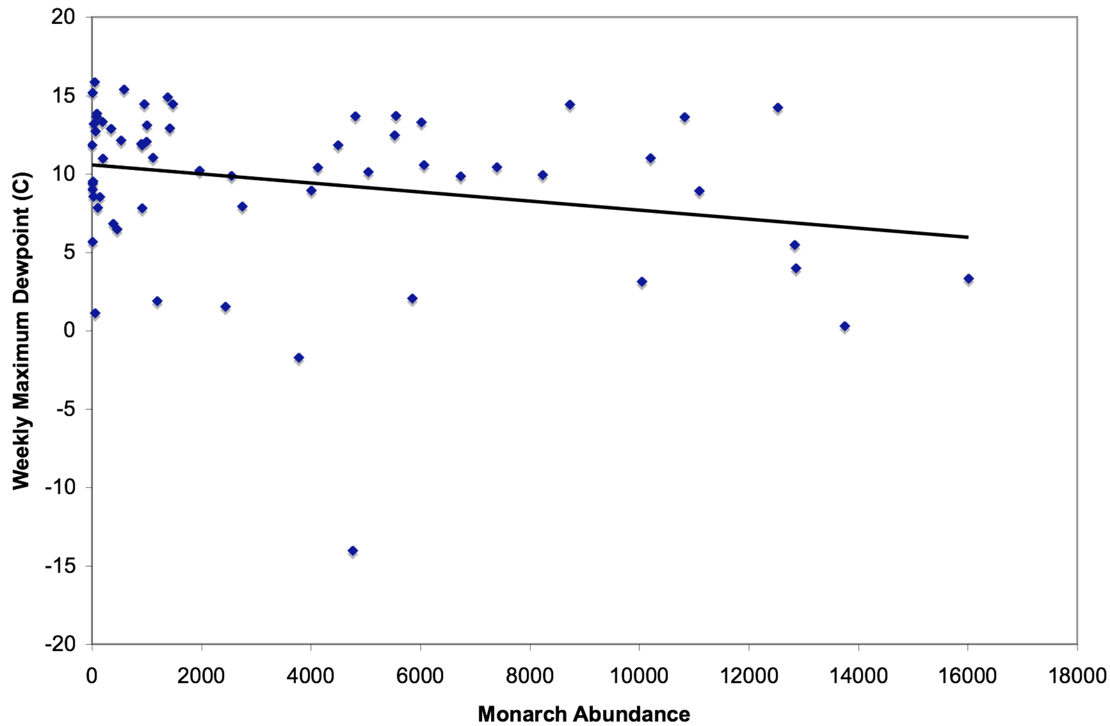


Figure 9. Correlation between weekly average dew point (°C) and monarch abundance at Molera Stand A (r = -0.403, P = 0.001).

