A Long-Term Monitoring Plan for a Threatened Butterfly

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Abstract: *A long-term monitoring plan using stratified random sampling of population densities of late instar larvae is presented for a large population of the threatened Bay checkerspot butterfly,* Euphydryas editha bayensis. *A topographic map of the habitat is analyzed for the distribution of slope exposures and a clear sky insolation model is applied to delineate microclimate strata. Sixth and seventh instar larval densities are estimated for square-meter quadrats on specific slope exposures, and these density samples are then grouped into the microclimate strata for estimating population size. Additionally, samples of larvae from different slopes are weighed to monitor developmental phenology. The larval population increased from 92,000 in 1985 to 783,000 in 1987, and decreased to 319,000 in 1988. The distribution of larvae changed between years, shifting from cool slopes to warmer slopes as the population grew. These shifts affect developmental phenology and the timing of adult emergence. The procedure produces labor- and cost-effective yearly estimates of population densities of larvae in different microclimates and documents within-habitat responses of the population to a variable climate.*

Resumen: *Se presenta un plan de monitoreo a largo plazo usando muestras estratificadas al azar sobre densidades de poblaciones de larvas instar para una gran población de mariposa,* Euphydryas editha bayensis, *especie amenazada. Se analiza un mapa topógrafico del medio ambiente para la distribución de las exposiciones de los laderos y se adapta un modelo de insolación con cielo despejado para delinear estratos de microclima. Se calculan las sextas y séptimas densidades de la larva instar por cuadrantes de metro cuadrado en manifestaciones específicas del declive; estas muestras de densidad son luego agrupadas en estratos de micro clima para estimar el tamaño de la población. Adicionalmente, se pesan muestras de larvas de diferentes laderos para medir el desarrollo fenológico. La población de larvas aumentó de 92,000 en 1985 a 783,000 en 1987, y disminuyó a 319,000 en 1988. La distribución larvatica cambio entre estos años, trasladándose de laderos frías a laderos calientes conforme la población crecía. El procedimiento produce estimaciones anuales de las densidades de poblaciones de larvas en microclimas diferentes y documenta las respuestas de la población a un clima variable.*

Introduction

The long-term monitoring of populations can be central to the conservation of threatened and endangered species. Certainly, the value of long-term data cannot be overstated in this era of great and rapid environmental change. Conservation biologists may choose from numerous methods for estimating animal and plant abundance (see Seber 1982 and Moore & Chapman 1986). Many factors must be carefully considered before choosing a technique, including repeatability, efficiency, statistical accuracy and precision, and, importantly, minimal dis-

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Paper submitted 5/10/88; revised manuscript accepted 7/27/88.

turbance or impacts on the population under study. These goals are often difficult to meet within the tight budgets typical of conservation projects. Examples of long-term monitoring plans include those of checkerspot butterflies at Jasper Ridge Biological Preserve on the Stanford University campus (Ehrlich et al. 1975; Ehrlich & Murphy 1987), chimpanzees at Gombe Stream Preserve (Goodall 1986), British butterflies surveys (Pollard, Hall, & Bibby 1986), chalk grassland orchids in Britain (Wells 1981), wolves on Isle Royale (Peterson & Page 1988), and birds in eastern United States hardwood forests (Whitcomb et al. 1981). These long-term studies and others are among the important contributions to our understanding of basic processes in ecology and conservation biology to date. Established preserves provide opportunities for long-term ecological monitoring research programs (Callahan 1984), especially if continued funding is provided through institutional devices such as habitat conservation plans or trust funds.

We recently developed a conservation plan for a large, topographically heterogeneous serpentine soil-based grassland that is densely populated by the federally protected Bay checkerspot butterfly, ***Euphydryas editha bayensis***. The success of this plan depends on our ability both to estimate overall population trends and to assess microhabitat use within the overall habitat area. This paper explains our chosen methodology and presents results from the first four years of monitoring of this population.

