# STATUS AND TRENDS

# HABITAT RESTORATION AND THE ENDANGERED PALOS VERDES BLUE BUTTERFLY AT THE DEFENSE FUEL SUPPORT POINT, SAN PEDRO, CALIFORNIA

**1994–2001**

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# 1 Introduction
## (Rudi Mattoni)

The conservation significance of the Defense Fuel Support Point (DFSP) at San Pedro California was underscored with discovery of the Palos Verdes blue butterfly (PVB) in 1994 (Anonymous 1994; Cone 1994; Mattoni 1994). This federally listed endangered butterfly had been believed extinct since 1983 when the last then known populations disappeared (Mattoni 1993).

Immediate funding to secure the species was provided by the Chevron Corporation in order to 1) determine the distribution and abundance of the butterfly population across the site and 2) institute a captive rearing program to assure its survival given the low apparent population density. Both efforts have continued to the present time

Later in 1994 a plan to mitigate pipeline repair was implemented. The plan involved enhancing the native plant community (revegetation) over 4 ha of the site. Other studies commenced to define biological values of the site as well as the surrounding Palos Verdes peninsula. Historic documentation of the biota across the peninsula, although incomplete, was begun to provide a baseline for restoration of the site. Restoration in the form of at least a partial revegetation of what we believed was the historic native plant community began in 1994.

Additionally, periodic observations and experiments were undertaken to provide guidelines for understanding the revegetation effort. Because of funding constraints both field manipulation experiments and monitoring were limited, with only basic work underway. Nevertheless data were gathered showing that invertebrate community structure is a function of the successional status in degraded and revegetated plant habitats at DFSP. These were cornerstone observations for a Ph.D. thesis. A large volunteer program was instituted from the beginning of work and several educational events depended on the site.

Efforts over the past seven years are summarized in this report. The three central topics covered include: 1) PVB population census, including a few other species found during time period of study, 2) PVB captive rearing, and 3) site revegetation. Adjunct studies are presented which include data for invertebrate community monitoring by various trapping procedures, PVB behavior studies, and experimental releases of PVB. The results and lessons to be learned from all these approaches are discussed. A general program for the future is set forth.

# 2 Census results for Palos Verdes blue butterfly and associated species, 1994–2001 (Rudi Mattoni and Travis Longcore)

## 2.1 Introduction

The program to determine the distribution and abundance of the PVB was initiated immediately following its discovery at DFSP in 1994. A transect was laid out at that time which included the obvious larger stands of foodplant across the site. This standard transect was subsequently added to several times in following years to include segments where butterflies were later found. The transect has provided regular annual counts for 8 years, producing significant data of general ecological interest. The butterfly's two foodplants, deerweed (*Lotus scoparius*) and milkvetch (*Astragalus trichopodus lonchus*) were sporadically monitored over the time period. All other readily identifiable flying insects were also noted. The standard transect as of 2001 is given as Figure 2-1, which is a copy of the actual field data sheet using during surveys. Figure 6-2 is a map of DFSP showing all polygons delineated. Note that polygon numbers and transect segments are not congruent.

We present here data from 1994 through the 2001 season and include an estimate of the adult population using a standardized algorithm developed for this purpose. Data for the other insects are summarized. Information is given on correlated habitat characteristics in a later section.