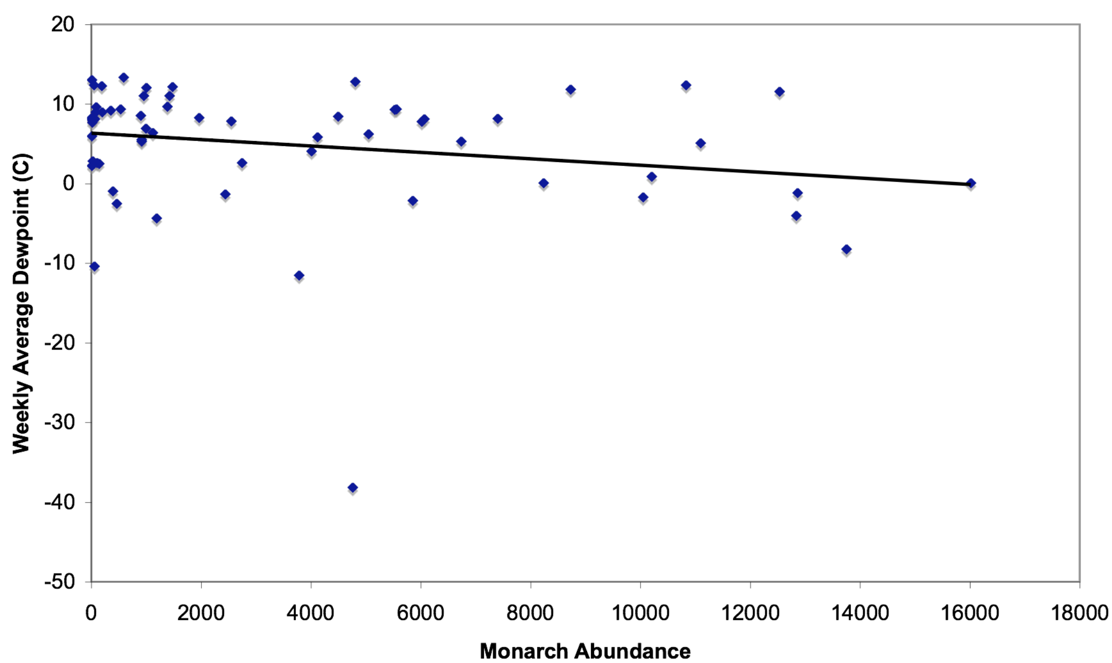


Figure 10. Correlation between weekly maximum RH (%) and monarch abundance at Molera Stand A (r = -0.509, P = 0.001).