The Study System

The Bay checkerspot butterfly at Morgan Hill, California (37° 10′N, 121° 40′W, elev. 150–400 m), occupies approximately 2,000 ha of serpentine soil-based grassland habitat (Fig. 1), and is the focus of a conservation agreement under Section 7 of the Endangered Species Act (Murphy 1988). Our primary study area is the lease site for a large Class 3 sanitary landfill and adjacent habitat, encompassing approximately 500 ha. Initial surveys during 1984 for postdiapause larvae, adult butterflies, and their plant resources pinpointed centers of checkerspot butterfly abundance. As a result, 100 hectares of prime habitat were set aside as a preserve.

Population monitoring was included as an integral component of the overall conservation agreement. The monitoring program allows year-to-year evaluation of an ongoing program that includes stringent guidelines for grazing, postprogram revegetation, and off-site introduction of the butterfly into suitable habitats. Reliable population estimates for the topographically complex habitat preserve (Fig. 1) were needed to provide baseline data to guide the plan.

The use of walking transects (see Pollard 1977; Pollard, Hall, & Bibby 1986) in the first study year in 1984 established the rough outlines of adult distribution, but produced only limited information on absolute population numbers, phenology, and microhabitat use. The adult population was far too dense and extensive in distribution to allow use of mark-recapture techniques for measuring population size (see Ehrlich 1984 for review). When more than 12,000 butterflies were handled in 1986 to assess adult dispersal among four small subsites, fewer than 10% of marked butterflies were recaptured. Application of mark-recapture techniques to the entire site, or even a significant portion of it, was clearly unrealistic during the study period, given constraints on labor and money.

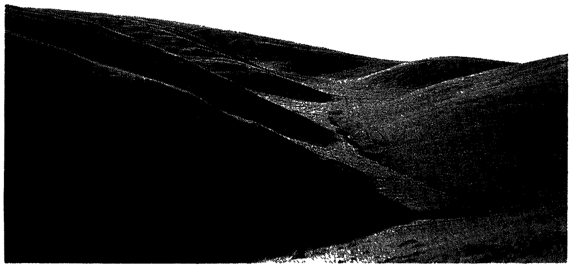


Figure 1. Typical serpentine soil-based grassland habitat at Morgan Hill. The relative smoothness of the contours and simple structure of the vegetation allow easy calculation of clear sky insolation and observation of large postdiapause larvae. The shaded slope in the left foreground is a very cool N 27° slope. The distance from the horizon line to the junction of the gullies is approximately 500 m. (Photo by R. R. White)

Studies of larval growth and dispersal identified topography as the dominant factor that determines habitat quality for the butterfly (Weiss et al. 1987; Weiss, Murphy, & White 1988). The phenology of postdiapause larval development was monitored by weighing samples of larvae from different slope exposures. Different slope orientations expose the grassland habitat to varying amounts of solar radiation, creating diverse thermal microenvironments during the rainy October–May host plant growing season. Ground level thermal conditions affect development rates of both the butterfly and its host plants (Singer 1972; Dobkin, Olivieri, & Ehrlich 1987; Weiss et al. 1987; Weiss, Murphy, & White 1988). Rainfall patterns, local microclimates, and thermal requirements of larvae and pupae interact to affect the phase relationship between adult emergence and host plant senescence, which in turn determines survival rates of the next generation of prediapause larvae. These prediapause larval survival rates are the primary cause of year-to-year changes in population size (Singer 1972; Ehrlich et al. 1975; Singer & Ehrlich 1979).

Densities of postdiapause larvae within the Morgan

Hill habitat vary with solar exposure (Weiss, Murphy, & White 1988). The distribution of late-instar larvae across microclimates reflects patterns of oviposition and prediapause larval survivorship, diapause and postdiapause larval mortality, and postdiapause larval dispersal (Singer 1972; Weiss et al. 1987). Furthermore, the distribution of larvae determines the pattern of adult eclosion for that flight season; larvae on warm, south-facing slopes grow, pupate, and eclose up to a month earlier on average than those on cool, north-facing slopes (Weiss, Murphy, & White 1988).