## 2.2 Methods

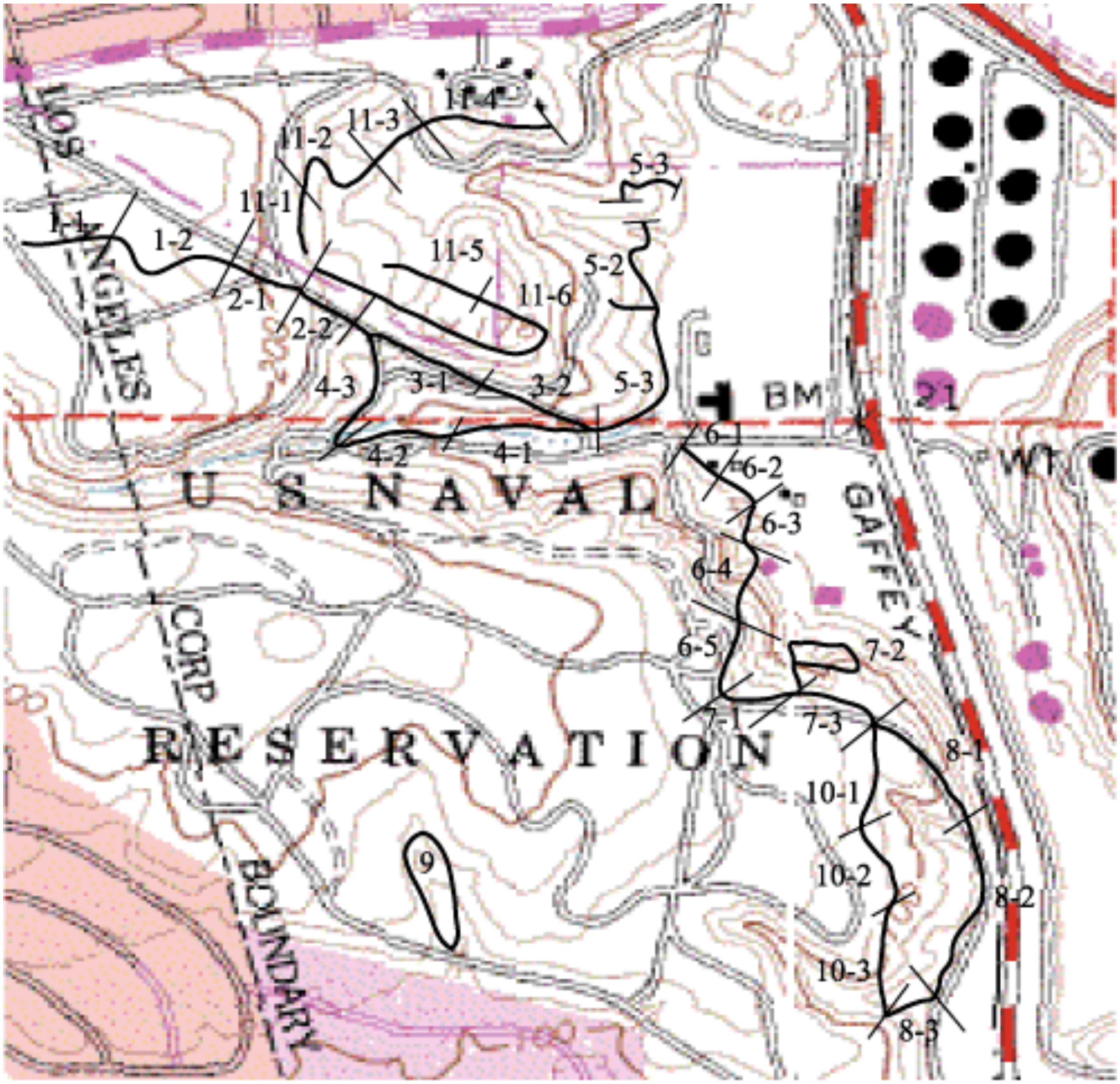
We counted butterflies on Pollard transect walks throughout the flight period (Zonneveld 1991). For purposes of population estimation, regular walks along a standard transect have been shown to be superior to other survey methods that do not involve handling butterfly individuals (Royer et al. 1998). Mark-release-recapture methods of population estimation were dismissed outright because of the damage done to small butterflies by marking and handling (Singer & Wedlake 1981; Morton 1982; Morton 1984; Murphy 1988). All identifiable insects were enumerated during the walk. Walks were initiated at the first sighting of PVB in the spring.

The transect is ~3.2 km long (Figure 2-1), which is divided into segments based on habitat characteristics. The transect remains the same as instituted in 1994, with two new segments, 5A and 9, added in 1996, and Segment 10 added in 1997. The transect includes all areas where the PVB was observed initially, where it could reasonably be expected, or along corridors between habitat patches. In 1999, the survey was further expanded to include part of the Navy housing area adjacent to DFSP where PVB were seen for the first time. The 2000 surveys included even more of this area, with additional transect distance covered and duplicate counts made for most days. In addition, captive-bred butterflies were released in 2000 within part of Segment 1. All individuals observed along this segment were assumed releases.

An estimation of total population size ($N_t$) can be made using the formula

$$N_t = \sum_{i=1}^{n} \frac{x_i d_i}{LSR}$$

**Figure 2-1. Location of insect transects at DFSP.**



where $N_t$ is total population size, $n$ is number days of observations, $x_i$ is the number of individuals on the $i$th day of observation, $d_i$ is the number of days from the $i$th survey to the $i$th + 1 survey, $L$ is the average lifespan of each individual (4 days), $R$ is the average sex ratio observed (70%), and $S$ is the assumed search efficiency (40%). The search efficiency was originally intuitively approximated, therefore, the population estimates are more properly construed as a population index. Because the butterflies in Segment 1 were released and of a known quantity during 2000, we were able to adjust our model assumptions. While we had previously assumed a search efficiency of 20%, this was shown to be too low. A search efficiency of 40% provided a better estimate of the number of butterflies in Segment 1 (64), compared to the number released (65). While this method of analysis lacks certain advantages of other more mathematically complex techniques (Zonneveld 1991), we have shown that population estimates correlate highly with both the Zonneveld model and the Pollard index (Mattoni and others 2001).

