# FACTORS INFLUENCING POPULATION VIABILITY OF HERMES COPPER (*LYCAENA HERMES*)

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presented to the

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in

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by

Daniel Alan Marschalek

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**SAN DIEGO STATE UNIVERSITY**

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Factors Influencing Population Viability of Hermes Copper (*Lycaena hermes*)

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# DEDICATION

This thesis is dedicated to Doug, Sharon, Jim, Nicole, June, George, Alfred and Dorothy, who have always supported and emphasized my education.

Let children walk with Nature, let them see the beautiful blendings and communions of death and life, their joyous inseparable unity, as taught in woods and meadows, plains and mountains and streams of our blessed star, and they will learn that death is stingless indeed, and as beautiful as life.

-John Muir
*A Thousand-Mile Walk to the Gulf*

## ABSTRACT OF THE THESIS

Factors Influencing Population Viability of Hermes Copper
(*Lycaena hermes*)
by
Daniel Alan Marschalek
Master of Science in Biology
San Diego State University, 2004

Hermes copper (Lepidoptera: Lycaenidae: *Lycaena hermes*) has experienced habitat loss due to population growth in San Diego County, CA. Reduced habitat and the wildfires of 2003 have elevated concern from wildlife biologists about the status of this species, leading to a second petition to list Hermes copper under the Endangered Species Act. Currently very little research regarding the biology of Hermes copper is present in the literature. This research provides biological and monitoring information specific to Hermes copper.

Pollard Walks were conducted to record abundances and locations of Hermes copper adults. Adults were present for roughly one to two months at any one location, with initial emergence of individuals varying among sites and years due to elevation and weather. Survey data showed elevation influenced the start of the flight season by only a couple days and the warmer weather of 2004 led to first detection of adults four days earlier than 2003. Densities also varied among sites and years, with adults often found nectaring or resting on *Eriogonum fasciculatum*. Logistic regression using habitat characteristics measured along transects did not successfully predict the presence of adults. Hermes copper were higher on edge transects, specifically the north and west side of roads. A movement study, following an individual for ten movements, demonstrated that most individuals remained in a small area, often times repeatedly resting on a particular section of a shrub. Mark-release-recapture data showed a resighting was most likely less than twelve meters from the previous sighting, with a maximum distance of 84 meters recorded. A 43 percent recapture rate resulted from the mark-release-recapture study, with significantly more males resighted than females. Searches for larvae in late April and early May were unsuccessful.

Insect Count Analyzer (INCA) is a sophisticated statistical model that estimates a population size based on survey data. Four of seven surveyed sites yielded unreliable estimates due to a high correlation between death rate and population size. Of the three successful estimates, population size CVs ranged from 0.16 to 0.41. Minor direct perturbations to survey data resulted in large changes to the INCA estimate. Random perturbations, involving simulated data, allow a comparison of INCA estimates and Max Count. Max Count is the highest number of Hermes copper adults observed during Pollard Walks at a site. Simulations demonstrated that INCA amplifies error and stabilizes bias while Max Count was biased with less error at all levels of variability tested. A power simulation showed that Max Count had a better ability to detect a population change than INCA. Power of Max Count to detect a population change increased from 0.26 to 0.95 for five to ten years of survey data used, with INCA increasing from 0.02 to 0.25. Mark-release-

recapture data was not appropriate to use in population size calculations due to few individuals reappearing after eluding detection. This high detectability of adults created problems in calculating population size and confidence intervals since individuals that were never resighted were treated as dead rather than mixing into the population. Mark-release-recapture may not be useful for Hermes copper based on the biology and behavior of the species.

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# INTRODUCTION

The area of San Diego, California has experienced substantial population growth over the last century. Current forecasts suggest that San Diego County will attract one million new residents by 2030, an increase of nearly 37 percent (SANDAG 2004). Increasing population pressures have led to many environmental problems including direct habitat loss, as native habitats have been lost to urban and suburban development. Coastal habitats like coastal sage scrub have been particularly hard hit. In fact coastal sage scrub represents only 10 to 15 percent of its former range (Westman 1981). The loss of habitat has contributed to the declines in several threatened or endangered species such as Stephen's kangaroo rat (*Dipodomys stephensi*), California gnatcatcher (*Polioptila californica californica*) (Atwood 1993), Palos Verdes Blue butterfly (*Glaucopsyche lygdamus palosverdesensis*) (Arnold 1987) and Quino checkerspot butterfly (*Euphydryas editha quino*) (USFWS 2003).

The intense human population pressures have led to many environmental conservation and preservation measures. Conservation efforts often include mitigation as a tool used to balance natural resources lost to urban development with those placed into native habitat reserves. Rare habitats and species are offered more protection with requiring higher ratios of preserved to destroyed habitat (CDFG 2004a).

The Multiple Species Conservation Plan (MSCP) was developed in an effort to conserve vegetation communities and species within a 900 square mile section of southwestern San Diego County (CDFG 2004b). This plan involves mitigation with a large-scale focused approach. Certain habitats and species are designated as conservation targets, focusing on preserving specific areas of high biological interest. Eighty-five plant and animal species (CDFG 2004b) are included in the MSCP to designate a reserve network so that habitat needs are met for all these species. Currently, Thorne's hairstreak (*Mitoura thornei*) and wandering skipper (*Panoquina errans*) are the only insects included.

These preservation efforts are predicated on the notion that populations of covered species will be viable on the habitats set aside for preservation. Monitoring of covered species is important in determining if mitigation is required as well as to determine the success of these preserved habitats. Reserves established under the MSCP also require monitoring to assess if biological objectives have been met. Thus monitoring is an important component of conservation efforts.

## MONITORING

It is difficult to develop accurate monitoring programs for use in conservation efforts, since monitoring programs must be tailored to the natural history of each species of interest. The relationship between the natural history of the target species and the design of the monitoring program is essential as monitoring of a long-lived sessile organism differs greatly from a short-lived migratory organism.

The goal of most monitoring programs is to obtain an accurate estimate of population size. This task is often deceptively difficult (Noss 1990, Sparrow *et al*. 1994). Population size estimates may be direct, involving known individuals of a population as in mark-release-recapture, or indirect, using survey numbers as an index as in Pollard Walk surveys (Pollard 1977). Sometimes estimates are based on surrogate variables that are easier to obtain which involves using signs of activity of the species. Examples are counting burrow holes for Stephen’s kangaroo rat (*Dipodomys stephensi*) or footprints and scat for carnivores (Kendall *et al*. 1992). Since monitoring is expensive, monitoring efforts should consist of the most efficient method of accurate estimation.

Insect populations are difficult to monitor because species are often difficult to detect, may be ephemeral, and vary greatly from place to place and time to time. Most insects are impossible to mark, so unique individuals cannot be identified. As a result, population estimates must be made from indices or surrogates. Despite these difficulties, adequate data has been collected to allow the United States Fish and Wildlife Service to list endangered species such as Palos Verdes blue (*Glaucopsyche lygdamus palosverdesenis*), El Segundo blue (*Euphilotes bernardino allyni*) and Quino checkerspot (USFWS 2003) butterflies in southern California.

Butterfly populations have been monitored with a variety of field and analytic methods including Pollard Walk surveys, mark-release-recapture, and population estimation with Insect Count Analyzer (INCA). Each of these methods has both strengths and weaknesses that need to be understood.

## Pollard Walks

In an attempt to assess population sizes of butterflies, a standardized method was developed in 1973 and modified in 1977 (Pollard 1977). This consists of recording number of individuals for each butterfly species while walking transects, or Pollard Walks, with a standardized walking speed, time of day and weather conditions. This low impact method requires little equipment and is not time intensive, particularly once transects are established. Disadvantages of Pollard Walks are that clumped distributions can be missed if the transect is not placed properly, and data are limited to year-to-year comparisons. The key statistic often used is the maximum count, providing a relative population size estimate (an index) rather than an absolute estimate of population size from each site every year.

## Mark-Release-Recapture

Mark-release-recapture techniques have been used to obtain absolute butterfly abundances in the past (Singer and Wedlake 1981, Morton 1982, Morton 1984, Gall 1985, Mattoni *et al*. 2001). This involves capturing a certain number of individuals, marking each with a unique pattern, then recapturing or resighting butterflies to determine a recapture rate. A population size is calculated based on the recapture rate and number of individuals initially marked (Gall 1985, Krebs 1998). This method provides an absolute estimate of population size, which is desirable. However, there are some disadvantages of using this technique, with low recapture rates (Singer and Wedlake 1981, McKelvey and Pearson 2001) one of the most significant. In this case, estimates are often unreliable. Low recapture rates may be a result of a large population, high level of movement within the population, or mortality among captured individuals (Singer and Wedlake 1981, Morton 1982, Morton 1984, Reisen *et al*. 1991, Smith and Wall 1998, Knapp and Wall 1999). The difficulty in obtaining an accurate estimate is further compromised when the behavior and survival of butterflies may be altered when captured. It has been shown that recapture rates are lower when butterflies are handled (Singer and Wedlake 1981, Morton 1982, Morton 1984). Although mark-release-recapture may yield an absolute population size estimate, they are impossible or inappropriate to use with many species of butterflies.

# INCA

Insect Count Analyzer (INCA) is a sophisticated statistical model designed to provide an absolute estimate of abundance based on simple and inexpensive standardized survey data (INCA 2002). The theory behind INCA is based on Zonneveld (1991), which calculates death rates from survey data. INCA assumes four conditions: generations do not overlap, no net migration, constant death rate, and adult emergence follows a logistic distribution (INCA 2002). The estimate of population size is based on a four-parameter model fit to observed survey data (Figure 1, Table 1).

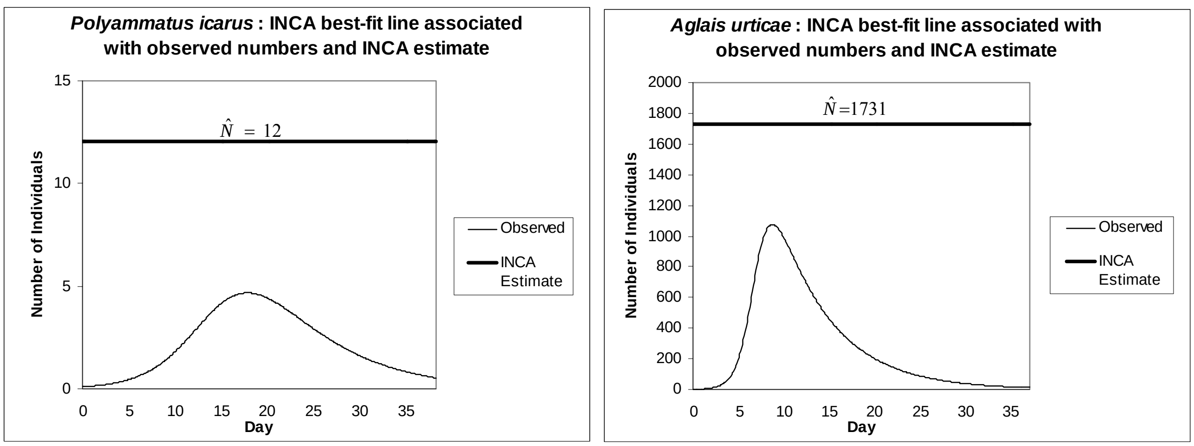


**Figure 1. INCA best-fit line (observed) based on survey data and population size estimate (note y-axis scales are not the same).**

**Table 1. INCA Estimate Parameters.**

| ***Aglais urticae*** | | | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Estimate** | **SD** | **CV** |
| **Alpha** | per day | 0.165 | 0.004 | 2.4% |
| **Beta** | day | 0.937 | 0.027 | 2.9% |
| **Mu** | day | 6.695 | 0.057 | 0.8% |
| **N** | individual | 1731.174 | 39.123 | 0.2% |

| Correlation Coefficients | | | | |
|---|---|---|---|---|
| | **Alpha** | **Beta** | **Mu** | **N** |
| **Alpha** | 1.0 | 0.469 | 0.690 | 0.872 |
| **Beta** | | 1.0 | 0.617 | 0.452 |
| **Mu** | | | 1.0 | 0.656 |
| **N** | | | | 1.0 |

| ***Polyommatus icarus*** | | | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Estimate** | **SD** | **CV** |
| **Alpha** | per day | 0.140 | 0.131 | 93.0% |
| **Beta** | day | 3.080 | 1.485 | 48.2% |
| **Mu** | day | 13.791 | 3.473 | 25.2% |
| **N** | individual | 12.047 | 10.206 | 84.7% |

| Correlation Coefficients | | | | |
|---|---|---|---|---|
| | **Alpha** | **Beta** | **Mu** | **N** |
| **Alpha** | 1.0 | 0.710 | 0.907 | 0.974 |
| **Beta** | | 1.0 | 0.759 | 0.720 |
| **Mu** | | | 1.0 | 0.911 |
| **N** | | | | 1.0 |

## HERMES COPPER (*LYCAENA HERMES*)

Hermes copper (*Lycaena hermes*) (Figure 2 and 3) may be another coastal sage scrub species in risk of extinction, as Wright (1930) described urban development replacing suitable habitat containing Hermes copper colonies over 70 years ago. Distribution of Hermes copper populations coinciding with urban areas associated with San Diego raises significant conservation concerns, as shown by the petition to the United States Fish and Wildlife Service (USFWS 1993, USFWS 1994, Hogan 2004) to list this species.

Relatively little biological information is known about this species. Females oviposit white eggs (Figure 4) singly on the stems of the host plant, spiny redberry (*Rhamnus crocea*) (Emmel and Emmel 1973, Pyle 1981, Faulkner and Klein 2001). Eggs overwinter until larvae emerge in early spring. Larvae are apple green, a dark green dorsal line with yellowish margins extending from the fourth to seventh segment, and two longitudinal yellow bands on each side (Comstock and Dammers 1935). Larvae take about 14 days to mature and another 10 to 14 days to emerge from the pupa (Faulkner and Klein 2001). Field observations of larvae range from 16 March to 24 May (Thorne 1963). Pupae, about 11 millimeters in length, are green with a yellow stripe from the fifth to ninth segment dorsally and a second longitudinally on the thorax and abdomen (Comstock and Dammers 1935).

Males and females are similar in appearance, with a wingspan of 1 to 1 ¼ inches (Opler and Peterson 1999, Faulkner and Klein 2001). Upper forewings are orange with a brown border and brown spots within the orange patch. Hindwings are brown with some orange on the posterior edge, where a tail is present. The underside of both wings is orange to yellow with some dark spots. Due to the presence of tails and unique coloration, it is very unlikely this species will be confused with any other butterfly in the area.

Hermes copper is univoltine, found as adults from mid-May to mid-July, however there is a discrepancy in the literature about the exact length of the flight season. Wright (1930) states that adults are present in late May, all of June and early July, whereas recent research stating flight length at any one location is about 30 days, with elevation affecting the emergence (Faulkner and Klein 2001). Past surveys indicate the flight season ranges from 20 May to 20 July (Thorne 1963). Males emerge first, a common occurrence within Lepidoptera (Scott 1986), with male Hermes copper peaking 10 June and females 20 June (Thorne 1963).

**Figure 2. Underside of Hermes copper (*Lycaena hermes*) on buckwheat (*Eriogonum fasciculatum*).** Photo by Daniel Marschalek (2003).

**Figure 3. Upperside of Hermes copper (*Lycaena hermes*) on buckwheat (*Eriogonum fasciculatum*).** Photo by Daniel Marschalek (2003).

**Figure 4. Egg of Hermes copper (*Lycaena hermes*) on spiny redberry (*Rhamnus crocea*).** Photo by Daniel Marschalek (2003).

Hermes copper is found in the vicinity of San Diego, inhabiting coastal sage scrub and southern mixed chaparral with spiny redberry (Brown 1991). The range extends 50 miles north of the US-Mexico, 45 miles east of San Diego and a few records extending 100 miles south into Baja Mexico (Emmel and Emmel 1973). The host plant, spiny redberry, extends from southern Baja California, north to just north of San Francisco (Munz 1974, Hickman 1996). It is not known why this butterfly has such a restricted range despite the extensive range of the host plant.