We applied stratified random sampling to this population (Cochran 1977). Larvae were counted in samples of 50–100+ quadrats in areas of relatively uniform slope exposure, providing repeatable measures of larval densities in an array of sample areas. Specific slope exposures were grouped into microclimate strata by applying a clear sky insolation model. A population estimate was calculated by multiplying larval densities within particular microclimates by the total area within that stratum. The proportion and absolute numbers of larvae in different microclimates can be compared from year to year to assess weather-related population dynamics. Adult population numbers can then be generated by applying mortality rates for late-instar larvae and pupae (White 1986; Weiss, Murphy, & White 1988).

Procedures

A 1:4800 scale map of the Morgan Hill site was constructed from United States Geologic Survey topographic maps. The map was divided into areas that correspond to management units as described in a habitat conservation plan for the property (Murphy 1988). This study concentrated on the 100 ha habitat preserve area that supports the densest portion of the butterfly population. A population estimate for an extension of habitat to the north of the habitat preserve is also included for 1987.

Late-instar postdiapause larvae are readily observed feeding and basking among the short grassland vegetation (Fig. 2). Samples of 50–100 one-square-meter quadrats, one every 9 to 25 square meters, were searched for larvae in areas of relatively uniform slope exposure when larvae were in their last two instars. Each sample was compared to a Poisson distribution by a coefficient-of-dispersion test (Seber 1982). Samples and groups of samples were compared by paired t-tests on square-root-transformed data (Sokal & Rohlf 1981).

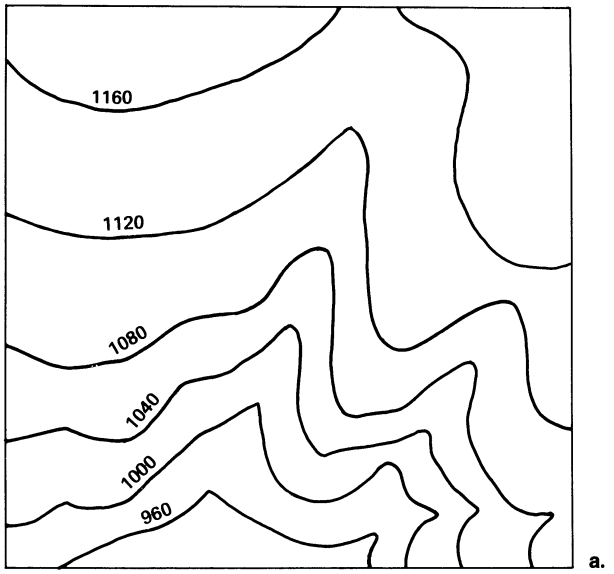
Determination of the distribution of slope exposures is illustrated in Figure 3. The map utilized a 1,000-foot grid system. Figure 3a shows a typical 1,000-foot × 1,000-foot grid square. Each grid square was further subdivided into 100-foot × 100-foot sections (about 30 × 30 meters). This sampling scale was approximately equal to the maximum dispersal range of last instar larvae over 2–3 days (Weiss et al. 1987).

Figure 2. A postdiapause Euphydryas editha bayensis *larva. Larvae typically bask in prominant locations and are easily observed within meter-square quadrats. This seventh instar larva is approximately 2.5 cm in length. (Photo by P. R. Ehrlich)*

The azimuth and tilt of each section were calculated by measuring the direction and length of a line orthogonal to the nearest contour lines. Azimuth was expressed as one of eight compass directions: N, NE, E, SE, S, SW, W, and NW. Tilt was calculated as arctan (40/D), where D is the distance between the 40 foot (c. 12 meter) contours, and was expressed as follows: 0–4° in any direction was classified as flat, 5–9° was considered to be 7°, and so on up to 25–29°, treated as 27°. The conversion from contour lines to azimuth and tilt is shown in Figure 3b. In ambiguous cases where contour lines did not allow assessment directly from the map, field surveys with a compass and clinometer determined azimuth and tilt. Totals for each azimuth/tilt combination were summed over the area. Nonhabitat areas (woodlands, brush, and nonnative grasslands) were identified as such.