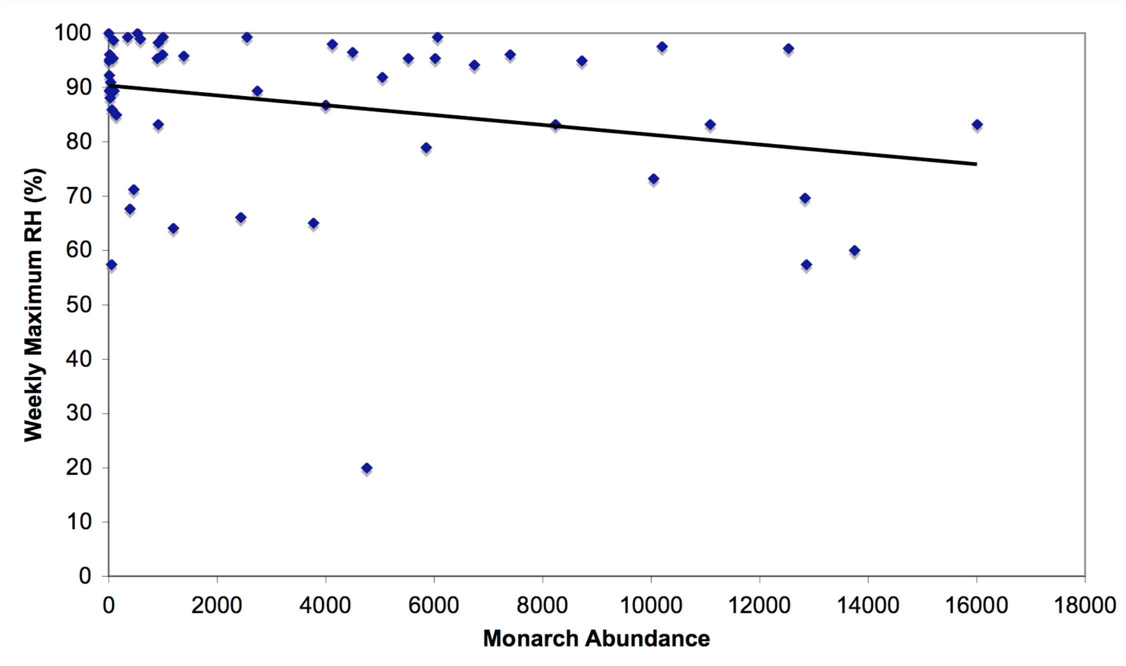
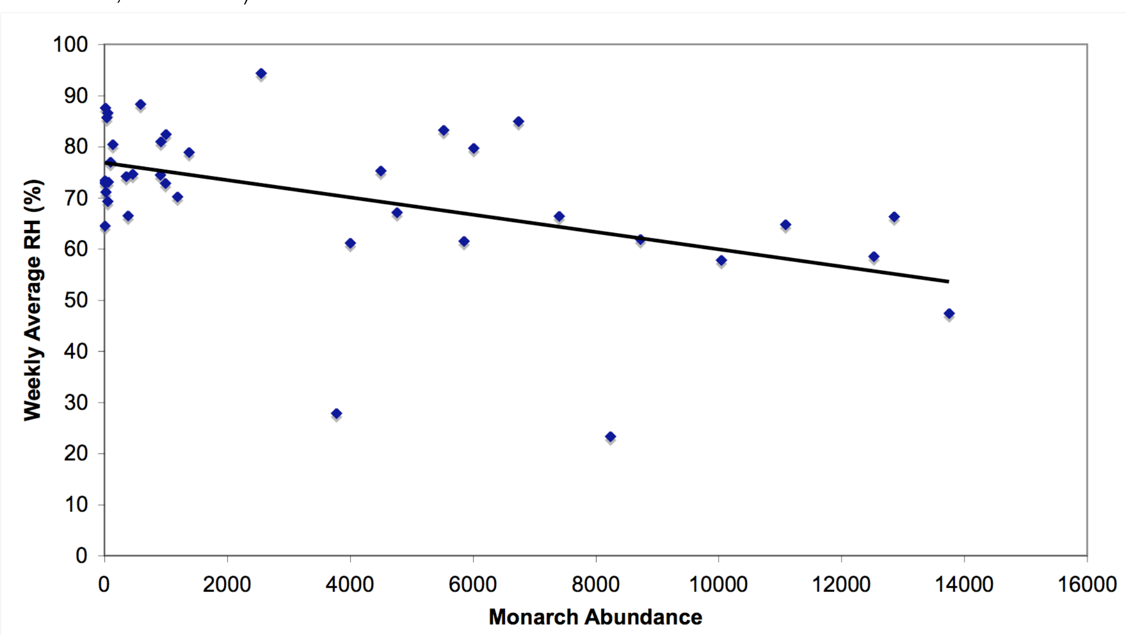
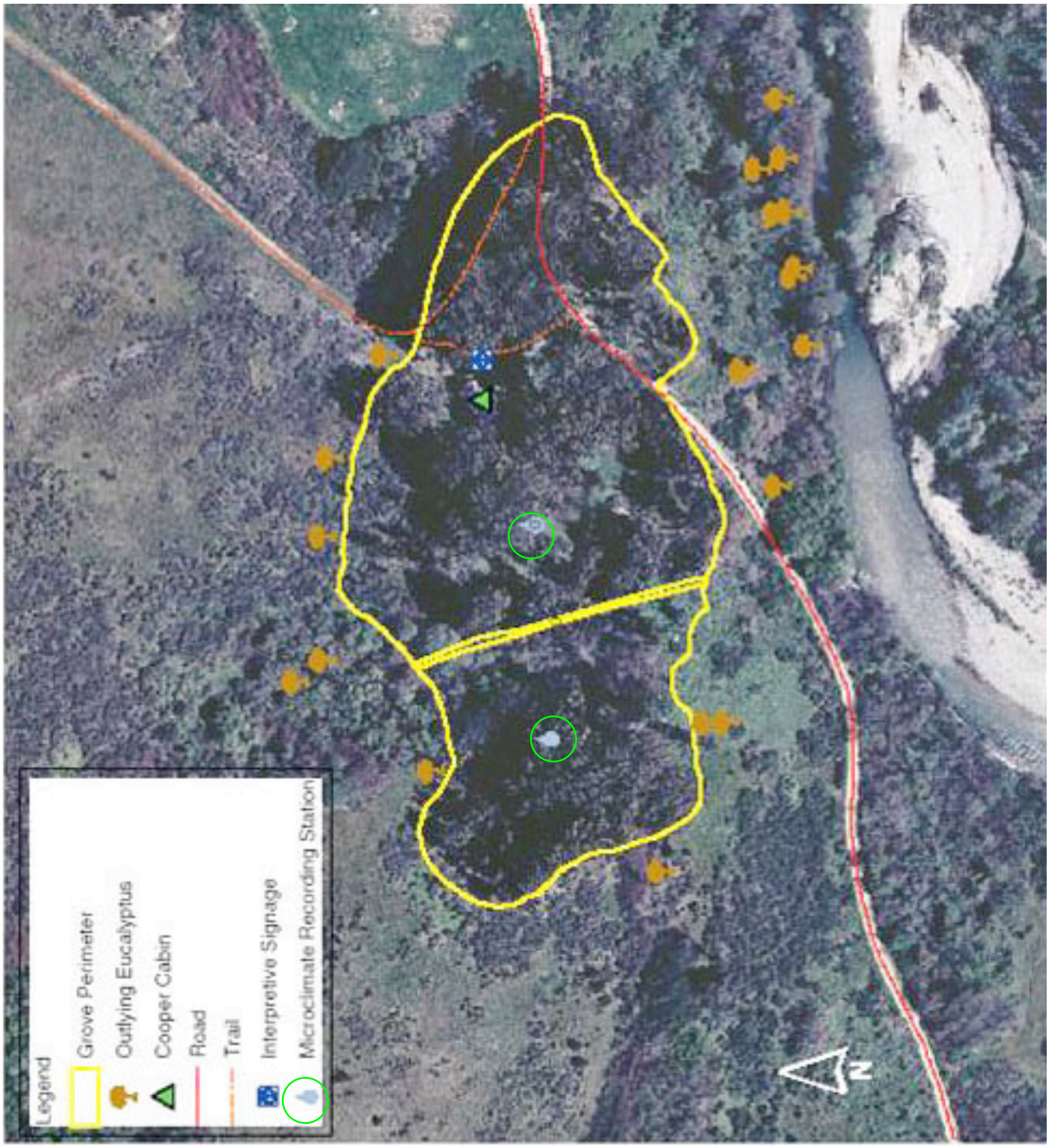