The estimation is designed to yield approximations in an understandable format, given the high visibility of the butterfly and the need to communicate its status with the public quickly and clearly. The method of population size estimation is a substantial modification (Mattoni and others 2001) of that of Watt et al. (1977) wherein total butterflies observed daily were divided by longevity as derived through mark-release-recapture.

## 2.3 Results

### *2.3.1 Transect counts 1994–2001*

Daily transect totals for 1994–2001 are given by date in Table 2-1. Complete transect data are provided in digital format with this report. PVB released in one experiment each in 2000 (Segment 1B) and 2001 (Segment 9) are not included in the tabulation. Data do include sightings of all common butterflies (PVB, funereal skipper, common hairstreak, green hairstreak, marina blue, and the Diego beefly, tabulated by segment and date for each year.

**Table 2-1. Total daily PVB observations by year, except released individuals.**

| Date | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|
| February | | | | | | | | |
| 22 | | | | | | | | |
| 23 | | | | 13 | | | | |
| 24 | | | | | | 5 | | |
| 25 | | | | | | | | |
| 26 | | | | | | | | |
| 27 | | | | | | 10 | | |
| 28 | | 8 | | | 2 | | | |
| March 1 | | | 1 | 3 | | | | |
| 2 | | | | | | | | |
| 3 | | | | | 2 | 14 | | |
| 4 | | 16 | | | | | | |
| 5 | | | | | 4 | | | |
| 6 | | 17 | | | | | | |
| 7 | | | 9 | 9 | 6 | | | |
| 8 | | 29 | | | | | | |
| 9 | | | 15 | | 22 | | | |
| 10 | | | | | | 14 | | |
| 11 | | | 28 | | 23 | | | |
| 12 | 4 | 13 | | | | 11 | | 2 |
| 13 | | | 11 | | | | 7 | |
| 14 | | 10 | | 10 | | 4 | | 2 |
| 15 | | | | | | | | |
| 16 | 11 | 16 | | | | | 13 | |
| 17 | | | | | | 5 | | 7 |
| 18 | 7 | | | 7 | | | | |
| 19 | | 2 | 25 | | 19 | 14 | | 13 |
| 20 | | | | | | | 15 | |
| 21 | 14 | | | | 22 | | | 11 |
| 22 | | 2 | | 0 | | | | |
| 23 | 12 | | 13 | | | | 25 | |
| 24 | | 4 | | | 14 | 12 | | |
| 25 | | | | 7 | | | | 4 |
| 26 | | 2 | 30 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 27 | | | | 6 | | 11 | 10 | |
| 28 | 9 | 0 | | | | | 8 | 13 |
| 29 | | | 16 | | | | | |
| 30 | 6 | | | | | | 10 | 7 |
| 31 | | | | | | | | |
| April 1 | 3 | 0 | 17 | | | | | |
| 2 | | | | 0 | 9 | | | |
| 3 | 3 | | | | | | 7 | 9 |
| 4 | | | 24 | | | | | |
| 5 | 2 | | | | | | | |
| 6 | | | 6 | | | | 3 | 5 |
| 7 | | | | 2 | | | | |
| 8 | 1 | | | | 5 | | | |
| 9 | | | 5 | | | | | |
| 10 | | | | 0 | | 0 | 6 | 2 |
| 11 | 0 | | 4 | | | | | |
| 12 | | | | | | | 4 | 3 |
| 13 | | | | | | | 2 | |
| 14 | | | 5 | | | 0 | | 0 |
| 15 | | | | | | | | |
| 16 | | | 2 | | 0 | | | |
| 17 | | | | | | 0 | | 2 |
| 18 | | | | | | | 0 | |
| 19 | | | 3 | | | | | 2 |
| 20 | | | | | | 5 | | |
| 21 | | | | | | | | |
| 22 | | | 2 | | | | | 0 |
| 23 | | | | | | 0 | | |
| 24 | | | | | | | | 3 |
| 25 | | | | | | | 1 | |
| 26 | | | | | | 9 | | |
| 27 | | | | | | | 0 | 1 |
| 28 | | | | | | | | |
| 28 | | | | | | | | |
| 29 | 0 | | | | | | | |
| 30 | | | 2 | | | 0 | | 0 |
| May 1 | | | | | | | | |
| 2 | | | 3 | | | | | 0 |
| 3 | | | | | | | | |
| 4 | | | | | | 1 | | |
| 5 | | | 1 | | | | | |