The map is a two-dimensional representation of the landscape, so correction factors were applied to obtain true surface areas. The correction factor is 1/cosine(tilt angle). Areas with a slope of 27°, for example, must be multiplied by 1/cos(27°), or 1.12. The topographic analysis was done manually, although this aspect of the procedure could be greatly facilitated through a geographic information system (GIS) and digitized maps.

As noted above, insolation differences between slopes are key determinants of habitat quality. Clear sky insolation striking the ground on March 21 was chosen as a microclimate index. Insolation values range from 3 to 7 kWh $m^{-2}d^{-1}$. Slopes were divided into six strata (Table 1). Steep east- and west-facing slopes (>17° tilt) were separated from the moderate slopes because they exhibited significantly different densities of larvae and



	1	2	3	4	5	6	7	8	9	10
1	NE 7	N 7	N 7	NW 7	NW 12	NW 17	NE 12	NE 17	F	F
2	N 12	N 12	N 12	N 12	NW 17	NW 17	E 17	E 12	E 7	F
3	N 12	N 12	N 12	N 17	NW 17	E 27	E 17	E 12	E 7	F
4	N 12	N 12	N 17	N 17	NW 22	E 27	E 17	NE 12	NE 7	N 7
5	N 12	N 17	N 22	N 22	NW 27	E 27	E 17	N 17	N 22	NE 12
6	N 17	N 17	NW 22	NW 27	E 27	E 27	NE 17	NW 27	E 27	NE 17
7	N 22	N 17	NW 27	NW 27	E 27	E 27	N 27	E 27	E 27	N 22
8	N 22	N 17	NW 27	NE 27	NE 27	N 27	N 27	NE 27	NE 27	NE 22
9	N 17	N 22	NW 27	N 27	NE 27	N 27	N 27	NE 27	SE 27	SE 22
10	NW 17	N 17	NW 17	SE 17	E 17	SE 17	SE 17	SE 17	SE 17	SE 17

b.

Figure 3. Topographic analysis procedure: (a) typical 300 × 300 m section of habitat (contour interval 40 ft/ca. 12 m); (b) azimuth and tilt of each 30 × 30 m area within the large section (F-Flat).

have solar exposure regimes different from other slopes with similar March 21 insolation values. "Very warm" slopes were separated from warm slopes for similar reasons—southwest-facing slopes are warmer than southeast-facing slopes of similar tilt, because maximum air temperatures occur in early afternoon when southwest-facing slopes receive maximal insolation (Geiger 1965).

The stratification scheme conceivably could be extended to every slope exposure by azimuth intervals of 45° and tilt intervals of 5° if necessary, for a total of 41 strata. We developed a coarser division into these microclimate classes because of the natural grouping of the data and a lack of large uniform slopes at the higher level of resolution (note the rounded topography in Fig. 1). The stratification scheme is adaptable if data suggest the need for finer resolution. Indeed, in 1988 more strata were utilized to account for extremely low densities of larvae on NE 7–12° slopes, and large differences between E 22° and W 22° within the MOD2 strata used in 1987 (see Table 2).

Table 1. Distribution of slopes within the habitat reserve in hectares. Flat areas are S 0°. Strata assignments are presented below the area measurements. W = warm, VW = very warm, M1 and M2 = moderate, C = cool, VC = very cool.