## OBJECTIVES OF THIS RESEARCH PROJECT

This research project addresses several biological and statistical issues associated with the conservation of Hermes copper. The research consists of four major objectives:

1. To better characterize the habitat preference of Hermes copper adults, specifically focusing on the larval host plant spiny redberry (*Rhamnus crocea*), and nectaring sources California buckwheat (*Eriogonum fasciculatum*) and chamise (*Adenostoma fasciculatum*).

2. To quantify movement of adults both within patches (intra-patch) and among patches (inter-patch) of spiny redberry (*Rhamnus crocea*).

3. To identify larval requirements, including food and microhabitats.

4. To evaluate methods for population size estimation including traditional Pollard Walks, Insect Count Analyzer (INCA), and mark-release-recapture, using Hermes copper survey data.

The information from this research is of immediate and great use for management of natural areas in southern California. Data will provide biological information to guide conservation of natural areas for the benefit of Hermes copper as well as indicate monitoring techniques appropriate for this species.

# METHODS

I conducted a series of field surveys to understand the general biology of Hermes copper including extensive surveys of larval host plants for eggs and caterpillars, determining habitat preferences of adults, and a pilot study on adult movement. In addition, I evaluated the performance of three methods for estimating population size. Two estimation methods were based on repeated Pollard walks on permanent transects in appropriate habitat. The utility of mark-release-recapture methods was evaluated during a second field season.

## GENERAL BIOLOGY

### Pollard Walk Surveys

Estimates of adult Hermes copper densities were essential for several of the research objectives. Pollard Walks were conducted from 9 May to 17 July in 2003 at six sites. Three sites, Crestridge Ecological Reserve (California Department of Fish and Game), Anderson Road (Cleveland National Forest) and Descanso (Cleveland National Forest), represent an elevational grade within Hermes copper range (Table 2) and were intensively surveyed. These sites were surveyed twice a week until two consecutive survey dates or a single survey under appropriate weather conditions resulted in zero Hermes copper sightings. Three other locations were surveyed one time per week: Meadowbrook Ecological Reserve (California Department of Fish and Game), Rancho Jamul Ecological Reserve (California Department of Fish and Game) and Sycamore Canyon County Park (San Diego County). Site maps are included in Appendix A.

**Table 2. Elevations of Sites Used for Intense Surveying in 2003.**

| Site | Elevation (feet above sea level) |
|---|---|
| Crestridge Ecological Reserve | 1,500 |
| Anderson Road | 2,700 |
| Descanso | 3,300 |

Originally, the three intensively surveyed sites were scheduled to be surveyed in both 2003 and 2004. Unfortunately, the October 2003 wildfires (Cedar Fire and Otay Fire, CDF

2003) destroyed the habitat at all permanent transects at these sites. As a result, the 2004 surveys were restricted to small patches of suitable habitat at Rancho Jamul Ecological Reserve. Pollard Walks in 2004 were conducted from 12 May to 17 June at Rancho Jamul Ecological Reserve at a different location than the 2003 surveys. Surveys were conducted every two or three days.

Pollard Walk surveys (1977) were conducted to detect Hermes copper adults by establishing permanent survey transects 250 meters in length through areas of known populations or in suitable habitat determined by the presence of *Rhamnus crocea*. Transects were paired, parallel to each other, with one on a trail or road (edge transect) and the second within undisturbed vegetation containing the host plant (interior transect) (Figure 5). The interior transect was always at least four meters from the spiny redberry patch edge and at least ten meters from the edge transect. Each pair of parallel transects represened a survey route.

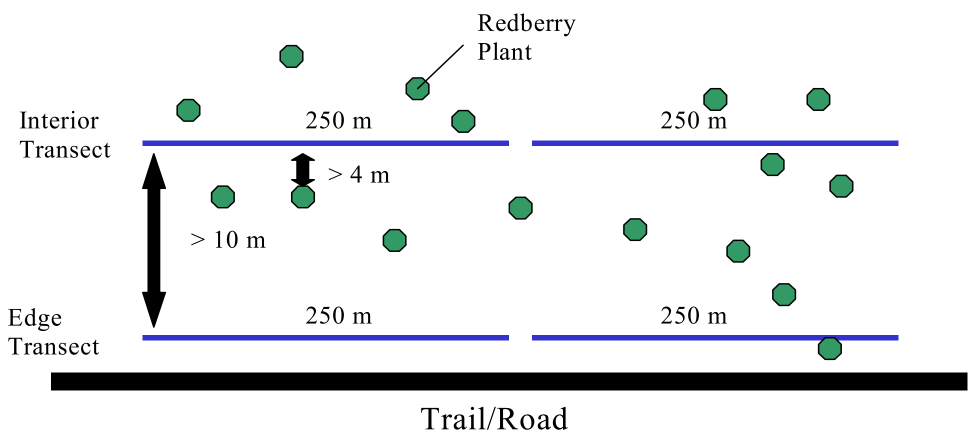


**Figure 5. Diagram of 250-meter survey transects on a trail or road edge (edge transect) and within undisturbed vegetation with spiny redberry (interior transect).**

Each survey transect was presumed to be independent since transects were spaced at least ten meters apart, assuring the same area would not be sampled by both parallel transects. Areas on both sides of small trails were surveyed simultaneously, however roadsides were surveyed separately because it was impossible to survey both sides of wide roads at the same time. The number of transects varied between sites due to the amount of suitable habitat at each site (Table 3).

**Table 3. Linear Distance of Surveyed Transects at Each Site in 2003.**

| Site | Meters |
|---|---|
| Crestridge ER | 1500 |
| Anderson Road | 1000 |
| Descanso | 900 |
| Rancho Jamul ER | 750 |
| Meadowbrook ER | 500 |
| Sycamore Canyon | 500 |

Abundances of all butterfly (superfamily Papilionoidea) and skipper (family Hesperidae) species were recorded within four meters of the transect. Distances greater than four meter were problematic for locating and identifying individuals in the taller and denser vegetation. Locations of all Hermes copper sightings were recorded with a GPS unit.

Surveys were conducted during appropriate weather conditions following the protocol developed for the Quino checkerspot butterfly (USFWS 2003), another rare southern California butterfly found in coastal sage scrub. United States Fish and Wildlife Service protocol calls for surveys between 900 and 1500, and precludes days with fog, drizzle or rain; wind greater than 15 mph; or temperatures below 60° F. When weather conditions did not meet the above requirements, surveys were postponed until acceptable conditions prevailed. Due to the persistence of fog and mist in 2003, one survey was conducted during suboptimal weather conditions.

To avoid a time of day bias, sites were surveyed during rotating time periods. All three intensively surveyed sites were sampled on the same day and, weather permitting, rotated site start times for each site at 900, 1100 and 1300. Three sites surveyed once a week were sampled on the same day, differing from the intensively surveyed group, again rotating sites through the above start times. Starts also alternated between routes and transects.

## Habitat Preference

For a rapid habitat assessment of transect areas, aspects of habitat (See Table 4) were measured every 20 meters on transects starting five meters from transect starting points. Each sampling location was recorded with a GPS unit. Measured characteristics fell into three broad categories: general habitat structure, adult nectar source abundance, and larval host plant abundance. When estimating percent cover, ten percent classes were used (e.g. 0-10%, 10-20%…90-100%). To associate Hermes copper use, or densities, with habitat

**Table 4. Measurements Taken at 20 Meter Intervals on Survey Transects to Determine Habitat Preference of Hermes Copper.**

| **Category** | **Measurements** |
|---|---|
| General Structure | Slope, aspect, # large shrubs[1]<br>% cover: shrubs[1], grasses[2], bare ground[3] |
| Adult Nectaring Sources | % cover: California buckwheat (*Eriogonum fasciculatum*), chamise (*Adenostoma fasciculatum*) |
| Larval Host Plant (*Rhamnus crocea*) | # of large plants[4], % cover |

[1]Included any woody vegetation.
[2] Included any non-woody vegetation.
[3] Included any non-vegetated area.
[4] Greater than 1.25 meters in height or diameter.

characteristics, each sighting was registered to the nearest vegetation sampling location using a measuring tool in GIS program ArcView 3.2. All habitat variables were included into the model to predict Hermes copper presence.

Count data are often right skewed resulting from a large number of zero and low counts since zero represents a lower limit (Devore and Peck 2001). Pollard Walks for this research were no exception and a square root transformation did not achieve normality. As a result, Hermes copper density was converted into presence/absence for analysis by logistic regression. Several of the vegetation variables had severely right-skewed distributions or had a limited range. Data transformations are shown in Table 5. Categories were created to have similar sample sizes within each category. I measured the amount of *Rhamnus crocea* using two variables: number of adult plants and percent cover of *Rhamnus crocea*. These variables were correlated with each other (Pearson's $r = 0.564$). Percent cover of shrubs and number of large shrubs were also correlated (Pearson's $r = 0.444$). Thus, the percent cover of *Rhamnus crocea* and number of adult shrubs were excluded from the analysis to avoid multicollinearity (Mansfield and Helms 1982).

To determine a preference for habitat edge or undisturbed vegetation, a comparison was made of Hermes copper adult densities between transects. A comparison was also made between sides of the road. Each Hermes copper observation was associated with the nearest sampling location located every 20 meters on each transect. This allows a comparison of densities between adjacent sampling locations on parallel transects. Exact tests constructed from the binomial distribution were used to test the null hypothesis of equal densities for each pair of sampling locations ($p < 0.05$, Zar 1999, Table in Appendix 133). Significant

**Table 5. Habitat Variables Used for Logistic Regression.**

| Variable | Categories |
|---|---|
| Site | 6 Sites |
| Transect | Trail, Interior |
| Percent Cover Shrubs | Continuous; 0-100% |
| Percent Cover Grasses | Square Root Transformation |
| Percent Cover Bare Ground | Square Root Transformation |
| Percent Cover *Eriogonum fasciculatum* | 0-10%, 10-20%, 20-80% |
| Percent Cover *Adenostoma fasciculatum* | 0-10%, 10-100% |
| *Rhamnus crocea* | Presence, Absence |

differences were only possible under these conditions if six or more individuals (in total) were detected at a pair of locations. For this reason, all pairs with fewer than six individuals were excluded from the analysis. Only points at Crestridge ER and Anderson Road satisfied this condition. Comparison between interior and edge transects on roads required summing adjacent sampling locations on each roadside. This is necessary to compare sampled areas of equal size, four meters of habitat on each side of the road and four meters on both sides of the interior transect. The preference for a transect location by Hermes copper adults is represented by an index of preference. The index is the number of adults found at the sampling location with the highest abundance divided by the total number of sightings of adjacent sampling locations. North and west sides of the road and edge transect are reference transects which are assigned positive values. South and east sides of the road and interior transect are given negative values.

## Movement Characteristics

Adults appear to remain close to redberry, resulting in a sedentary behavior, which creates independent colonies (Thorne 1963, Murphy 1990, Faulkner and Klein 2001). Adult movement and dispersal patterns were quantified, providing data on movement within habitat patches, or colonies, and providing insight into movement among patches. Sampling for movement characteristics was conducted at the Rancho Jamul Ecological Reserve site since there was a large population and the vegetation was more open allowing me to keep up with individual butterflies. The large population ensured a sufficient sample size, with samples stratified throughout the day.

It was not possible to census the population and then randomly select adults for the movement study. Instead, different areas of the site were selected systematically and then I followed the first butterfly located. Once a butterfly was sampled in an area, typically an opening, this area was avoided and the next area or opening in which an individual was encountered was sampled. Attempts were made to select males and females, with females identified by a swollen abdomen. Methods follow Turchin *et al*. (1991), following a butterfly for ten movements, and placing a flag at each resting point. Data collected from mapped flights included straight-line distances between consecutive rest locations (flight length), bearing of flight path, flight and resting times, and resting behavior. Flight length was measured with a tape measure, bearing of flight path with a compass, and flight and resting times with a stopwatch. Behavior at each rest was classified as nectaring, resting, or basking, with the plant species or substrate type recorded.

To complement following of individuals, movement data from the mark-release-recapture study was used. Methods are included in the "Mark-Release-Recapture" section under "Population Size Estimators."

## Larval Requirements

Very little is known about the larval stages of this butterfly since earlier researchers have been unable to find adequate numbers of larvae (Thorne in Comstock and Dammers 1935). I used two methods to obtain Hermes copper larvae. One was locating larvae on host plants in the field by a combination of passive (visual searching) and active (beating sheet) techniques. Larval searches started 14 April and continued until adults appeared, 16 May in 2003 and 12 May in 2004. The second method involved inducing captive females to lay eggs by offering redberry clippings or seedlings, then rearing larvae from the egg stage. Individual females were placed in a cage with a single clipping from a relatively large redberry plant or seedlings from a nursery. Once eggs were oviposited by the female, the egg and branch were periodically misted with water to maintain moisture. Eggs were either kept in captivity or returned to the original habitat. The returned eggs were placed on a living redberry plant by attaching a portion of the egg's original branch to a branch of the living plant.

# POPULATION SIZE ESTIMATORS

## Pollard Walks

Pollard Walk surveys resulted in the number of Hermes copper adults observed along transects on a particular day throughout the flight season. Associated with this count is the largest number recorded (Max Count), which represents the lowest possible population size. Due to factors such as mortality and dispersal, the actual population size must be equal or greater than the Max Count, assuming the absence of repeated sampling individuals within a single survey. The Max Count represents a simple estimator. INCA can also be used to estimate a population size from the survey data.

Estimation in INCA is based on the Runge-Kutta integration algorithm. Runge-Kutta is a numerically-stable technique that finds the best-fit abundance curve to count data using discrete steps. Parameters are calculated based on the assumption that the emergence of adults follows a logistic curve and mortality follows an exponential curve. Parameters from this model are correlated and INCA provides the correlation coefficients among the 4 parameters in the model. The most important correlation is between population size (N) and death rate (α, alpha). This correlation is often greater than 0.95 making it hard to separate their effects, creating an imprecise estimate. In the sample datasets provided by INCA, survey data for *Aglais urticae* has a good fit between the model and the data with a correlation between N and α of 0.87. In contrast, the correlation coefficient is over 0.95 for the sparse *Polyommatus icarus* dataset, with an imprecise estimate.

Coefficient of variation (CV) calculates the precision of the parameter (standard error) divided by the parameter estimate. Thus, standard deviation is reported in terms of the magnitude of the parameter, with a value less than 0.25 desired. INCA provides categories with values less than 0.1 "very good," 0.1-0.25 "reasonably good," 0.25-0.5 "still useful," 0.5-1.0 offers only the magnitude of the parameter, and greater than 1.0 is "unusable." Some INCA estimates may be deemed unreliable based on unacceptably high CVs.

Not all survey data results in a reliable INCA population size estimate and the intermediate results should not be trusted (INCA 2002). This occurs when one of the two algorithms (Simplex minimization algorithm and Newton root solving algorithm) INCA uses to fit the model to survey data fails to converge. If one of these algorithms fails to converge, INCA will produce a warning message. These cases will be referred to as an unsuccessful estimates or the estimate was not successful. With "successful" INCA estimates, reliability must still be determined from the parameter calculations.

## Sensitivity Analysis

The stability of the INCA estimate was investigated by altering survey data in two ways, direct perturbations that simulate monitoring issues and random perturbations that demonstrate the robustness of the estimate. For the sensitivity analysis, survey data from Crestridge Ecological Reserve (Table 6) were used since the site was intensively surveyed and the INCA population size estimate was the most precise among all sites.