### 2.3.2 *Flight period characteristics*

The date of first observation ranged from February through mid-March, with the flight season ending from late March to early May (Table 2-2, Figure 2-2). The flight period ranged from 30 to 77 days, but this phenomenon can largely be explained as a statistical artifact. Higher population sizes results in a longer observed flight period because the larger population increases the probability of seeing early and late specimens (Wolda 1988). This is shown by the significant linear regression of flight period on the estimated population ($F_{1,8}$= 14.47, p<0.008, $r^2$=0.7).

**Table 2-2. Adult PVB survey results, 1994–1999, including housing area.**

| Year | First Day | Last Day | Flight Period (days) | Daily Maximum | Estimated Population |
|---|---|---|---|---|---|
| 1994 | March 12 | April 8 | 30 | 14 | 161 |
| 1995 | February 28 | March 26 | 27 | 29 | 245 |
| 1996 | March 1 | May 5 | 67 | 30 | 574 |
| 1997 | February 23 | April 7 | 50 | 12 | 253 |
| 1998 | February 28 | April 8 | 50 | 23 | 462 |
| 1999 | February 24 | May 4 | 77 | 14 | 485 |
| 2000 | March 13 | April 26 | 45 | 25 | 308 |
| 2001 | March 12 | April 27 | 46 | 13 | 323 |

### *2.3.3 Estimated population size*

The total estimated population has not increased significantly since 1994, even including released individuals (Table 2-2, Figure 2-3). Actually, the number observed in 2001 may be the lowest since 1994 given that 1994 counts did not begin at the start of the flight period and that many of those counted in 2000 and 2001 are from experimental releases.

Of the total of roughly 323 butterflies estimated for 2001, 63% were found in populations surveyed on DFSP since 1994. Another 110 PVB (34% of the 2001 population) were estimated in areas where captive-reared individuals were released. The final 3% of the population was found along transects in the Navy housing area. In 1999, 11% of the PVB population was documented in this area, while in 2000, 20% of adult PVB were in the housing area. In 2001 the population in the housing area diminished significantly with only 3 sightings over 13 sampling days compared with 17 sightings over 12 sampling days in 2000.