Figure 11. Correlation between weekly average RH (%) and monarch abundance at Molera Stand A (r = -0.494, P = 0.001).



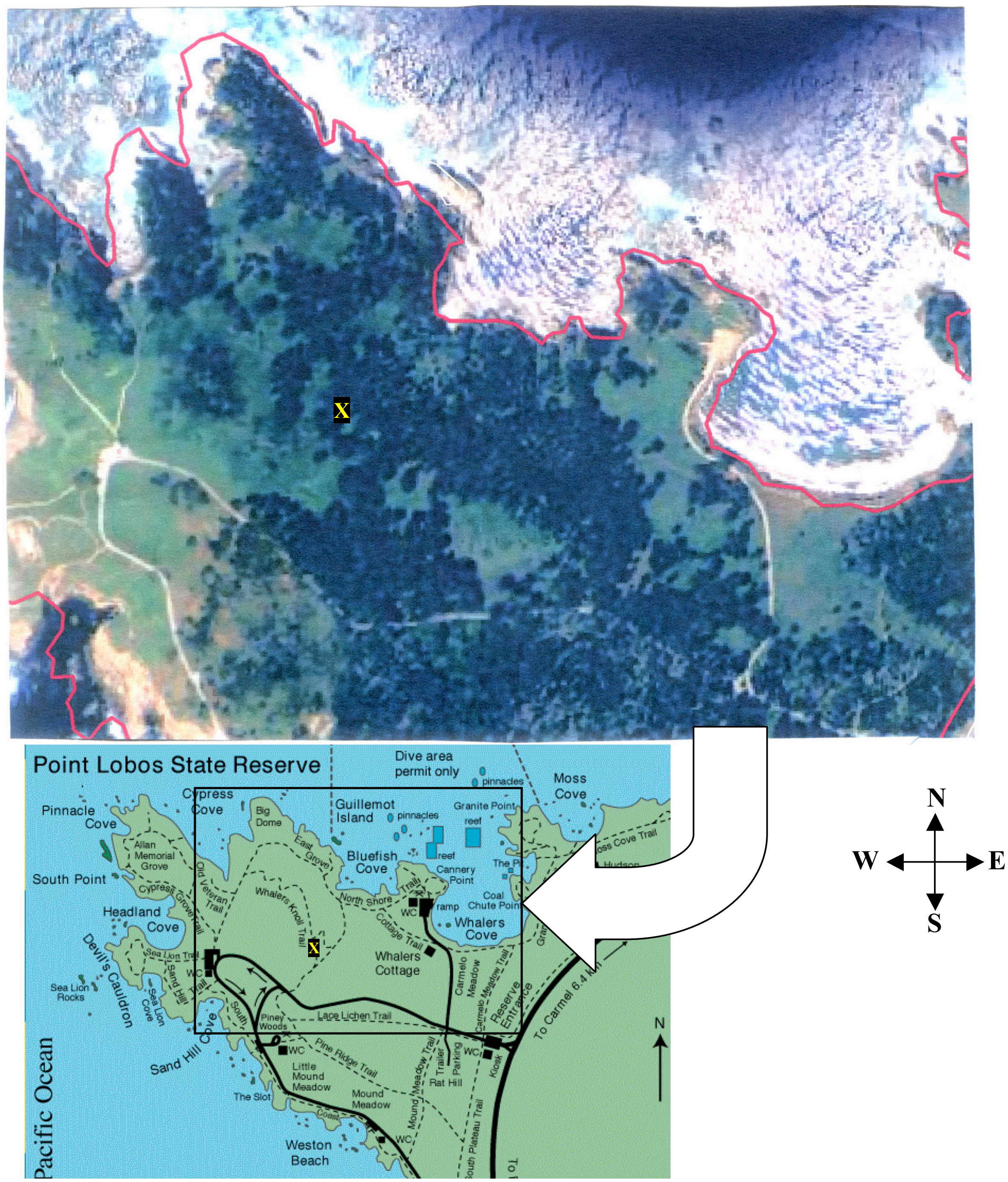
Appendix A. Study sites: Stand A and Stand B at Andrew Molera State Park, Monterey County, California.