	Tilt in degrees					
Exposure	*0*	*7*	*12*	*17*	*22*	*27*
S	9.99	0.55	0.92	1.04	0.49	0.10
	M1	W	W	VW	VW	VW
SW	----	0.64	0.09	0.76	0.39	0.10
		W	W	VW	VW	VW
SE	----	1.18	1.75	3.67	2.92	0.60
		W	W	W	VW	VW
W	----	0.27	0.83	0.47	0.76	0.50
		M1	M1	M1	M2	M2
E	----	2.27	1.48	5.09	1.65	1.22
		M1	M1	M1	M2	M2
NW	----	0.82	0.74	1.26	2.92	1.72
		M1	M1	C	VC	VC
NE	----	4.27	7.63	6.40	1.75	0.81
		M1	M1	C	VC	VC
N	----	4.63	4.42	6.88	3.69	1.72
		M1	C	C	VC	VC
Nonhabitat	2.70	Total = 92.02 ha				

The impact of the postdiapause larval distribution on flight season phenology is monitored by tracking postdiapause development on different slopes. We chose four slopes (warm SE 13°, moderate flat, cool N 17°, and very cool N 30°) where groups of 30–50 larvae are collected, weighed, and promptly returned to the field. These samples are repeated every 10–15 days through the growth season and are used to predict the timing of adult eclosion and the effects of weather variations on larval development. These data can be combined with larval densities to estimate the proportions of the population eclosing at various points in the flight season.

Raw field data are entered into a set of electronic spreadsheets (Lotus 123) for calculations and statistical analysis.

Results

Larval density samples for 1987 are presented as an example of how data are grouped into strata (Table 2). No significant within-strata differences could be detected (the largest within-strata difference is between the FLAT and the E 12° slopes, $t = 1.35$, $df = 157$, $.10 < p < .20$). All differences between combined samples in adjacent

Table 2. Larval density samples for 1987. Quadrats = square meters searched, N = larvae observed, CD = coefficient of dispersion, INS = March 21 isolation in kWh m^2 d^{-1}. The lower section of the table presents paired t-tests between adjacent strata, using square-root-transformed data.

Exposure	*Date*	*Quadrats*	*N*	*Density*	*CD*	*Strata*	*INS*
S-SW 20°	FEB 18	68	13	.19	.97	V WARM	6.6
SE 17°	FEB 18	51	34	.67	1.00	WARM	6.2
SE 10°	FEB 20	72	67	.93	3.55[a]	WARM	6.0
FLAT	FEB 18	99	159	1.61	3.51[a]	MOD	5.6
N-NW 7°	FEB 22	78	106	1.36	1.26	MOD	5.2
E 12°	FEB 22	60	68	1.13	1.42	MOD	5.5
N 7°	FEB 18	75	90	1.20	2.73[a]	MOD	5.1
W 22°	FEB 18	53	8	.15	.83	MOD2	5.3
E 22°	FEB 22	50	3	.06	.95	MOD2	5.3
N 17°	FEB 22	52	48	.92	.83	COOL	4.2
N 17°	FEB 27	99	88	.89	1.17	COOL	4.2
N 17°	FEB 27	54	46	.85	1.04	COOL	4.2
NW 25°	FEB 27	53	27	.51	1.07	V COOL	4.0

Comparisons	*t*	*df*	*p*
V WARM–WARM	3.91	188	<.001
WARM–MOD	3.02	433	<.01
MOD–COOL	2.49	503	<.02
COOL–V COOL	2.53	254	<.02
MOD–MOD2	7.55	403	⩽.001