**Table 6. Survey Data From Crestridge Ecological Reserve in 2003.**

| Day | Count |
|---|---|
| 0 | 0 |
| 12 | 1 |
| 15 | 10 |
| 19 | 25 |
| 22 | 49 |
| 27 | 12 |
| 30 | 49 |
| 36 | 36 |
| 40 | 32 |
| 48 | 24 |
| 51 | 15 |
| 54 | 4 |
| 57 | 3 |
| 61 | 6 |
| 64 | 7 |
| 68 | 2 |
| 71 | 0 |

### DIRECT PERTURBATIONS

Survey data were altered in a non-random way to determine where in the abundance curve the INCA estimate is most sensitive. Initially, data were broken up into three different sections based on half of the highest count, 49. Emergence time period was defined as dates before counts reached 24.5, decline after numbers fall below 24.5, and peak between the two sections (Figure 6). Each survey count was systematically increased by ten percent of the highest count in that section resulting in one added to emergence, five to peak and two to

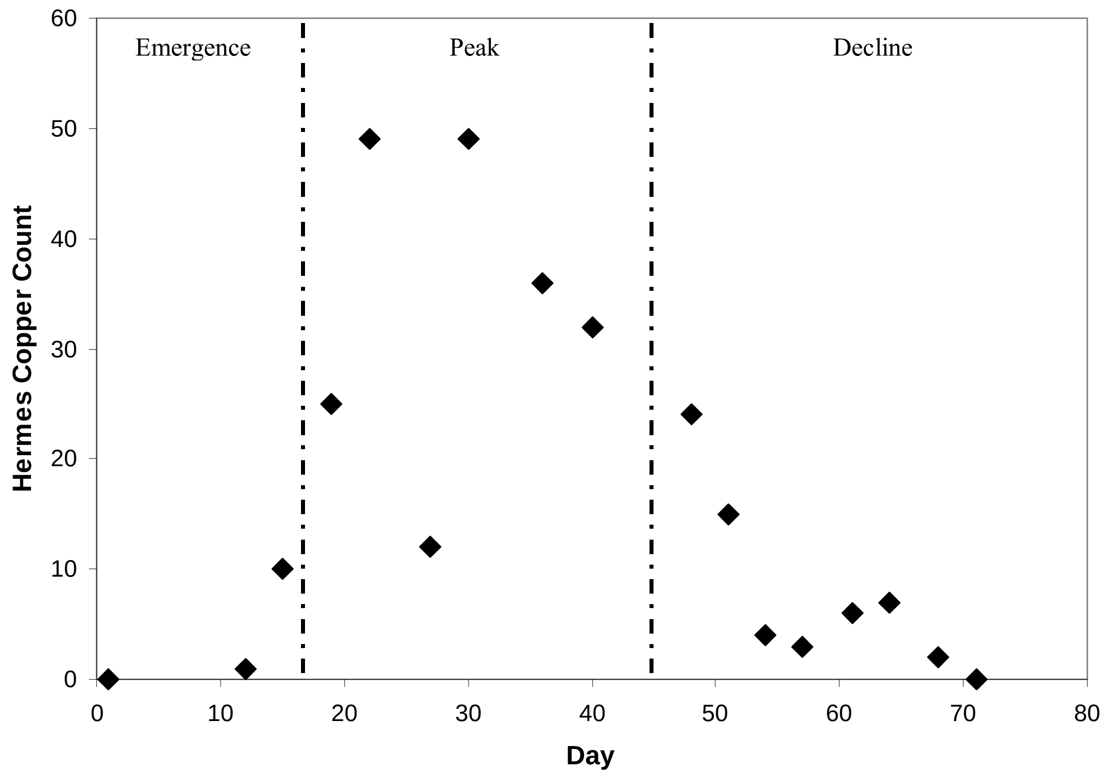


**Figure 6. Crestridge Ecological Reserve survey data used for direct perturbations.** Data were divided into three sections (emergence, peak and decline) based on half of the maximum count (49). Values greater than 24.5 were considered the peak flight section, with emergence section preceding the peak and decline section following the peak.

decline counts. Altering one count at a time, the new datasets were analyzed by INCA to estimate a population size. Direct perturbations were designed to explore and illustrate the effect minor changes in survey data have on the INCA estimate. For this reason, somewhat arbitrary abundance curve sections were created to look at early, mid and late season counts.

The count data were also altered to simulate issues biologists may encounter, with the first simulation investigating the effect of when surveys are conducted outside of the flight season. Dates with zero counts were shifted and additional zero counts were inserted into the dataset. The effect of poor weather was also investigated since there was one obvious survey date (day 27 in Figure 6) where weather was not ideal for butterfly activity. This count was replaced by counts of 0 to 150 percent of the maximum count (49 individuals), increasing by 25 percent increments. Again, each new dataset resulting from each perturbation was analyzed by INCA to estimate a population size.

### RANDOM PERTURBATIONS

Random perturbations consisted of adding four different levels of random noise to each butterfly count to create new datasets to be estimated by INCA. These levels added a maximum of 10, 20, 30 or 40 percent change to each count, with numbers rounded to the nearest whole number, replicating realistic count data. Days with very low counts, such as 0 and 1, created a problem since even a 40 percent change will never be rounded up to the next whole number. Each count was given, on average, a 33 percent chance of increasing by one, therefore allowing 0 and 1 counts an opportunity to be altered. Fifty datasets were calculated for each level of variance, then an INCA population size estimate and maximum number of individuals (Max Count) was calculated for each dataset. Analysis involved calculations of root mean square error (RMSE), variance and bias calculated for each level of random noise for INCA estimate and Max Count. A one sample t-test was used to determine significance between the mean of the simulated dataset and the original INCA estimate or Max Count for of each level of variation.

A long term monitoring scenario was simulated to determine the efficiency of INCA and Max Counts of detecting an annual five percent decline. The Crestridge ER count data was reduced by five percent every year for 10 years, with 30 percent variation added to create five new datasets for each year. Thirty percent variation is a conservative level when compared to actual variation in natural systems as demonstrated by low count at Crestridge ER on day 27 (Figure 6), a 75 percent decline. This conservative level also allows better analysis by INCA. An INCA estimate and Max Count were calculated for each simulated dataset. One of five INCA estimates and Max Counts were randomly selected (100 replicates) to create 100 datasets. Linear regression was used to determine if the INCA estimate or Max Count for each dataset detected a significant decrease in population size. Regression analysis used five to ten years of data to investigate performance of each estimator over a range of years. The power of INCA estimate and Max Count were determined by the proportion of significant regressions.

## Mark-Release-Recapture

During 2003, some time also was dedicated to determining if mark-release-recapture (MRR) techniques could be used for Hermes copper. A reason for concern about MRR methods is that recapture rates are often reduced after butterflies are handled from altered behavior (Morton 1982, Morton 1984) or handling-induced mortality (Singer and Wedlake 1981). With a 25 percent resighting rate in 2003, this technique was implemented in 2004.

In 2004, Hermes copper adults were marked at Rancho Jamul Ecological Reserve to estimate population size and investigate movement of individuals. Individuals associated with a relatively isolated patch of redberry was the subject for this MRR study. This area was adjacent to a 46,000-acre wildfire in 2003 (CDF 2003), and is surrounded by exotic grassland and dry, sparse coastal sage scrub which does not contain redberry. Two other areas containing redberry within the Ecological Reserve were over 100 meters away. These other areas with redberry were periodically surveyed as well.

Transects were about 2,100 meters in length, covering about 6,300 square meters, traversing the entire redberry patch including a central area dominated by buckwheat. Surveys were conducted about every third day during the flight season and any unmarked adults were captured and uniquely marked with a felt-tipped marker as they were encountered. Unique markings consisted of a series of colored dots drawn on the underside of the hindwings. All sightings were spatially recorded with a Garmin 76 GPS handheld unit.

Although often ignored in the literature, small population sizes make several estimators unreliable, and Program MARK cannot be used (McKelvey and Pearson 2001). With adults emerging throughout most of the flight season, the population must be treated as an open population, requiring the use of the Jolly-Seber Method and excluding the Peterson and Schnabel Methods (Jolly 1965, Seber 1965, Krebs 1998).

# RESULTS

## General Biology

### Surveys

Maximum counts on transects for each site ranged from five at Meadowbrook ER to 73 at Anderson Road, with Crestridge ER and Rancho Jamul ER having relatively high counts as well, 49 and 42, respectively. Maximum numbers at each site were observed from 27 May to 12 June. All sites showed a rapid increase to the maximum count followed by a slow decline until no individuals were observed (Table 7). Detailed survey data are included in Appendix B.

Two fluctuations were seen in the three intensively surveyed sites, at the peak and tail end of the flight. Crestridge ER, Anderson Road, and Descanso all showed an anomalously low count during peak of the flight season, only to have sightings rebound to or exceed the previous counts. At Crestridge ER and Descanso, slight fluctuations were observed at the end of the flight season, including an early zero count.

In 2003, the first Hermes copper adult observation was on 16 May at Crestridge ER and the last on 14 July at Crestridge ER and Anderson Road. Crestridge ER had the longest observed flight of 60 to 64 days. The first adult observation at Crestridge ER in 2003 was not on a transect so it is not reflected in the survey data.

While walking transects, other behavioral observations were made, including nectaring sources and temperature thresholds. Throughout the two field seasons, adults used California buckwheat almost exclusively as a nectaring source, with the exception of one individual observed nectaring on black mustard (*Brassica nigra*). Adults would typically rest on buckwheat inflorescence (open or closed) and redberry leaves. Other vegetation was occasionally used, and adults were never observed resting on bare ground.

Activity of Hermes copper appeared to drastically increase around 72 degrees F. This was seen in the survey data, individual movement data and the behavior of captive females. Experimental surveys throughout the day demonstrated that numbers were low early in the

**Table 7. Number of Adult Hermes Copper Observed on Survey Transects at Each Site in 2003 and 2004.** Shaded Areas Represent the Confirmed Flight Season at Each Site. General Dates Provide a General Time, Not Always Representing Exact Survey Dates (Detailed Survey Data is Included in Appendix B). First and Last Detection and Minimum Flight Length are Based on Exact Survey Dates.

| General Date | Crestridge ER 2003 | Anderson Road 2003 | Descanso 2003 | Rancho Jamul ER 2003 | Rancho Jamul ER 2004 | Meadowbrook ER 2003 | Sycamore Canyon 2003 |
|---|---|---|---|---|---|---|---|
| May 10 | | | | | | | |
| May 12 | | | | | 2 | | |
| May14 | | | | | 2 | | |
| May 17 | 0 | 0 | | 0 | 7 | 0 | 0 |
| May 19 | 1 | 7 | 0 | 5 | | | 5 |
| May 23 | 10 | 16 | 1 | | 4 | | |
| May 27 | 25 | 11 | 1 | 26 | 9 | 5 | 7 |
| May 30 | 49 | 39 | 8 | | 9 | | |
| June 4 | 12 | 13 | 12 | 42 | 5 | 4 | 4 |
| June 7 | 49 | 26 | 13 | | 3 | | |
| June 10 | | | 3 | 23 | 3 | | |
| June 13 | 36 | 73 | 13 | | 1 | | |
| June 16 | 32 | 45 | 10 | 20 | 0 | 4 | 1 |
| June 20 | | | 9 | | | | |
| June 24 | 24 | 48 | 9 | 4 | | 1 | 0 |
| June 28 | 15 | 26 | 0 | | | | |
| July 1 | 4 | 11 | 1 | 1 | | 0 | |
| July 4 | 3 | 9 | 3 | | | | |
| July 8 | 6 | 6 | 0 | 0 | | | |
| July 11 | 7 | 1 | | | | | |
| July 15 | 2 | 1 | | | | | |
| July 17 | 0 | 0 | | | | | |
| First Detection | May 16 | May 19 | May 22 | May 20 | May 12 | May 23 | May 20 |
| Last Detection | July 14 | July 14 | July 3 | July 1 | June 14 | June 25 | June 17 |
| Minimum Flight Length (days) | 60 | 57 | 43 | 43 | 34 | 34 | 29 |

morning and would increase as the temperature rose into the 70's. Once the temperature reaches the mid 70s, butterfly activity was near a maximum. No flights were witnessed, as individuals remained sedentary when the temperature was below 72, often basking in the sun. Captive females also provided evidence for a temperature threshold of 72 degrees. As the room heated in the morning, the butterflies would first start to fly in the cages when the thermostat read 72 degrees. In the evening, activity would decrease and finally cease when the temperature dropped below 72. There also appears to be an upper threshold, as adult numbers were slightly lower as the temperature exceeded 95 degrees F, particularly from 1300 to 1500. At high temperatures, observed individuals were often resting in the shade of a large shrub or small tree.

In 2003 and 2004, 38 species of butterflies and skippers were observed (Table 8) within four meters of transects while conducting surveys. The most common species, in declining order of abundance, were checkered white (*Pontia protodice*), unidentified blues (Polyommatinae), Hermes copper, common buckeye (*Junonia coenia*), cabbage white (*Pieris rapae*), Pacific orangetip (*Anthocharis sara*) and Behr's metalmark (*Apodemia virgulti*). Blues were often difficult to identify quickly to species level since they often remained in flight for minutes. Behr's metalmarks in flight posed the most problem in correctly identifying Hermes copper since they are about the same size and flight patterns were similar.

## Habitat Preference

Habitat was a poor predictor of Hermes copper presence. Site and cover of *Eriogonum fasciculatum* were the only significant predictors of (chi-square = 85.200, $p < 0.001$, 7 df) (Table 9). The addition of percent cover of grasses or presence of *Rhamnus crocea* increased the predictive power of the model slightly, however neither were significant. Since sites greatly differed in presence of Hermes copper, models were created for each site. Forward stepwise logistic regression models with a $p = 0.15$ cutoff resulted in models with different variables and slopes. This indicates the habitat characteristics measured do not predict adult presence throughout the range of the species.

### EDGE VS. INTERIOR

Hermes copper density was much higher on edge transects compared to paired interior transects. Nineteen locations at Anderson Road had Hermes copper counts of six or more, allowing for a statistical comparison. Fifteen locations had higher counts on the edge transect, three higher on the interior and one equal numbers. Nine locations had significant differences ($p < 0.05$), all more abundant on the edge transect (Figure 7). Of the 13 locations

**Table 8. Species Observed During Hermes Copper Surveys in 2003 and 2004.**

| **Common Name (Scientific Name)** | **Common Name (Scientific Name)** |
|---|---|
| Anise swallowtail (*Papilio zelicaon*) | Bernardino blue (*Euphilotes Bernardino*) |
| Tiger swallowtail (*Papilia rutulus*) | Southern blue (*Glaucopsyche lygdamus*) |
| Pale swallowtail (*Papilio eurymedon*) | Acmon blue (*Icaricia acmon*) |
| Checkered white (*Pontia protodice*) | Behr's metalmark (*Apodemia virgulti*) |
| Cabbage white (*Pieris rapae*) | Callippe fritillary (*Speyeria callippe*) |
| Pacific orangetip (*Anthocharis sara*) | Gabb's checkerspot (*Chlosyne gabbii*) |
| Orange sulphur (*Colias eurytheme*) | Mourning cloak (*Nymphalis antiopa*) |
| Hartford's sulphur (*Colias harfordii*) | American lady (*Vanessa virginiensis*) |
| California dogface (*Zerene eurydice*) | Painted lady (*Vanessa cardui*) |
| Cloudless sulphur (*Phoebis sennae*) | West coast lady (*Vanessa annabella*) |
| Sleepy orange (*Eurema nicippe*) | Red admiral (*Vanessa atalanta*) |
| Dainty sulphur (*Nathalis iole*) | Common buckeye (*Junonia coenia*) |
| Hermes copper (*Lycaena hermes*) | Lorquin's admiral (*Limenitis lorquini*) |
| Mountain mahogany hairstreak (*Satyrium tetra*) | Common ringlet (*Coenonympha tullia*) |
| Hedgerow hairstreak (*Satyrium saepium*) | Great Basin wood-nymph (*Cercyonis sthenele*) |
| Brown elfin (*Callophrys augustinus*) | Queen (*Danaus gilippus*) |
| Gray hairstreak (*Strymon melinus*) | Funereal duskywing (*Erynnis funeralis*) |
| Marine blue (*Leptotes marina*) | Northern white-skipper (*Heliopetes ericetorum*) |
| Ceraunus blue (*Hemiargus ceraunus*) | Rural skipper (*Ochlodes agricola*) |

**Table 9. Comparison of Logistic Regression Models Determining the Presence of Hermes Copper.**

| **Variable(s)** | **Deviance ($\chi^2$)** | **Degrees of Freedom** | **AIC** |
|---|---|---|---|
| Site | 72.2 | 5 | 62.2 |
| Site, *Eriogonum fasciculatum* | 85.2 | 7 | 71.2 |
| Site, *Eriogonum fasciculatum*, *Rhamnus crocea* | 86.7 | 8 | 70.7 |

at Crestridge ER, eleven had higher counts on the edge transect and two higher on the interior. Five demonstrated a significant difference, all with higher counts on the edge transect.