Appendix B. Study Site: Point Lobos State Reserve, Monterey County, California.

Legend

X Microclimate Recording Station



Appendix C. Microclimate summary data for Point Lobos, Molera Stand 1 and Molera Stand 2, November 2002 to March 2007

Stand	2002-03	2003-04	2004-05	2005-06[b]	2006-07[c]
Sunlight Intensity (lm x m^2)					
Molera A	0.41 ± 0.03[a]	0.32 ± 0.03	0.22 ± 0.04	-0.29 ± 0.03	0.24 ± 0.04
Molera B	0.16 ± 0.03	0.19 ± 0.03	0.10 ± 0.03	0.01 ± 0.03	-0.09 ± 0.03
Point Lobos	0.24 ± 0.03	0.45 ± 0.03	0.33 ± 0.04	0.38 ± 0.03	0.37 ± 0.04
Temperature (C°)					
Molera A	11.80 ± 0.05[a]	10.64 ± 0.04	10.91 ± 0.04	11.89 ± 0.07	10.22 ± 0.05
Molera B	11.93 ± 0.05	10.72 ± 0.04	10.95 ± 0.04	11.93 ± 0.06	10.45 ± 0.05
Point Lobos	12.70 ± 0.06	11.18 ± 0.05	11.77 ± 0.05	12.43 ± 0.08	11.25 ± 0.07
Relative Humidity (%)					
Molera A	82.83 ± 0.25[a]	74.49 ± 0.34	80.97 ± 0.30	70.42 ± 0.54	67.75 ± 0.35
Molera B	81.44 ± 0.22	86.12 ± 0.21	91.48 ± 0.21	85.51 ± 0.45	N/A[d]
Point Lobos	79.86 ± 0.26	85.71 ± 0.21	85.06 ± 0.24	86.77 ± 0.43	87.10 ± 0.28
Dew point (C°)					
Molera A	8.50 ± 0.06[a]	4.75 ± 0.11	6.58 ± 0.10	3.93 ± 0.22	2.11 ± 0.15
Molera B	8.51 ± 0.05	8.14 ± 0.05	9.10 ± 0.06	8.42 ± 0.12	N/A[d]
Point Lobos	8.67 ± 0.05	8.49 ± 0.04	8.81 ± 0.05	9.36 ± 0.08	8.20 ± 0.05

[a] Measurements are mean ± standard error.
[b] Data from 9 November 2005 to 5 January 2006 only
[c] Data from 8 December 2006 to 2 March 2007 only
[d] Data lost due to equipment failure