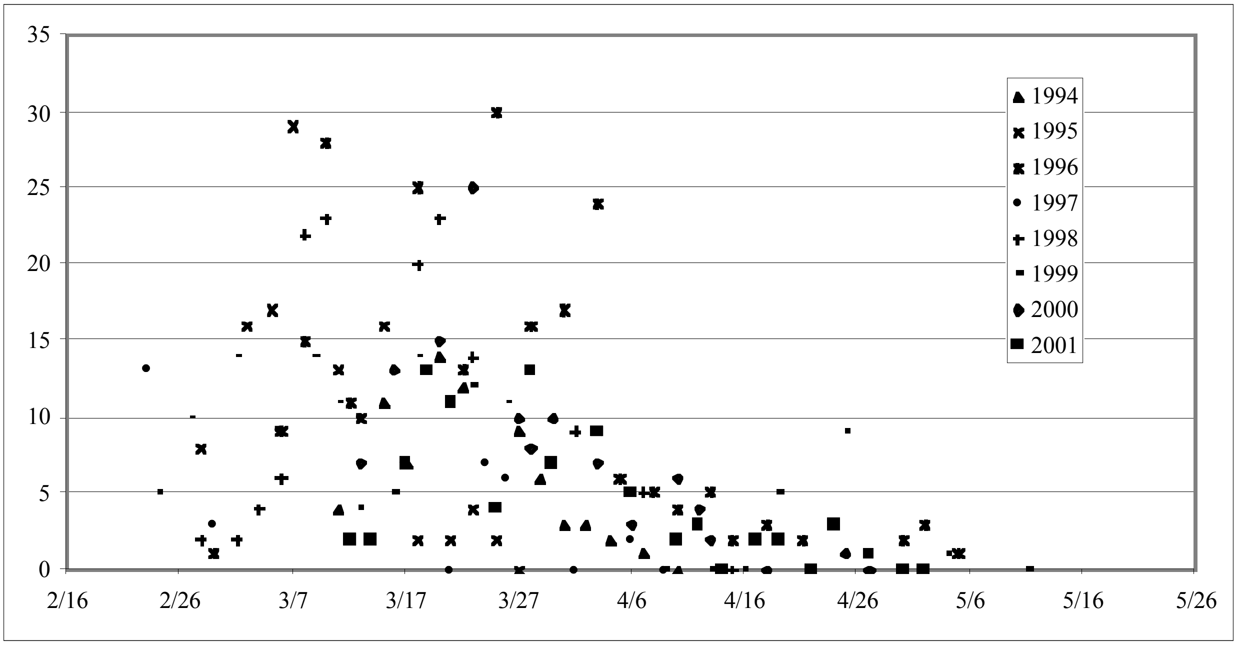


**Figure 2-2. Total daily adult PVB observed on DFSP transect and housing base in 1994–2001.**

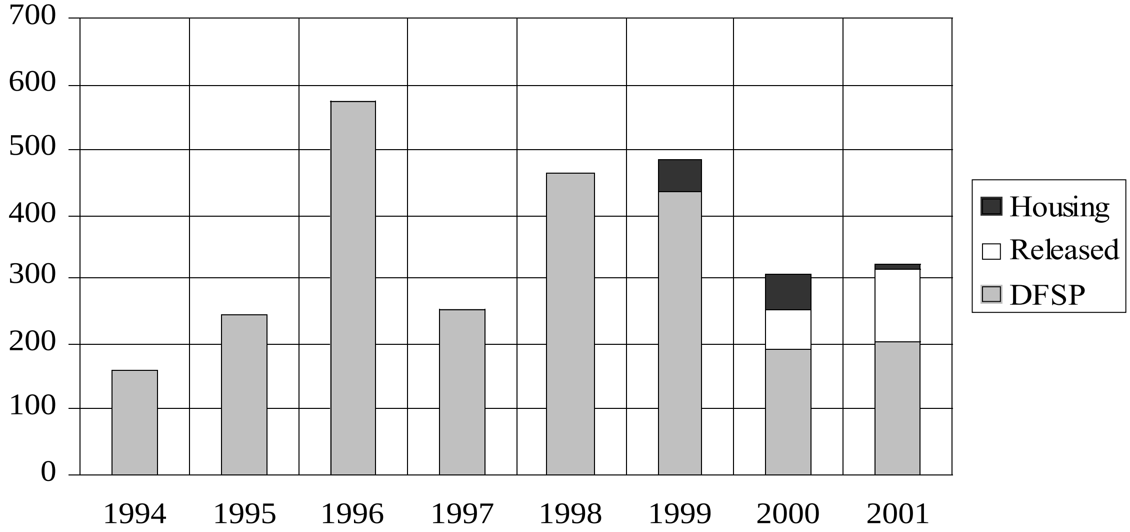


**Figure 2-3. Estimated adult PVB population, 1994–2000, showing relative proportion at DFSP, adjacent housing, and released from captive-bred stock.**