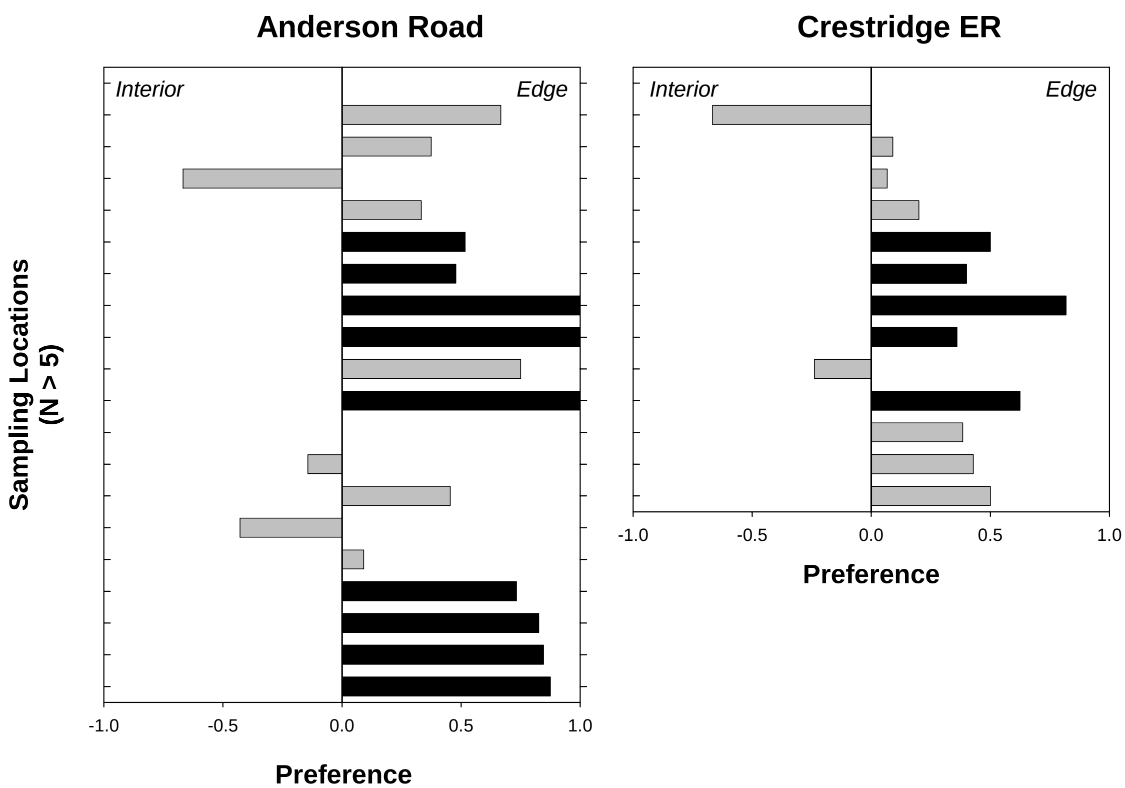


**Figure 7. Distribution of Hermes copper adults, comparing road or trail edges with native vegetation at Anderson Road and Crestridge Ecological Reserve.** Preference represents the proportion of adults found on the transect with the highest density between the two sampling locations. Analysis only involves locations with greater than five Hermes copper observations. Black identifies significant difference in abundance.

### SIDE OF ROAD COMPARISON

Hermes copper densities were also strongly asymmetrical on opposite sides of large roads. Of 14 locations along roads with six or more Hermes copper counts at Anderson Road, eleven had higher counts on the west, two higher on the east, and one had equal numbers on both sides. Seven had significantly greater counts on one side ($p < 0.05$), all on the west side of the road (Figure 8). All ten locations at Crestridge ER produced higher counts on the north side of the road, with seven having a significantly higher density than the south side.

## Movement Characteristics

Collecting data on individual movements proved to be problematic for several reasons, the first involving deciphering males from females. Sampling from trail and interior

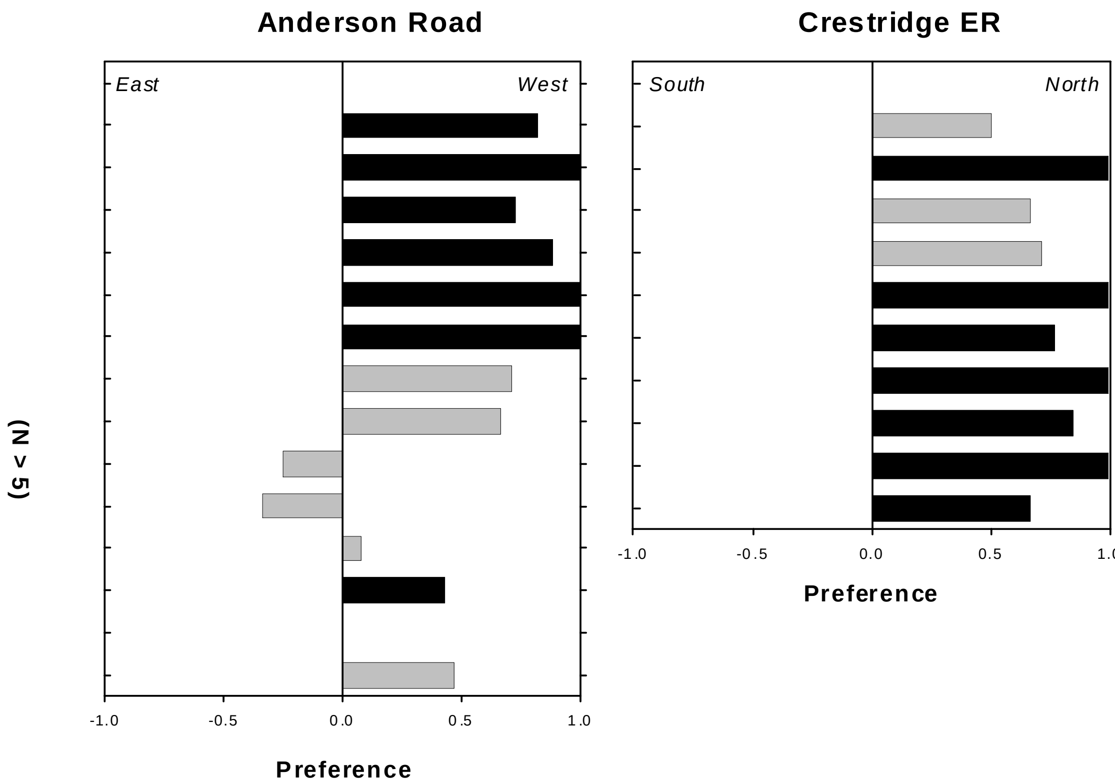


**Figure 8. Distribution of Hermes copper adults along road edges at Anderson Road and Crestridge Ecological Reserve.** Preference represents the proportion of adults found on the transect with the highest density between the two sampling locations. Analysis only involves locations with greater than five Hermes copper observations. Black identifies significant difference in abundance.

vegetation locations was designed to detect males developing territories along edges and females searching host plants. However, it was very difficult to determine sex without disturbing the individual, since close observation was necessary to detect the larger abdomen of females. It appeared that males establish territories along trails or any other small opening within denser vegetation.

The second problem involved the ability to adequately describe male territories by only marking rest locations. The tendency for males to rest in a small area or on a particular plant severely under estimated the area a male patrols. Locations where the flight reached a maximum distance from the preferred resting location would need to be recorded to accurately describe territory size. One observation resulted in a male chasing another Hermes copper more than 29 meters before returning to the original rest location. Besides other adult Hermes copper, males were observed chasing a hummingbird, Hymenoptera, white butterfly (Pierinae), sulphur butterfly (Coliadinae), brown elfin (*Callophyrys augustinus*), Behr's metalmark (*Apodemia virgulti*) and blue butterfly (Polyommatinae).

Following females was difficult as well. Often females were observed making a couple of short flights, then would make a fast flight over a long distance. The last flight was impossible to follow due to the speed of the butterfly through dense vegetation. This flight consisted of the butterfly ascending to a height where the wind was not slowed by vegetation or topography, and was in a similar direction as the wind.

Seven individuals were uniquely marked and seven identically marked in a pilot study in 2003 at Crestridge ER. Due to time constraints, surveys for these individuals rarely included hours of peak activity, reducing the probability of resightings. Significantly more males (21 individuals) were originally captured than females (8 individuals) ($p = 0.024$). One male was injured during capture, and is omitted from resighting analysis. Intensive surveying at Rancho Jamul ER in 2004 yielded 12 of 28 marked individuals being resighted. Eleven of 20 males were resighted and only one of eight females. The difference in resighting rates between males and females is nearly significant ($p = 0.088$). The odds of resighting a male was 8.6 times higher than adds of resighting a female. Distances between consecutive observations for an individual ranged from zero to 83 meters, with a median movement of 5.9 meters. The distribution is right-skewed with 15 of 22 movements less than 12 meters (Figure 9). No Hermes copper adults were observed at two nearby patches of redberry (about 450 and 2,000 meters away).

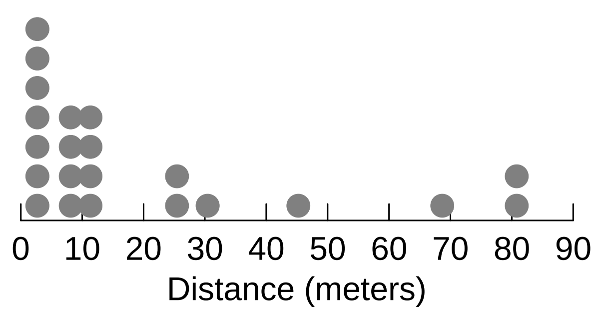


**Figure 9. Distribution of straight-line distances between consecutive observations for each marked individuals.**

## Larval Requirements

No Hermes copper larvae were found in 2003 or 2004, with approximately 60 and 140 redberry plants surveyed, respectively. During this time, larvae of two other Lepidoptera species were found foraging on redberry, with a possible third. The most common was *Itame guenearia* (Geometridae), of which several larvae of twig-like appearance were found on individual plants. The foraging pattern of this species consists of feeding on one side of the leaf, starting near the base and working towards the apex. This results in a distinct curve-shape missing from the leaf, which is confirmed by rearing larva to adults. Adults were occasionally seen on redberry plants during 2004 surveys. *Epinotia* (Tortricidae) larvae were also found foraging on redberry. In captivity the larvae fed and pupated within leaves attached together with silk. A third species of the genus *Hemerocampa* (Lymantriidae) was found on redberry. However, when collected and offered redberry clippings feeding never occurred.

Three captive females oviposited a total of 23 eggs (1, 9 and 13), 22 on redberry clippings and one on the glass of the aquarium. Thirteen were on the current year's new growth on a branch below a leaf petiole, three at the base of a second branch (two had leaves present), two on a branch with no other structure and one on a leaf blade. Another three eggs fell off prior to or during inspection of the clippings. Eggs were not found with the two females placed with planted redberry seedlings. Eggs did not hatch, whether they remained in captivity or were translocated onto living plants.

A female in the field was observed in behavior similar to ovipositing, although no oviposition was observed. The butterfly was flying slowly and less than 0.24 meters above the ground through vegetation, then landed on a very small (about 0.5 meters tall) redberry shrub. While walking on the redberry, the female would touch the tip of her abdomen on the stem about every second, in a repetitive motion. This continued for 1 to 2 minutes. The individual then flew to another redberry plant, which was much larger (about 2 meters tall) again continuing to probe with her abdomen tip. However, at one point she spent about 5 seconds at the base of two branches. She then visited another large (about 2 meters tall) redberry plant and exhibited the same behavior.

## POPULATION SIZE ESTIMATORS

### Pollard Walks

Population estimates were attempted on survey data from all seven sites (Rancho Jamul ER 2004 counted as a new site). Three yielded INCA population size estimates, while estimation did not succeed for the other four datasets, failing in the second phase. Crestridge ER had an estimate of 100.402 individuals (68.358 to 132.446, 95% confidence interval) for the 12,000 square meters surveyed (66.93 individuals per km of transect; Table 10, Figure 10). The coefficient of variation for time of peak emergence (mu) falls within the INCA category of "very good," while death rate (alpha), spread in emergence times (beta), and population size (N) were "reasonably good." The correlation between death rate and population density was relatively low (0.927). This was the most precise output with the CV for N of 16.3 percent and under 20 percent for all other parameters.

Descanso had a population estimate of 33.455 adults (6.703 to 60.207, 95% confidence interval) for the 7200 square meters surveyed (37.17 individuals per km of transect; Table 11, Figure 11). The time of peak emergence parameter was "reasonably good," however the other three parameters were weaker, falling within the "still useful" category. This dataset resulted in a higher correlation between death rate and population density (0.962), with higher CVs, including 40.8 percent for N.

**Table 10. INCA Statistical Output for Crestridge Ecological Reserve 2003 Survey Data.**

| Parameter | Unit | Estimate | Standard Deviation | Coefficient of Variation | Reliability of Estimate |
|---|---|---|---|---|---|
| **Alpha (α)** | per day | 0.082 | 0.012 | 0.149 | Reasonably Good |
| **Beta (β)** | day | 4.227 | 0.643 | 0.152 | Reasonably Good |
| **Mu (μ)** | day | 22.621 | 1.271 | 0.056 | Very Good |
| **N** | individual | 100.402 | 16.349 | 0.163 | Reasonably Good |

Correlation Coefficients

| | Alpha (α) | Beta (β) | Mu (μ) | N |
|---|---|---|---|---|
| **Alpha (α)** | 1.000 | 0.670 | 0.833 | 0.927 |
| **Beta (β)** | | 1.000 | 0.667 | 0.640 |
| **Mu (μ)** | | | 1.000 | 0.792 |
| **N** | | | | 1.000 |

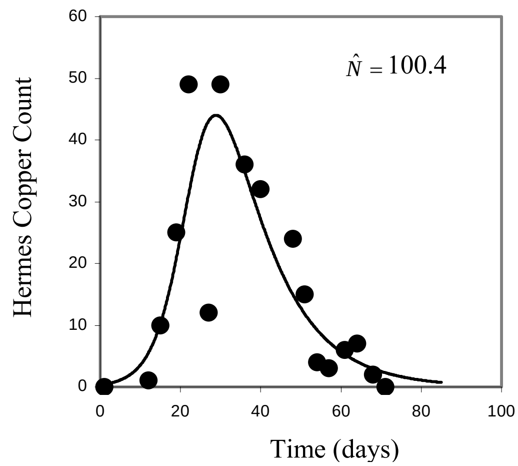


**Figure 10. INCA generated graph with survey data (black circles) and INCA calculated best-fit line for Crestridge Ecological Reserve 2003 survey data.** $\hat{N}$ is the INCA estimated population size for the survey data.