[a] *Samples that show significant clumping.*

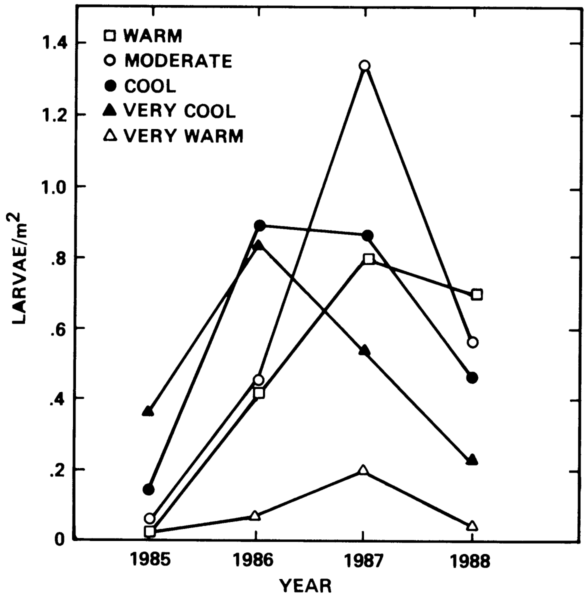


Figure 4. Changes in larval density from 1985–1988 within five microclimate strata.

strata are significant (see bottom of Table 2). Data for 1985 and 1986 can be found in Weiss et al. 1988, (data for 1988 are available upon request).

High coefficients of variation in several samples indicate significant clumping of larvae within the habitat. The primary source of the clumped distributions appears to be small-scale topography, which affords post-diapause larvae slightly warmer areas within broad topographic exposures in which to bask. For example, within the FLAT sample in 1987, quadrats containing 7, 8, 9, and 13 larvae/m^2 (versus a mean of 1.61 larvae/m^2) were found on the warmer side of a low crest. The patchy distribution of the larval host plant, *Plantago erecta*, and oviposition behavior appear also to contribute to the observed clumped distributions.

The year-to-year changes in larval densities within the five major strata illustrate how larval densities in microhabitats varied during the four years of study (Fig. 4). In 1985, larvae were most dense on very cool slopes, and virtually no larvae were found on warm slopes. In 1986, all slopes exhibited higher larval densities, still in the same relative rank order. In 1987, the density of larvae on moderate slopes sharply increased, while the density on cool slopes leveled off, and the density on very cool slopes dropped by a factor of two. Finally, in 1988, densities on moderate, cool, very cool, and very warm slopes all dropped by a factor of two, while those on warm slopes dropped only slightly.

These data, translated into proportions of the larval population in different microclimates, show disproportionate changes across microclimates during the four-year period (Table 3). As the overall larval population rose about eightfold, from 92,500 in 1985 to 783,000 in 1987, the proportion of larvae on cool slopes decreased from 46% to 9%. During that same period the proportion of larvae on moderate slopes increased from 19% to 59% and the proportion of larvae on warm and very warm slopes increased from 4% to 11%. In 1988, the larval population decreased from 783,000 to 319,000, but all slopes did not equally share the decrease. The proportion of larvae on the warm slopes actually increased along with that on the cool slopes. The proportion on moderate slopes decreased while the proportion on very cool slopes remained the same.

The size of the adult population was calculated by applying mortality rates of late-instar larvae and pupae. Mortality among late-instar larvae from parasitoids has not exceeded 5% in field-collected late-instar larvae reared in the laboratory during 1985–1988. Pupal mor-

Table 3. Larval population estimates and distribution by microclimate. The range presented for each year is the 95% confidence interval based on the normal approximation (made possible by the large total sample size [Cochran 1977]). All moderate strata have been grouped together.

	Habitat Area	*1985*	*1986*	*1987*	*1988*
Total number of Larvae	89.32 ha	92,000 ±27,500	472,000 ±56,500	783,000 ±81,000	319,000 ±36,000
V. Warm	7%	1%	1%	2%	1%
Warm	10%	3%	8%	9%	19%
Moderate	48%	19%	33%	59%	43%
Cool	21%	31%	36%	21%	28%
V. Cool	14%	46%	22%	9%	9%
Adult Numbers	---	46,000	236,000	391,000	159,000

tality has been estimated at close to 50% in each of the study years; for example 203/388 (52%) of pupae placed in the field duirng February and March 1985 eclosed successfully (Weiss, Murphy, & White 1988). No significant variation in pupal mortality between years has yet been observed, but variation could easily be included in the calculations. A mortality rate of 50% applied to the larval population estimates produces a reasonable approximation of adult numbers in the habitat preserve. These estimates are presented on the bottom row of Table 3.