**Table 11. INCA Statistical Output for Descanso 2003 Survey Data.**

| Parameter | Unit | Estimate | Standard Deviation | Coefficient of Variation | Reliability of Estimate |
|---|---|---|---|---|---|
| **Alpha (α)** | per day | 0.112 | 0.047 | 0.415 | Still Useful |
| **Beta (β)** | day | 4.159 | 1.101 | 0.265 | Still Useful |
| **Mu (μ)** | day | 17.053 | 2.624 | 0.154 | Reasonably Good |
| **N** | individual | 33.455 | 13.649 | 0.408 | Still Useful |

Correlation Coefficients

| | Alpha (α) | Beta (β) | Mu (μ) | N |
|---|---|---|---|---|
| **Alpha (α)** | 1.0 | 0.744 | 0.887 | 0.962 |
| **Beta (β)** | | 1.0 | 0.731 | 0.739 |
| **Mu (μ)** | | | 1.0 | 0.856 |
| **N** | | | | 1.0 |

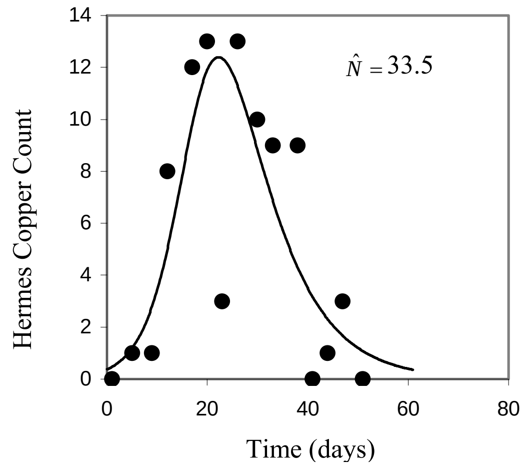


**Figure 11. INCA generated graph with survey data (black circles) and INCA calculated best-fit line for Descanso 2003 survey data.** $\hat{N}$ is the INCA estimated population size for the survey data.

Rancho Jamul ER had a population estimate of 142.570 adults (45.897 to 239.243, 95% confidence interval) for the 6000 square meters surveyed in 2003 (190.09 individuals per km of transect; Table 12, Figure 12). Again, time of peak emergence parameter had the lowest coefficient of variation, in the "very good" category. The spread in emergence times was "reasonably good" and death rate and total population density were "still useable." As with the Descanso population, the correlation between death rate and population density (0.961) and CV for N (34.6 percent) were high.

**Table 12. INCA Statistical Output for Rancho Jamul Ecological Reserve 2003 Survey Data.**

| Parameter | Unit | Estimate | Standard Deviation | Coefficient of Variation | Reliability of Estimate |
|---|---|---|---|---|---|
| **Alpha (α)** | per day | 0.157 | 0.051 | 0.323 | Still Useful |
| **Beta (β)** | day | 4.100 | 0.971 | 0.237 | Reasonably Good |
| **Mu (μ)** | day | 21.301 | 1.750 | 0.082 | Very Good |
| **N** | individual | 142.570 | 49.323 | 0.346 | Still Useful |

Correlation Coefficients

| | Alpha (α) | Beta (β) | Mu (μ) | N |
|---|---|---|---|---|
| **Alpha (α)** | 1.0 | 0.769 | 0.842 | 0.961 |
| **Beta (β)** | | 1.0 | 0.594 | 0.774 |
| **Mu (μ)** | | | 1.0 | 0.780 |
| **N** | | | | 1.0 |

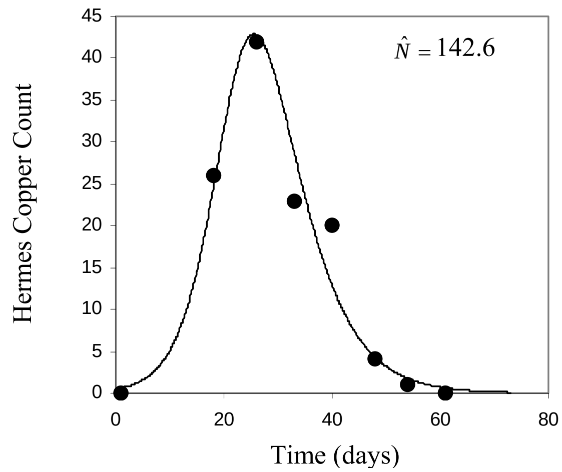


**Figure 12. INCA generated graph with survey data (black circles) and INCA calculated best-fit line for Rancho Jamul Ecological Reserve 2003 survey data.** $\hat{N}$ is the INCA estimated population size for the survey data.

## DIRECT PERTURBATIONS

Direct perturbations of the survey data altered the INCA estimate with varying degrees depending on which specific count was altered (Table 13, Figure 13; complete perturbation tables are included in Appendix C). Effects of additions to early counts resulted in estimates greater than the original data, while these perturbations to late counts resulted in a lower estimate.

Increasing the first survey count (Dataset 2) resulted in the greatest increase (19.3 percent increase) of INCA estimate. Perturbations to emergence counts had a reduced impact the later in the flight season the count appeared (Dataset 3). Perturbation to the last count (Dataset 8) resulted in an estimate of the greatest difference from the original, an estimate 25.2 percent lower. Perturbations to decline counts had a reduced impact the earlier in the season the count appeared (Dataset 7). Thus, INCA is mostly sensitive to small changes at the tails, far from peak counts.

Timing of surveys outside of the flight season altered the INCA estimate in magnitude similar to the previous section. An additional zero count prior to the flight season (Dataset 1) decreased the INCA estimate while the addition of a zero count following the flight season (Dataset 9) increased the estimate. This is counterintuitive since these zero counts contain no additional data on Hermes copper.

Increasing the number of butterflies counted on a date with marginal weather did not necessarily increase the population estimate as would be expected. The analysis with the original data, representing 25% of the adjacent survey counts, gave an estimate of 100.4 individuals. Increasing the low count to 50% of the adjacent survey counts (Dataset 6) resulted in a lower estimate of 90.7. Excluding the survey date with marginal weather (Dataset 5) from INCA analysis gave a larger estimate of 112.6. Understanding variability in the INCA estimate resulting from minor direct perturbations requires a more complete sensitivity analysis with random perturbations.

**Table 13. Direct Perturbation Datasets Showing Change of INCA Estimate.** Dataset Numbers Correspond to Figure 13.

| | **Original Data** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| **6 May** | | **0** | | | | | | | | |
| **8 May** | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | ~~0~~ |
| **19 May** | 1 | 1 | 1 | **2** | 1 | 1 | 1 | 1 | 1 | 1 |
| **22 May** | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| **26 May** | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| **29 May** | 49 | 49 | 49 | 49 | **54** | 49 | 49 | 49 | 49 | 49 |
| **3 June** | 12 | 12 | 12 | 12 | 12 | ~~12~~ | **24** | 12 | 12 | 12 |
| **6 June** | 49 | 49 | 49 | 49 | 49 | 49 | 49 | 49 | 49 | 49 |
| **12 June** | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| **16 June** | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| **24 June** | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| **27 June** | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| **30 June** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **3 July** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **7 July** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | **8** | 6 | 6 |
| **10 July** | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **14 July** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **17 July** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **2** | 0 |
| | | | | | | | | | | **0** |
| **Estimate:** | 100.4 | 95.2 | 119.7 | 107.0 | 74.9 | 112.6 | 90.7 | 89.8 | 75.1 | 136.5 |
| **Change** | -- | -5.2% | 19.2% | 6.6% | -25.4% | 12.2% | -9.7% | -10.6% | -25.5% | 36.0% |

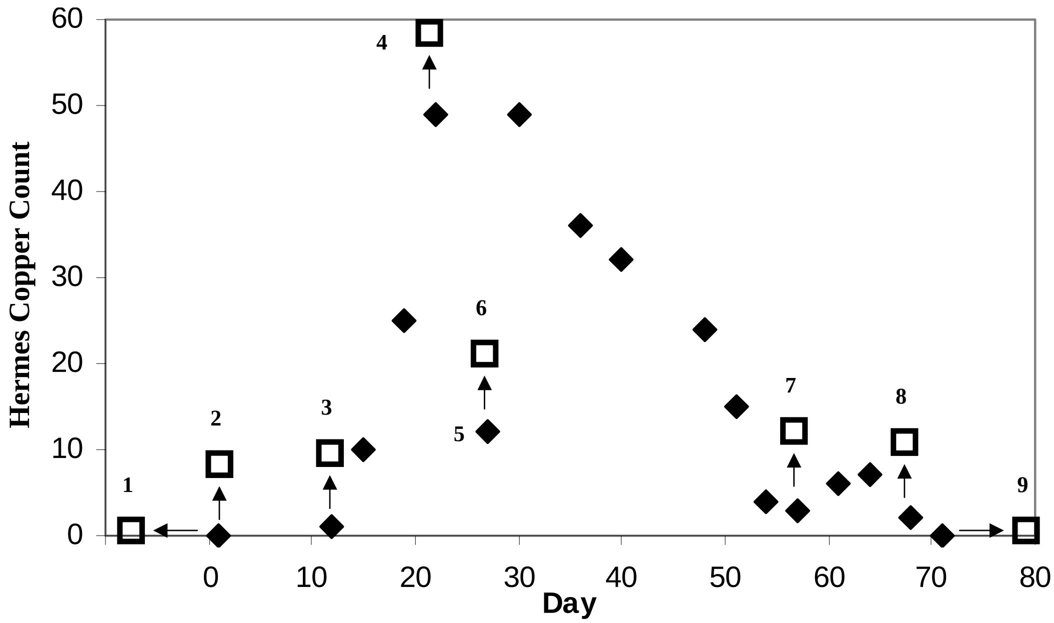


**Figure 13. Abundance curve showing direct perturbations.**

## RANDOM PERTURBATIONS

INCA estimates, although unbiased, were extremely sensitive to small changes in the input data. INCA estimate averages for each level of variation was relatively stable, increasing from the 10 to 20 percent level, then dropping to similar values for 30 and 40 percent, with 106.4 the highest estimate at twenty percent variation. Distribution of estimates shifted from fairly normal at 10 percent variation to slightly right-skewed for the other three levels (Figure 14). In contrast, Max Count estimates were consistently biased. Max Count averages increase as the percent variation in input increased, ranging from 52.28 to 62.42 (6.7 to 27.4 percent increase). Distribution of Max Counts was normal for all levels of variation, with an increased spread with increased sampling error.

Variability in INCA estimate was extremely high, even with relatively minor changes in input data. Root mean square error (RMSE) (expressed as a proportion of the mean) was 23 percent for ten percent input variation and reached 49 percent for 30 percent input variation (Table 14). Variance and bias are at similar levels for Max Count throughout the range of input variation. Compared to INCA, Max Count is more biased with lower variance. All 10 and 20 percent datasets yielded INCA population size estimates, with one unsuccessful estimate at 30 percent and five at 40 percent.

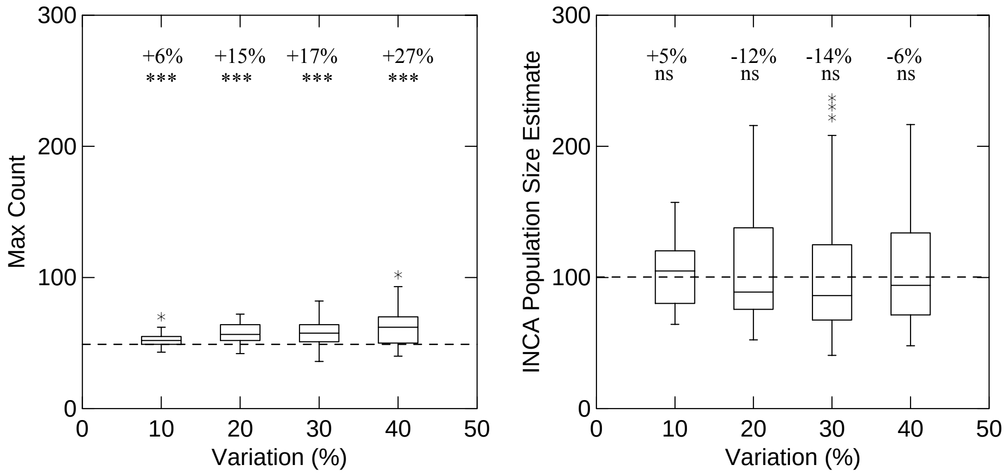


**Figure 14. Distribution of Max Counts and INCA population estimates from datasets created by introducing different levels of random variation to the original Crestridge Ecological Reserve data (n = 50 replicate simulations for each level of variation).**

**Table 14. Source of Error from INCA Estimate and Max Count.**

| ***INCA*** **Variation** | **RMSE** | **CV (rmse/mean)** | **Proportion Variation** | **Failures (out of 50)** |
|---|---|---|---|---|
| **10%** | 24.25 | 23% | 98% | 0 |
| **20%** | 38.84 | 37% | 97% | 0 |
| **30%** | 51.06 | 49% | 99% | 1 |
| **40%** | 43.31 | 41% | 99% | 5 |
| ***Max Count*** **Variation** | **RMSE** | **CV (rmse/mean)** | **Proportion Variation** | |
| **10%** | 6.13 | 12% | 71% | |
| **20%** | 12.11 | 21% | 50% | |
| **30%** | 14.27 | 25% | 59% | |
| **40%** | 20.28 | 32% | 56% | |

Power for Max Count and INCA decreased with the fewer years monitored, with Max Count always having the higher power with a given year (Figure 15). Max Count had a 95% detection rate of a decline after ten years, while INCA had a 25% rate. Max Count had over 50% detection with seven or more years. Results would be similar for an increase in population size over time since linear regression is evaluating error term of the slope [t=b/se(b)], rather than a positive or negative change. Mark-release-recapture methods were not applicable to the power simulation.

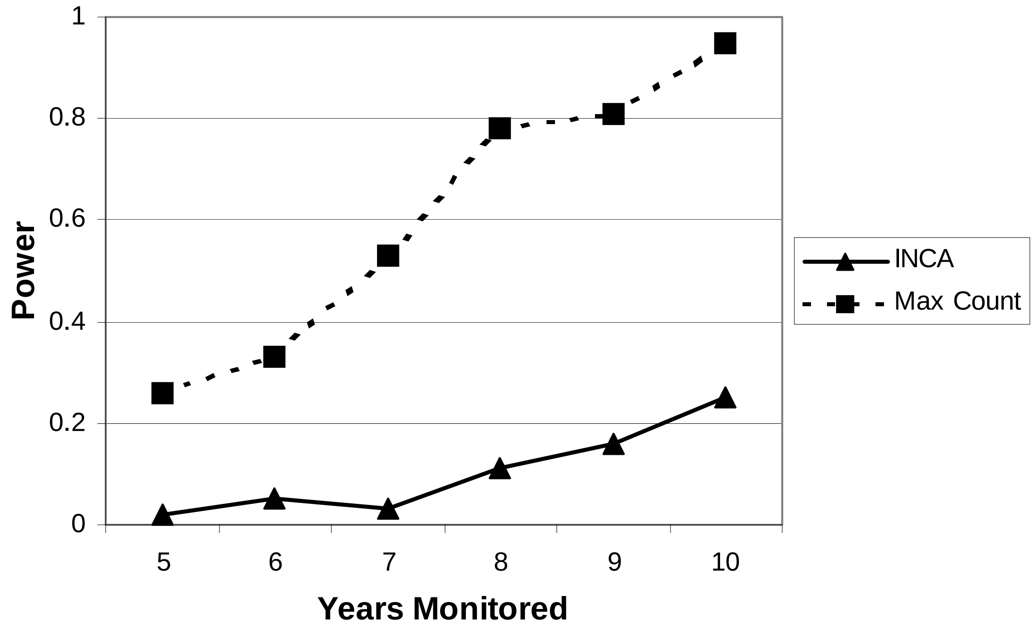


**Figure 15. Effectiveness of INCA and Max Count to detect a simulated population decline of five percent per year.**

## Mark-Release-Recapture

A total of 29 individuals were marked and released, however the first individual marked was too damaged to regain normal behavior so it was removed from further analysis. To prevent injury or damage to others, the forewing tips were held together on the outside of the net, then inverting the net to expose the body and hindwings for marking (Ehrlich and Davidson 1960). Of the 28 possible individuals, 12 were observed at least a second time for a 43 percent resighting rate (Table 15). Eight individuals had only one resighting, with few individuals resighted two or more times. The maximum number of resightings was six. The proportion of individuals resighted was greatest for those individuals initially captured at the beginning of the flight season. Three of 4 were resighted in the first third of the flight season, 8 of 18 in the middle third, and 1 of 8 in the final third. Only three individuals failed to be detected and then were later observed.

**Table 15. Total Number of Resightings for Individual Hermes Copper Adults at Rancho Jamul ER, 2004.**

| **Number Times Resighted** | **0 (initial mark)** | **1** | **2** | **3** | **6** |
|---|---|---|---|---|---|
| **Number Individuals** | 16 | 8 | 1 | 2 | 1 |

Calculation of population size was unreliable due to this low number of individuals avoiding detection, pushing the population size estimate lower than the number observed at time t. Not only does the population size have to be equal to or greater than the number captured, but confidence interval calculations failed. This precludes a comparison to INCA population size estimate and Max Count.

Recorded lifespan of marked Hermes copper had a right-skewed distribution. A single individual was resighted over a 17-day span, including seven consecutive surveys with a positive observation. Since surveys were conducted on non-consecutive days, it could have been as long as 21 days. The median lifespan among resighted individuals was 4.5 days, but since surveys were conducted on non-consecutive days, it could be as high as 8.0.

# DISCUSSION

## GENERAL BIOLOGY

Adult Hermes copper densities varied greatly site to site, with the flight season initiation and duration varying as well. Surveys conducted in 2003 indicate that sites with more redberry shrubs and taller vegetation have longer flight seasons. Two aspects of the flight season deviated from past literature, since adults emerged earlier than previously recorded and peak numbers were observed before mid-June (Thorne 1963). As expected, Rancho Jamul ER had lower counts in 2004 following a dry winter (NOAA 2004), as precipitation can dictate the number of butterflies observed in a year (Pollard 1988, Roy *et al*. 2001). A warmer spring in 2004 (NOAA 2004) also caused an earlier flight season. Although the same area was not surveyed at Rancho Jamul ER in 2003 and 2004, flight season characteristics should be similar.

Three intensively surveyed sites showed fluctuations in the number of adults counted during surveys due to suboptimal weather, reducing the likelihood of detecting individuals. Weather related influences were present in June when heavy fog and light mist persisted for over a week. Surveys during these weather conditions could not be used or compared with the other surveys due to the reduced butterfly activity. Descanso was an exception as it appears to be located far enough east to avoid fog and precipitation associated with the marine layer on most days.

Migration into the transect area is the probable cause for fluctuations at the end of the flight season. Mark-release-recapture data supports this, as individuals are observed during surveys until they permanently leave the area due to migration or mortality. The resighting rate of marked individuals decreased late in the flight season the initial capture and marking took place. There is no reason to believe that the mortality rate increases throughout the year, so adults may be dispersing to other areas. With several movements of over 20 meters recorded, it is very possible for individuals to move to and from the surveyed area.

Habitat analyses identified site as the most important predictor of Hermes copper presence, and *Eriogonum fasciculatum* as the only significant vegetation measurement. This results from transects being established in areas of known populations or in a patch of redberry, sampling only suitable habitat. Estimating population sizes and describing fluctuations in survey counts were a major focus of this research, requiring transect placement in areas of dense Hermes copper populations. Transects extending well beyond redberry patches or methods using larval locations on redberry are needed to determine important habitat components. The sampling only of suitable habitat and mobility of adults explains the lack a relationship between *Rhamus crocea* and Hermes copper. Clearly, *Rhamnus crocea* is important to Hermes copper (Thorne 1963).

Asymmetrical densities on roadsides were unexpected, but it appears to be related to thermoregulation. West and northern sides tended to have shorter vegetation, allowing more sunlight, leading to warmer temperatures. The eastern side would receive direct sunlight in the afternoon, however at this time ambient temperatures are quite high. It is at these times that Hermes copper individuals would reduce activity and were often times found resting in the shade of large shrubs. *Eriogonum fasciculatum*, a primary nectaring source, is often found in these warmer areas with shorter vegetation.

The disproportionate number of butterflies found at the road or trail may be due to vegetation height or food sources. Vegetation is generally shorter at the edge with no vegetation on the road or trail itself. Adults rarely flew high and were typically less than one meter above the ground whether in flight or rest. Food may also dictate densities as the main nectaring source, *Eriogonum fasciculatum*, comprises a larger component in these disturbed edge habitats.

Hermes copper dispersal is still uncertain. Thorne (1963) states that adults are confined to the vicinity of the host plant, but there must be inter-colony movement. Faulkner and Klein (2001) believe this inter-colony movement is likely from a couple males. In this study, more than half of the marked individuals were never observed after the initial capture and presumed to have left the redberry patch. Interestingly, females were resighted at a lower rate, suggesting that females travel greater distances and are responsible for inter-colony movement. Another explanation is that females may be harder to recapture or resight, as mark-release-recapture also measures activity. Individuals that were repeatedly observed in small areas were territorial males establishing and holding territories until mortality, at which time another may claim the area. This difference in flight behavior between males and females was also evident from the movement study following individuals. The females were more likely to make higher, longer flights, often wind-aided.

Obtaining larvae by searching on redberry or rearing from ovipositing females was completely unsuccessful. Many redberry shrubs were sampled, yielding only larvae of other species. Thorne (1963) noted that larvae were present in late March, which must be the end of the larval stage. Given this timing, the pupal stage lasts over one month. The early flight seasons of 2003 and 2004 may have led to a mistiming of larval sampling, thus resulting in the absence of mature larvae. Females, which Thorne (1963) and I found to readily oviposit in captivity, did not do so when offered redberry seedlings. This suggests that females may require older shrubs (Klein pers. comm.), but with one trial only using seedlings from a nursery rather than the immediate area, caution should be taken when interpreting these results.

## POPULATION SIZE ESTIMATE: INCA

INCA is a sophisticated statistical model that attempts to provide information about death rate, emergence characteristics and an absolute population size. Max Count is a simple statistic that makes fewer assumptions about factors influencing population size. In this analysis, INCA reduced the amount of bias in population size estimates, however had a higher RMSE than Max Count. This error propagation is more of a concern than having a statistic that describes system functionality. The lower power demonstrated by INCA indicates a high Type II error, failing to detect a changing population when there is in fact a change.

Since a main objective of monitoring programs is to detect changes in population size, INCA may have limited use. In cases of endangered, threatened and rare species, rapid detection of a change in population size is essential. In cases of a population decline, detection will trigger management action benefit the species, therefore increasing numbers. It is also important to detect population increases so that current management actions will continue.

Max Count is more robust than INCA in detecting the simulated population decline, although it is a biased statistic. Intermediate techniques can be used, such as taking the average of the highest three counts. This approach might have reduced the amount of bias displayed in this analysis. An advantage of using Max Count is that the statistic is always available, whereas INCA is not always able to calculate a population size estimate due to numerical procedures not fully converging. An additional year of monitoring may be required to detect a density change for each year INCA does not successfully estimate a population size. Max Count is also less time intensive, since sampling is not required at the tail of the flight season when field wildlife biologists are convinced numbers will slowly decline to zero, saving time and money.

The power simulation, which compared the ability of Max Count and INCA to detect a population change, is limited in that it used an ideal situation of a regular population change. Including population cycling or boom/bust dynamics in the analysis would likely affect both estimators. Regression would yield similar results if the trend were reversed. Regression calculates the error, which makes the sign associated with population change irrelevant.

In cases where wildlife biologists want to use INCA, caution must be taken since a small change in survey counts can have a large effect on the population size estimate. This emphasizes the need for ideal weather conditions during all surveys for all years included in the monitoring program. Something as simple as a temporary change in weather may keep a few butterflies inactive and prevent detection, greatly influencing the population estimate. A difference in observer experience and technique may have the same effect.

Wildlife biologists must also choose which data are to be included in the INCA analysis. Survey counts of zero before and after the flight season will alter the estimate if they are included or removed. If two surveys with no detections are required to stop yearly surveys, the same decision to include one or both must be made for all years to be analyzed. It will be important to make the same decisions from year-to-year, otherwise human choices are, in part, controlling the estimate. This is also the case for low counts due to weather.

Ultimately, the possibility of using INCA as a monitoring tool comes down to the shape of the abundance curve rather than the species being surveyed. High population size and density, low variability in counts, and intensive surveying appear to be characteristics in which INCA will provide precise population size estimates. It is also important for the abundance curve to have a distinct peak (INCA 2002).

Mark-release-recapture methods were unsuitable for this Hermes copper study, due to the low number of individuals reappearing after not being detected. As a result, it was impossible to differentiate movement and mixing from death of individuals. The behavior and biology of Hermes copper appears to render mark-release-recapture methods unsuitable for this method. Adults rarely avoid detection due to their bright color and tendency to fly in a small area rather than leaving the area.

## RECOMMENDATIONS

It is recommended that the Rancho Jamul ER 2004 site be intensively surveyed for the entire flight season for several years to determine yearly fluctuations, most likely driven by weather. This site can also serve as a reference for flight season timing and abundances as United States Fish and Wildlife Service has established for Quino checkerspot (USFWS 2003, 2004).

Surveys should also continue for larvae so that this information can be included into the reference site data. Future sampling should start at the beginning of March in areas of known populations. Due to limited movement abilities, larvae may give a better indication of required environmental components. Larval preferences and requirements will also answer the important management question of whether mature shrubs are required for foraging. This has direct implications to wildfires and the ability of Hermes copper to recolonize disturbed or restored areas.

The only signs of mortality observed were due to being hit by vehicles. For reserves that have roads passing through suitable Hermes copper habitat, vehicles or their speeds should be restricted during the flight season. The two sites where roadkills were located have light traffic, but speeds higher than 20 mph. Presumably the slower speeds of vehicles at the other site prevented individuals from being hit and killed.

While INCA has many useful components, Max Count seems to be more reliable in terms of the most common monitoring question, "Are Hermes copper numbers changing through time?" The key to wildlife biologists is to detect declining trends as quickly as possible so that management actions are implemented to benefit the species and allow populations to recover.

## ACKNOWLEDGEMENTS

I would like to thank my committee members, Dr. Deutschman, Dr. Williams and Dr. Lin for their enthusiasm and guidance throughout the process of this research project. There were many questions and issues that required their knowledge to keep the project moving along. To M. Klein and A. Anderson, I am very appreciative for the time they have given me, including the willingness to share their knowledge and desire to assist in this research. California Department of Fish and Game offered a great amount of support and encouragement that was essential to the completion of this project. I would also like to thank M. Bates, J. O'Brien, B. Reed, L. Sirota, R. Smith, and C. Swartz for their fieldwork, and C. Miller for assistance with GIS.

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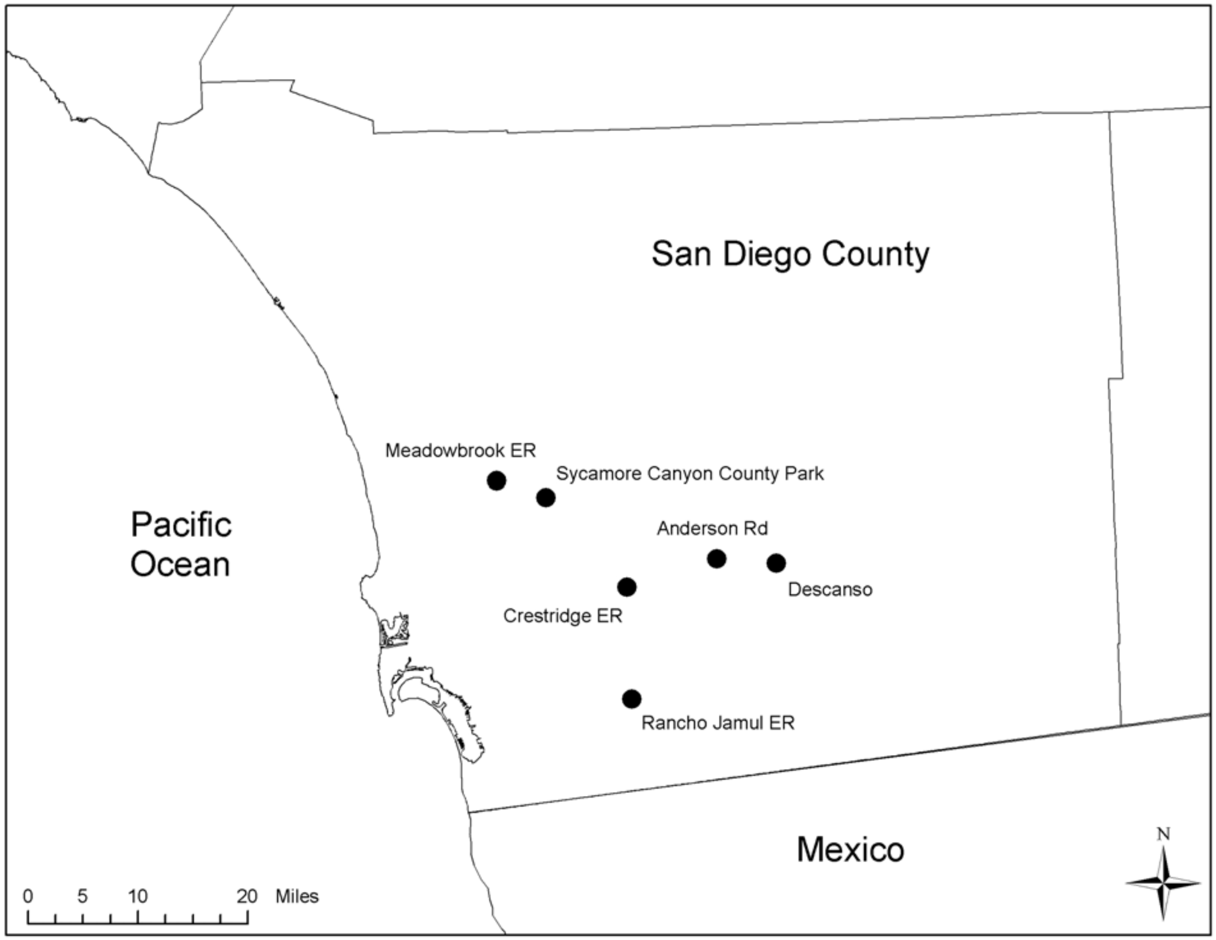
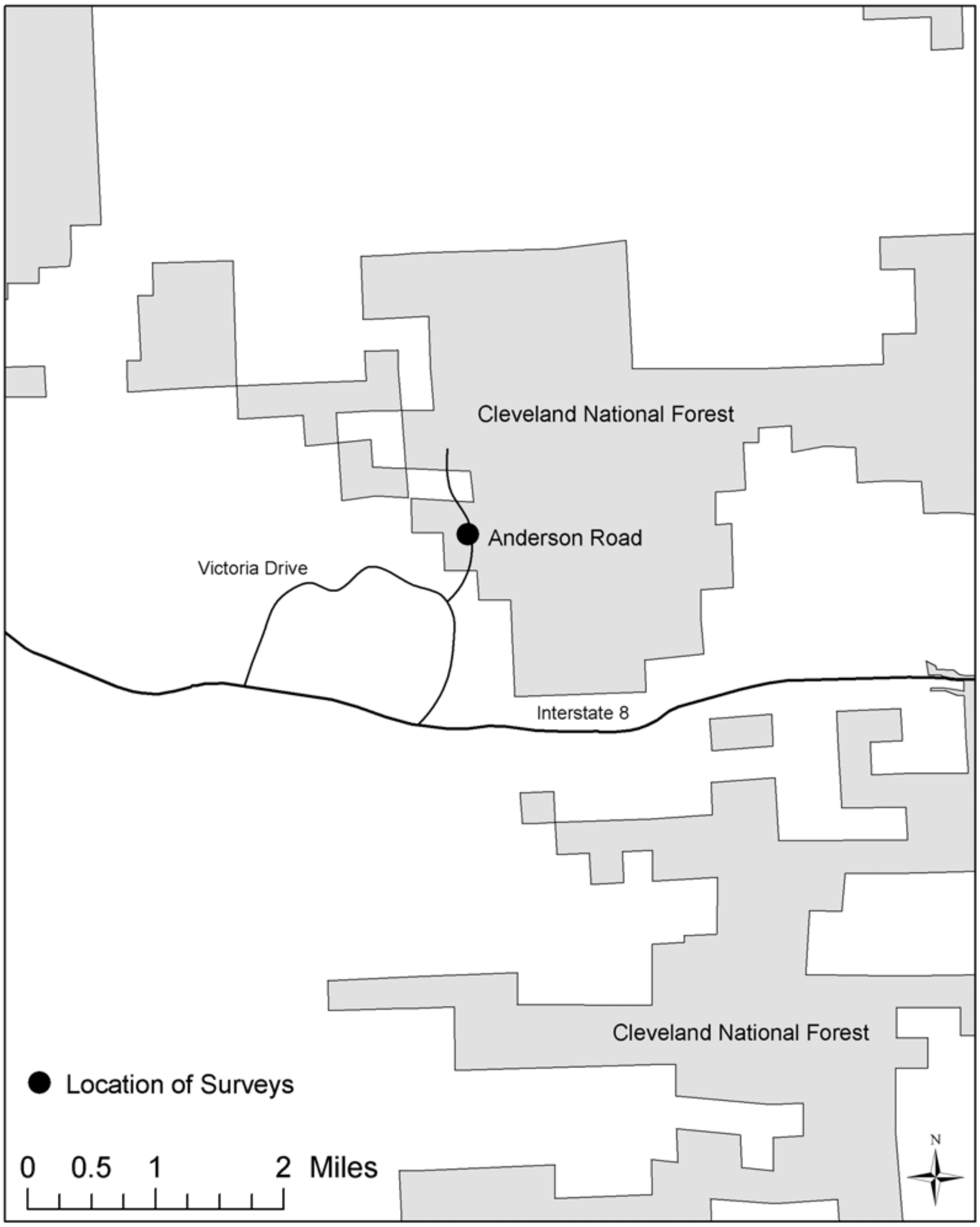
# APPENDIX A