Postdiapause larval growth phenology for 1987–1988 is shown as a single-year example (Fig. 5). Note that larvae on warm slopes grow much more rapidly than those on cooler slopes, hence reach size for pupation as much as one month earlier than larvae on the very coolest slope. These data suggest that proper timing of larval monitoring is necessary, such that larvae have reached sufficient size to be easily observed, but have not yet pupated.

Discussion

The major causes of severe declines in Bay checkerspot butterfly population sizes are weather patterns that disrupt the phase relationship between adult flight and host plant senescence (Singer 1972; Singer & Ehrlich 1979). A poor phase relationship causes what might be termed a "thermal retreat"; that is, the next generation of postdiapause larvae are found on cooler slopes than the current generation. Prediapause larvae are unable to reach diapause in the microclimate where their mother developed, but can reach diapause if situated on cooler slopes where larval host plants senesce later. Thermal retreat may result either from drought or from particularly cold, wet winters (Singer & Ehrlich 1979; Ehrlich et al. 1980; Dobkin, Olivieri, & Ehrlich 1987). Population extinction in a year of thermal retreat may occur when females find no cooler slopes for oviposition than those on which they developed as larvae and pupae.

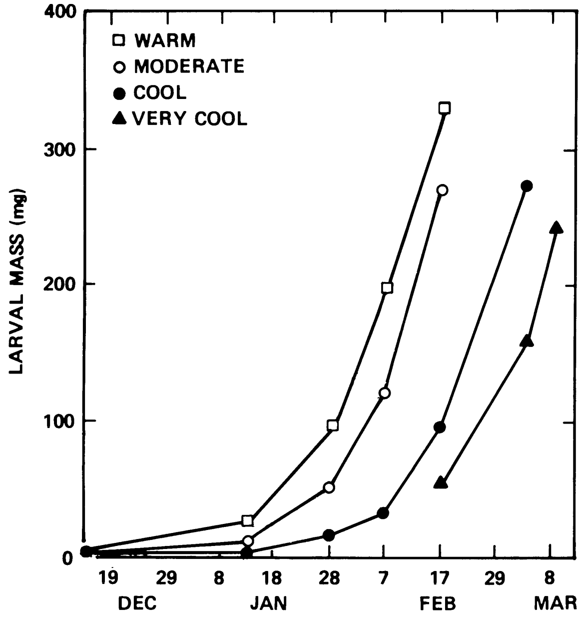


Figure 5. Growth of postdiapause larvae during 1987–1988. Larvae pupate at 300–500 mg.

Conversely, in favorable years, populations may exhibit a "thermal advance" — females can successfully oviposit on slopes warmer than those on which they developed. Once larvae are established on warmer slopes, a positive feedback process can start. Females that eclose early from warm slopes produce more offspring that can survive to diapause on warm slopes, possibly even on the warmest slopes in the habitats. This feedback is also augmented by larval dispersal from cool slopes to warmer slopes (Weiss et al. 1987).

This study population underwent a striking thermal advance during the period of population growth from 1984 through 1987. In spring 1983, a poor phase relationship caused a population decline at nearby Jasper Ridge Biological Preserve when heavy and extended winter rains delayed larval and pupal development far more than they delayed host plant senescence (Dobkin et al. 1987). In February 1984, surveys for larvae at Morgan Hill found them almost exclusively on cool slopes. Favorable weather from 1984 through 1986 (heavy early season rains, extended periods of winter sunshine, and sufficient late-season rains in March), substantial contributions from larval dispersal, and variance in larval growth rates (which results in some larvae pupating and eclosing substantially earlier than average on a specific slope exposure [Weiss et al. 1987; Weiss, Murphy, & White 1988]) allowed large portions of the population to thermally advance, so that in 1987 the bulk of the population resided on moderate to warm slopes. The dry rainy season of 1986–1987 cut short the host plant growth season, and all slopes exhibited decreased population densities in 1988. The fact that a significant proportion of the population eclosed relatively early from warm and very warm slopes appears to have partially ameliorated the effects of the dry year, allowing a large proportion of the population to survive to diapause on warm slopes in spring 1987. The effects of a spring 1988 drought might similarly prove to be buffered by a high proportion of early eclosing adults.