# SITE MAPS

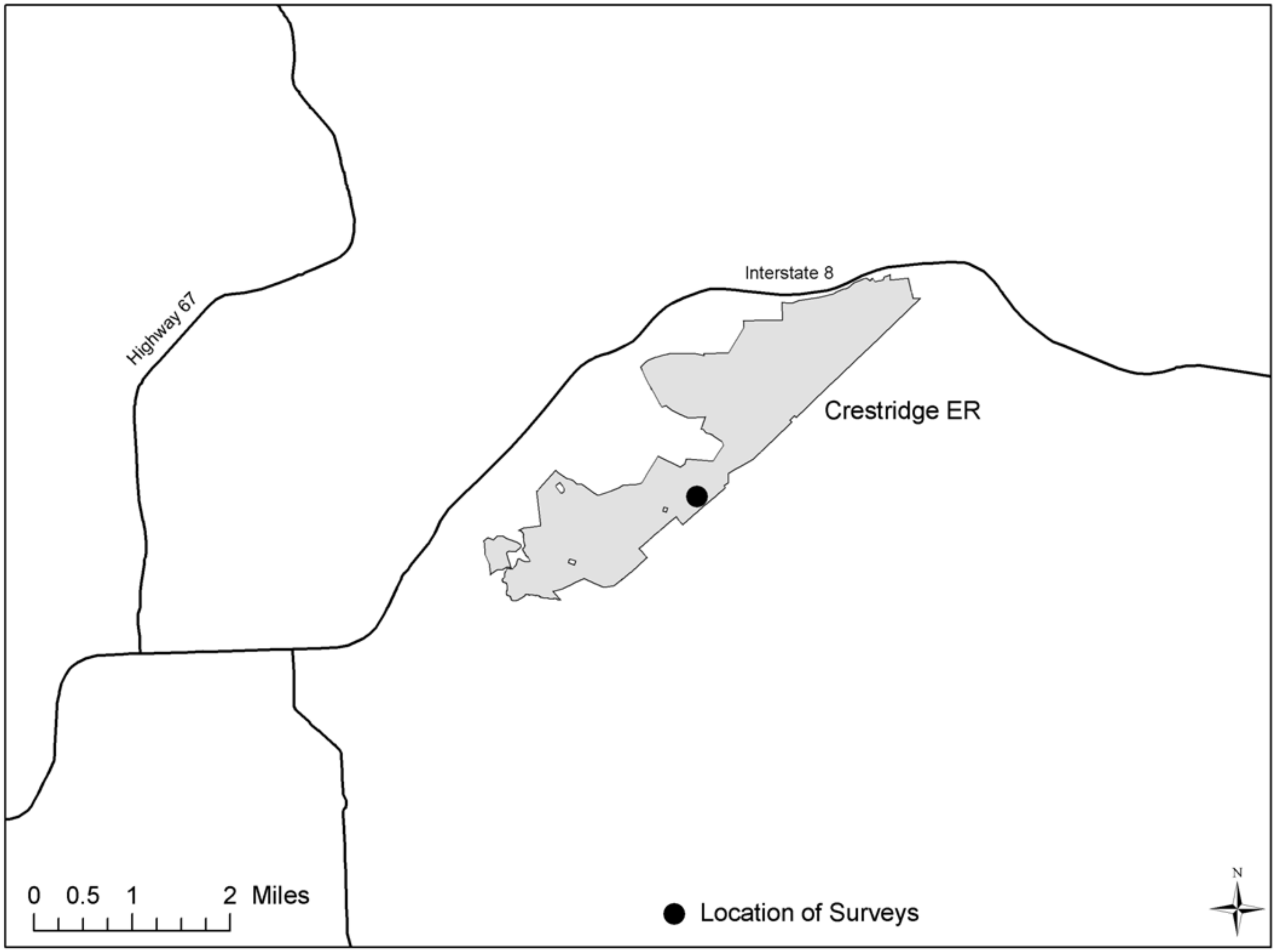
Research Sites in San Diego County.



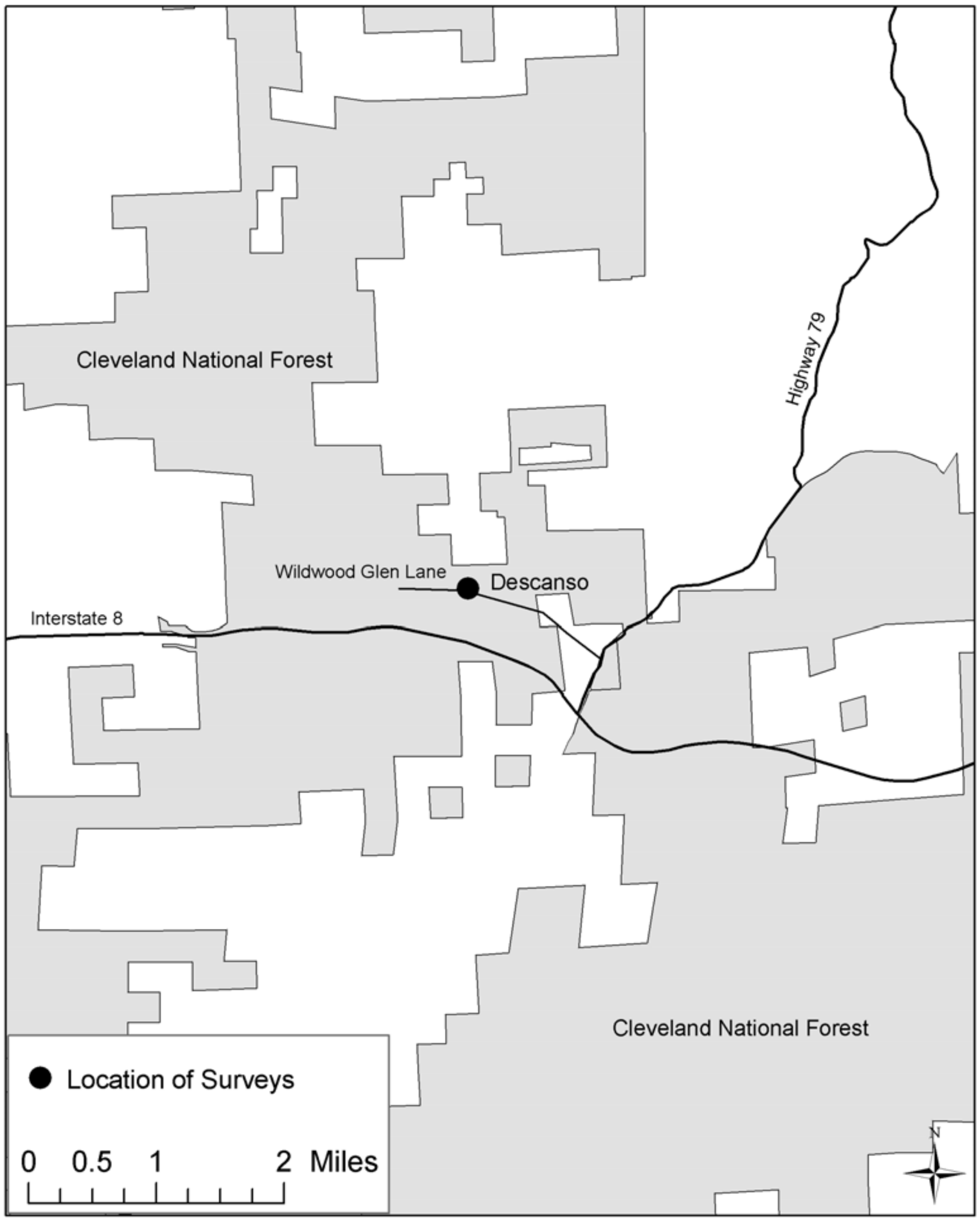
Anderson Road (Cleveland National Forest)



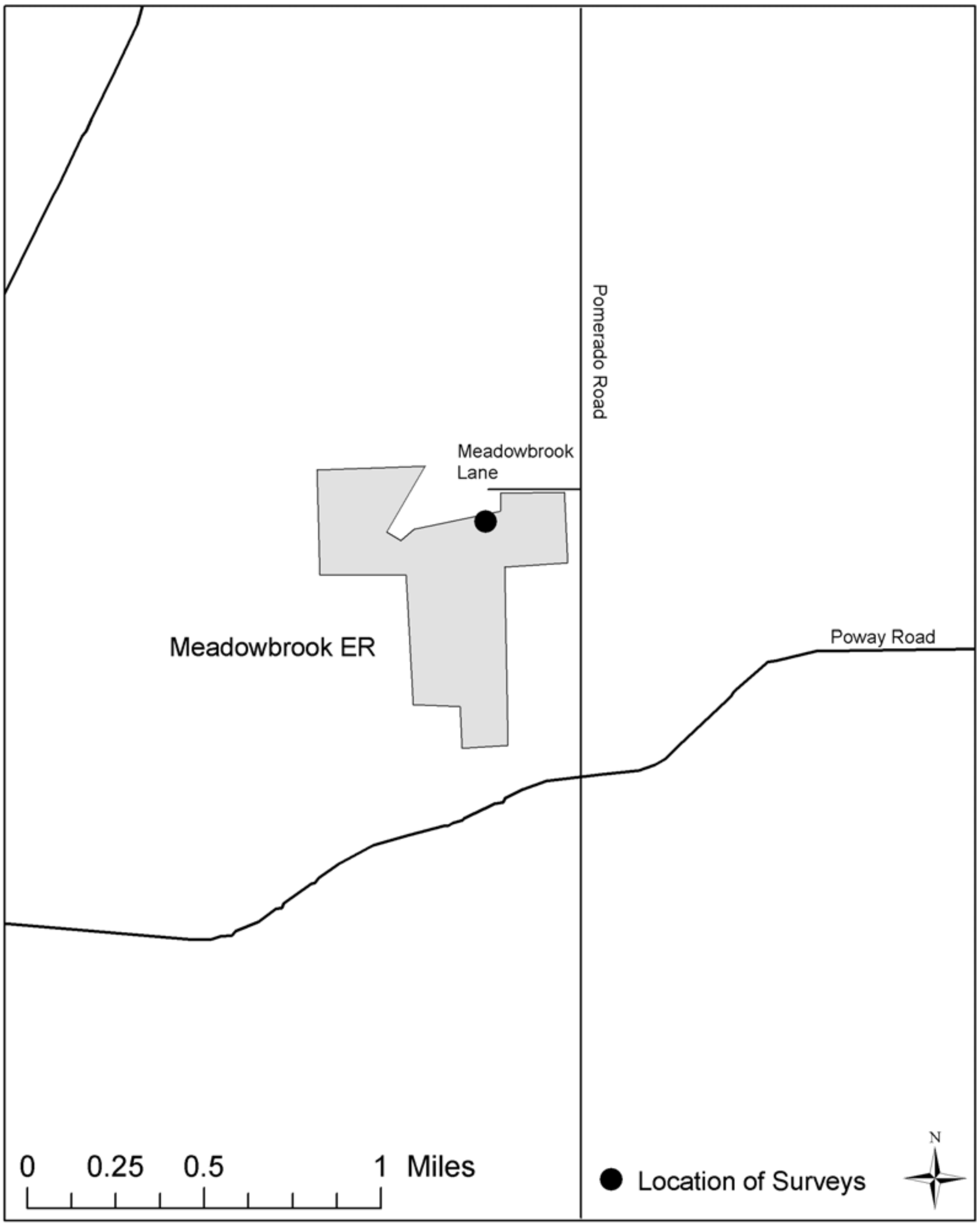
Crestridge Ecological Reserve (California Department of Fish and Game).



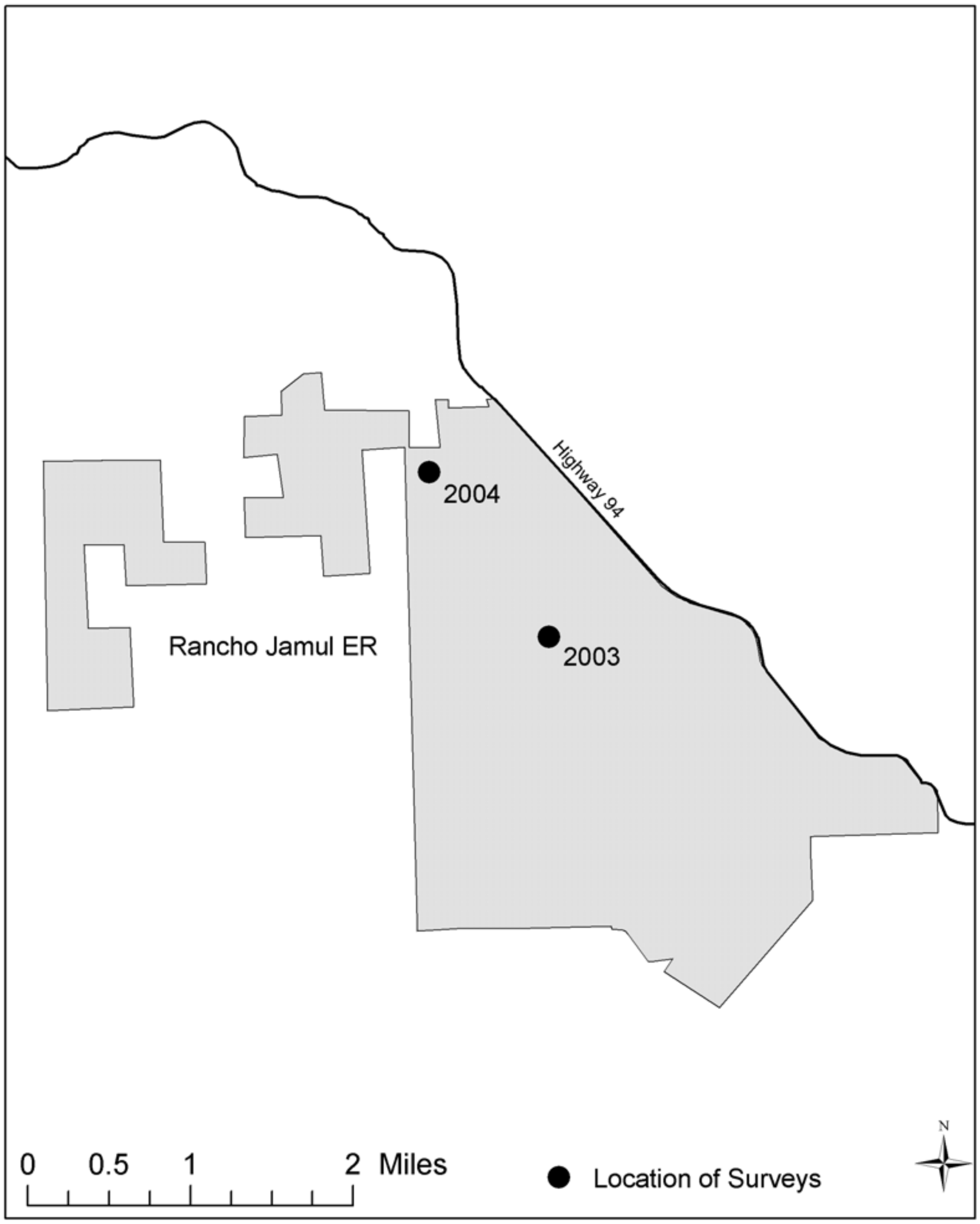
Descanso (Cleveland National Forest)



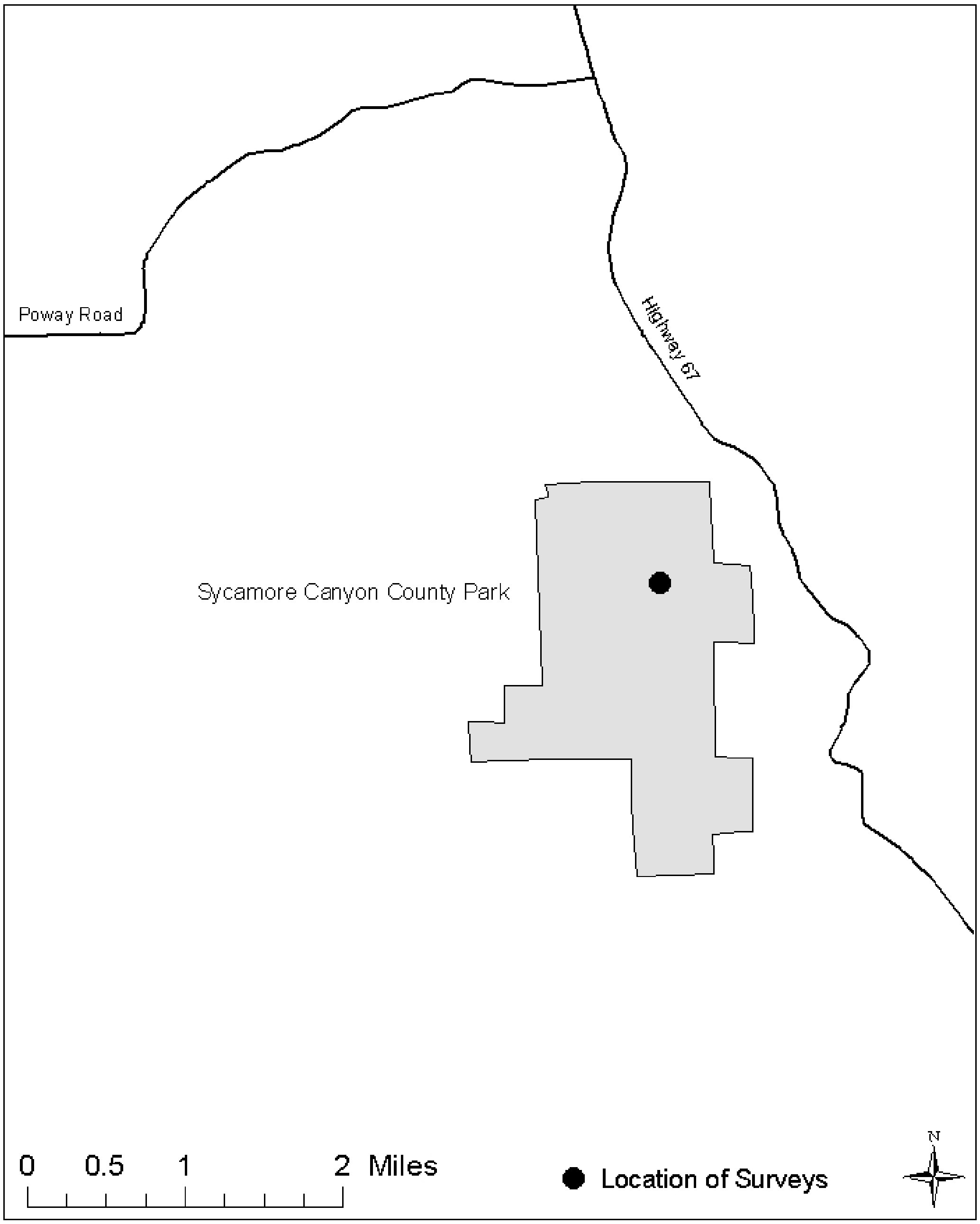
Meadowbrook Ecological Reserve (California Department of Fish and Game)



Rancho Jamul Ecological Reserve (California Department of Fish and Game)



Sycamore Canyon County Park (San Diego County)



# APPENDIX B

# DETAILED SURVEY DATA

Detailed Survey Data

| Crestridge ER 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 8 May | 1 | 0 |
| 19 May | 12 | 1 |
| 22 May | 15 | 10 |
| 26 May | 19 | 25 |
| 29 May | 22 | 49 |
| 3 June | 27 | 12 |
| 6 June | 30 | 49 |
| 12 June | 36 | 36 |
| 16 June | 40 | 32 |
| 24 June | 48 | 24 |
| 27 June | 51 | 15 |
| 30 June | 54 | 4 |
| 3 July | 57 | 3 |
| 7 July | 61 | 6 |
| 10 July | 64 | 7 |
| 14 July | 68 | 2 |
| 17 July | 71 | 0 |

| Anderson Road 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 11 May | 1 | 0 |
| 19 May | 9 | 7 |
| 22 May | 12 | 16 |
| 26 May | 16 | 11 |
| 29 May | 19 | 39 |
| 3 June | 24 | 13 |
| 6 June | 27 | 26 |
| 12 June | 33 | 73 |
| 16 June | 37 | 45 |
| 24 June | 45 | 48 |
| 27 June | 48 | 26 |
| 30 June | 51 | 11 |
| 3 July | 54 | 9 |
| 7 July | 58 | 6 |
| 10 July | 61 | 1 |
| 14 July | 65 | 1 |
| 17 July | 68 | 0 |

| Descanso 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 18 May | 1 | 0 |
| 22 May | 5 | 1 |
| 26 May | 9 | 1 |
| 29 May | 12 | 8 |
| 3 June | 17 | 12 |
| 6 June | 20 | 13 |
| 9 June | 23 | 3 |
| 12 June | 26 | 13 |
| 16 June | 30 | 10 |
| 19 June | 33 | 9 |
| 24 June | 38 | 9 |
| 27 June | 41 | 0 |
| 30 June | 44 | 1 |
| 3 July | 47 | 3 |
| 7 July | 51 | 0 |

| Rancho Jamul ER 2004 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 12 May | 1 | 2 |
| 14 May | 3 | 2 |
| 16 May | 5 | 2 |
| 18 May | 7 | 4 |
| 23 May | 12 | 4 |
| 25 May | 14 | 10 |
| 27 May | 16 | 9 |
| 30 May | 19 | 9 |
| 1 June | 21 | 5 |
| 4 June | 24 | 5 |
| 7 June | 27 | 3 |
| 10 June | 30 | 3 |
| 14 June | 34 | 1 |
| 17 June | 37 | 0 |

| Rancho Jamul ER 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 10 May | 1 | 0 |
| 27 May | 18 | 26 |
| 4 June | 26 | 42 |
| 10 June | 33 | 23 |
| 17 June | 40 | 20 |
| 25 June | 48 | 4 |
| 1 July | 54 | 1 |
| 8 July | 61 | 0 |

| Meadowbrook ER 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 23 May | 1 | 0 |
| 27 May | 5 | 5 |
| 4 June | 13 | 4 |
| 17 June | 26 | 4 |
| 25 June | 34 | 1 |
| 1 July | 40 | 0 |

| Sycamore Canyon 2003 | | |
|---|---|---|
| **Date** | **Day** | **Count** |
| 20 May | 1 | 5 |
| 27 May | 8 | 7 |
| 4 June | 16 | 4 |
| 17 June | 30 | 1 |
| 25 June | 38 | 0 |

# APPENDIX C

# COMPLETE DIRECT PERTURBATION TABLES

Summary of INCA output calculations comparing the effect of altering survey counts.

| | | **Addition of 1 to Emergence Counts** | | | |
|---|---|---|---|---|---|
| | **Original Data** | **1** | **2** | **3** | **All** |
| **N** | 100.402 | 119.681 | 106.970 | 102.899 | 125.460 |
| **St. Dev.** | 16.349 | 24.327 | 18.824 | 16.902 | 27.654 |
| $\rho_{\alpha:N}$ | 0.927 | 0.955 | 0.939 | 0.931 | 0.962 |

| | **Addition of 5 to Peak Counts** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **All** |
| **N** | 72.703 | 74.902 | 93.019 | 105.161 | 117.761 | 120.970 | 112.044 |
| **St. Dev.** | 8.276 | 8.591 | 13.038 | 16.745 | 21.737 | 23.423 | 16.176 |
| $\rho_{\alpha:N}$ | 0.849 | 0.850 | 0.903 | 0.927 | 0.946 | 0.951 | 0.916 |

| | **Addition of 2 to Decline Counts** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **All** |
| **N** | 105.643 | 102.908 | 99.622 | 95.866 | 89.843 | failed | 76.620 | 75.139 | 66.199 |
| **St. Dev.** | 17.789 | 16.962 | 16.076 | 14.774 | 13.012 | | 8.328 | 9.110 | 7.997 |
| $\rho_{\alpha:N}$ | 0.934 | 0.931 | 0.927 | 0.920 | 0.909 | | 0.857 | 0.867 | 0.863 |

Effect of Poor Weather Perturbation Table

| | **Original** | **Excluded** | **50%** | **75%** | **100%** | **125%** | **150%** |
|---|---|---|---|---|---|---|---|
| **N** | 100.402 | 112.627 | 90.681 | 96.185 | 104.038 | 111.849 | 120.695 |
| **St. Dev.** | 16.349 | 13.845 | 11.386 | 11.282 | 11.627 | 12.000 | 12.526 |
| $\rho_{\alpha:N}$ | 0.163 | 0.860 | 0.881 | 0.868 | 0.860 | 0.854 | 0.849 |

Zero Effect Perturbation Table

| | Count | Count | Count | Count | Count | Count |
|---|---|---|---|---|---|---|
| **6 May** | | 0 | | | | |
| **8 May** | 0 | 0 | 0 | | | |
| **13 May** | | | 0 | | | |
| **19 May** | 1 | 1 | 1 | 1 | 1 | 1 |
| **22 May** | 10 | 10 | 10 | 10 | 10 | 10 |
| **26 May** | 25 | 25 | 25 | 25 | 25 | 25 |
| **29 May** | 49 | 49 | 49 | 49 | 49 | 49 |
| **3 June** | 12 | 12 | 12 | 12 | 12 | 12 |
| **6 June** | 49 | 49 | 49 | 49 | 49 | 49 |
| **12 June** | 36 | 36 | 36 | 36 | 36 | 36 |
| **16 June** | 32 | 32 | 32 | 32 | 32 | 32 |
| **24 June** | 24 | 24 | 24 | 24 | 24 | 24 |
| **27 June** | 15 | 15 | 15 | 15 | 15 | 15 |
| **30 June** | 4 | 4 | 4 | 4 | 4 | 4 |
| **3 July** | 3 | 3 | 3 | 3 | 3 | 3 |
| **7 July** | 6 | 6 | 6 | 6 | 6 | 6 |
| **10 July** | 7 | 7 | 7 | 7 | 7 | 7 |
| **14 July** | 2 | 2 | 2 | 2 | 2 | 2 |
| **17 July** | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | 0 | 0 |
| | | | | | | 0 |
| **Estimate:** | 100.402 | 95.215 | 75.513 | 115.848 | 136.463 | 152.357 |

# ABSTRACT OF THE THESIS

Factors Influencing Population Viability of Hermes Copper
(*Lycaena hermes*)
by
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Hermes copper (Lepidoptera: Lycaenidae: *Lycaena hermes*) has experienced habitat loss due to population growth in San Diego County, CA. Reduced habitat and the wildfires of 2003 have elevated concern from wildlife biologists about the status of this species, leading to a second petition to list Hermes copper under the Endangered Species Act. Currently very little research regarding the biology of Hermes copper is present in the literature. This research provides biological and monitoring information specific to Hermes copper.

Pollard Walks were conducted to record abundances and locations of Hermes copper adults. Adults were present for roughly one to two months at any one location, with initial emergence of individuals varying among sites and years due to elevation and weather. Survey data showed elevation influenced the start of the flight season by only a couple days and the warmer weather of 2004 led to first detection of adults four days earlier than 2003. Densities also varied among sites and years, with adults often found nectaring or resting on *Eriogonum fasciculatum*. Logistic regression using habitat characteristics measured along transects did not successfully predict the presence of adults. Hermes copper were higher on edge transects, specifically the north and west side of roads. A movement study, following an individual for ten movements, demonstrated that most individuals remained in a small area, often times repeatedly resting on a particular section of a shrub. Mark-release-recapture data showed a resighting was most likely less than twelve meters from the previous sighting, with a maximum distance of 84 meters recorded. A 43 percent recapture rate resulted from the mark-release-recapture study, with significantly more males resighted than females. Searches for larvae in late April and early May were unsuccessful.

Insect Count Analyzer (INCA) is a sophisticated statistical model that estimates a population size based on survey data. Four of seven surveyed sites yielded unreliable estimates due to a high correlation between death rate and population size. Of the three successful estimates, population size CVs ranged from 0.16 to 0.41. Minor direct perturbations to survey data resulted in large changes to the INCA estimate. Random perturbations, involving simulated data, allow a comparison of INCA estimates and Max Count. Max Count is the highest number of Hermes copper adults observed during Pollard Walks at a site. Simulations demonstrated that INCA amplifies error and stabilizes bias while Max Count was biased with less error at all levels of variability tested. A power simulation showed that Max Count had a better ability to detect a population change than INCA. Power of Max Count to detect a population change increased from 0.26 to 0.95 for five to ten years of survey data used, with INCA increasing from 0.02 to 0.25. Mark-release-recapture data was not appropriate to use in population size calculations due to few individuals reappearing after eluding detection. This high detectability of adults created problems in calculating population size and confidence intervals since individuals that were never resighted were treated as dead rather than mixing into the population. Mark-release-recapture may not be useful for Hermes copper based on the biology and behavior of the species.