These data confirm previous speculations that although warm slopes may contribute little to population size in some years, they are important to the persistence of populations by allowing faster larval and pupal development (Singer 1972, Singer & Ehrlich 1979; Ehrlich & Murphy 1987; Weiss, Murphy, & White 1988) and increasing realized fecundity through availability of early-season nectar (Murphy, Launer, & Ehrlich 1983; Weiss, Murphy, & White 1988). The data presented here also support the assertion that habitat diversity may be a more important determinant of habitat quality for this butterfly than habitat area (Weiss et al. 1987; Weiss, Murphy, & White 1988). For example, a dense population at Coyote Reservoir went extinct during the 1975–1977 California drought, in part due to the relatively uniform eastern exposure of the habitat (Ehrlich & Murphy 1987; Murphy & Weiss 1988). The limited range of microclimates at Coyote Reservoir apparently did not allow the population there to survive consecutive thermal retreats during the two-year drought.

The long-term record of these changes in this population will provide a valuable testing ground for theories of population persistence in a variable climate. Estimates of larval density generated by this sampling regime also can be used to assess the impact of postdiapause larvae on their host plant resources. For example, the probable cause of the drop in larval density on gentle NE-facing slopes from 1987 to 1988 appears to be large-scale defoliation of *Plantago erecta* in these areas.

The methodology presented here meets many goals desired of a conservation-oriented study. Specifically, the technique (1) is nonintrusive and low impact—the insects are not handled and damage to habitat is minimal; (2) is repeatable; (3) gives absolute as opposed to relative population estimates; (4) documents demographic processes responsible for year-to-year fluctuations in population size; (5) provides a baseline for future monitoring and mapping of topographic features that contribute to habitat quality; and (6) is labor-efficient, uses simple tools, and hence is low cost (the size of the larval population was estimated by a single person in five field days).

Stratified sampling is more widely used in fields other than ecology (Goldsmith, Harrison, & Morton 1986) and is one of the most powerful sampling methods available (Cochran 1977; T. R. E. Southwood, personal communication). The present study was specifically tailored to the habitat and life history of *Euphydryas editha bayensis*. Stratification by microclimate was suggested by our previous knowledge of the life history of the butterfly and by observations that larvae were more dense on specific slope exposures in any given year. Our specific procedures would undoubtedly have to be modified for use with other species, particularly those in habitats with more vertical vegetation structure, which can complicate microhabitat distinctions and make more difficult the survey of the target species. Species with particularly cryptic early stages or with low densities may not lend themselves to this mode of survey. The goals of these procedures, however, are shared in conservation studies of most invertebrate species. This method thus is presented as an example of a low-impact, information-rich technique that can integrate population estimates and distributional information. We hope that this presentation will stimulate others to seek low-impact survey methods for the study of endangered species.

Acknowledgments

We gratefully acknowledge generous access to the Morgan Hill site and financial support for this study by Waste Management, Inc. Raymond R. White provided field support. Jack Baughman, Marybeth Buechner, Paul Ehrlich, Kathy Freas, Susan Harrison, and Lynn LeChevalier criticized early drafts of this manuscript. Grants from the National Science Foundation (DEB 82-06091 and BSR 87-00102) have provided continual funding for population studies of the Bay checkerspot butterfly.

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