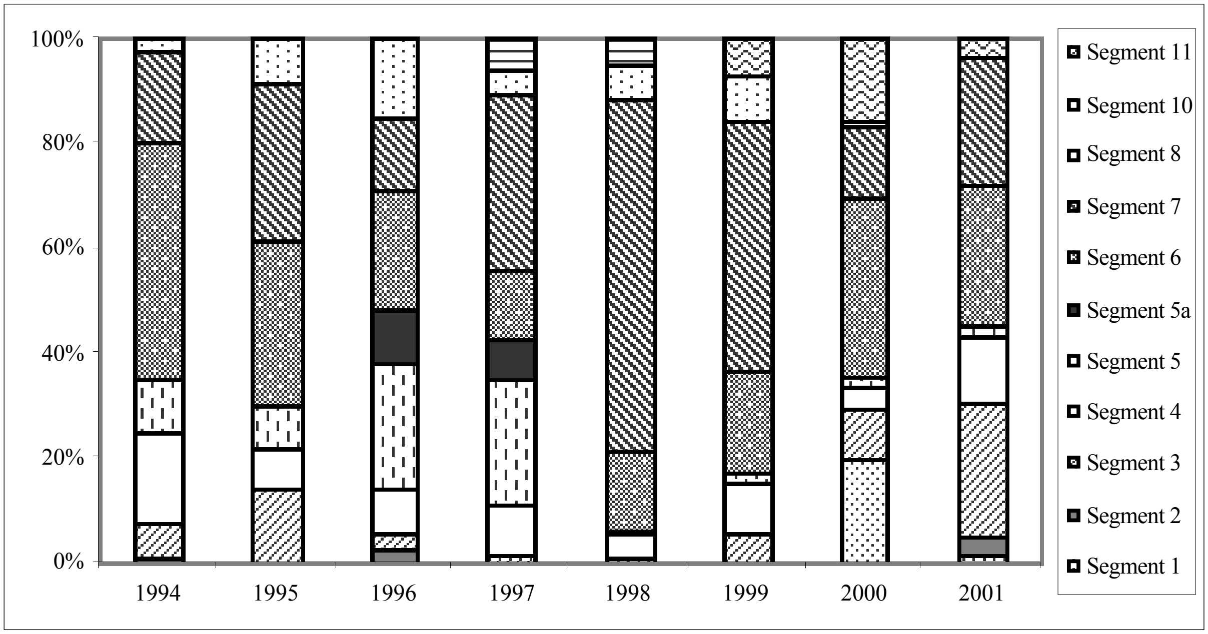


**Figure 2-4. Percentages of PVB observed per transect, 1994–2001, based on raw count data. Segment 1 represents captive-bred individuals, and Segment 11 is the Navy housing.**

### *2.3.4 Metapopulation: non-random distribution across the site*

The distribution among the transect segments varies substantially from year to year (Figure 2-4). This is characteristic of a species with a metapopulation structure in which abundance of the species across separate habitat patches varies asynchronously. Segment 7 increased in importance through 1998, then declined in 1999 and 2000. Segment 6, which has been subject to intense revegetation, increased in importance in 2000. Other habitat patches support individuals for a few years, then do not (segments 5a, 10). Within this context, the importance of all occupied habitats to the species becomes evident. From the patterns observed in 1994–2001, it is impossible to predict which area will support the most individuals during the coming years.

Deerweed is the best predictor of PVB presence and abundance in regressions of habitat characteristics along the transect segments (Lipman and others 1999). Deerweed exhibits a short life cycle typical of a disturbance-adapted species in which it senesces after only a few years. The pattern of increasing and decreasing PVB densities among transect segments may track a pattern of maturation and senescence. As such, it is important that connectivity among habitat patches be maintained so that populations are not isolated and that new foodplant patches can colonized. Metapopulation stability can only be obtained if enough habitat patches are linked sufficiently closely for the butterfly to maintain this dynamic of local extinction and colonization (Hanski and others 1996; Hill and others 1996). It will be noted, however, that although PVB cannot exist without its foodplant, there are sites (transect segments 1 and 9) with abundant deerweed but no naturally occurring PVB.

### *2.3.5 Four other butterfly species and one beefly*

Five large flying insects are usually sighted during the flight period with PVB in early spring. The four other butterflies also share deerweed as a foodplant. These are the green hairstreak (*Callophyrs affinis perplexa*), the common hairstreak (*Strymon melinus*), the marina blue (*Leptotes marina*), and the funereal skipper (*Erynnis zarucco funeralis*). The green hairstreak, like the PVB, is univoltine, flying at the same time and with a ground or below ground pupation site. The marina blue and common hairstreak have continuous yearround generations and feed on many other plants. They are urban garden butterflies, meaning highly vagile and able to colonize appropriate foodplants throughout the urban matrix (Mattoni 1990). The skipper feeds solely on deerweed, but unlike PVB has continuous generations. The Diego beefly (*Bombylius diegensis*) is univoltine and flies synchronously with PVB. Its life history is completely different; it is a parasite that in the larval stage feeds on the young of ground dwelling bees (anthophorids and andrenids).

Figure 2-5 gives the numbers of the five sighted on all transect segments from 1994–2001. The most striking finding, not shown in the figure, was the reappearance of the green hairstreak, which we believed to have been extirpated. It was not seen in 1998–2000, but reappeared on two transect segments in 2001 in association with deerweed. The other species were usually associated with deerweed patches, but in a more random pattern than PVB and distributed more widely across the transect.

We correlated the log-transformed total number of each species on each transect segment over all years. All correlations were positive and significant, confirming that all species prefer similar habitat (Table 2-3). This is expected for species depending on the same foodplant. However, slightly lower but still significant correlations with beefly abundance were also found. This provides support for a community-based approach to restoration. Habitat good for native butterflies is also good for at least one native Dipteran.

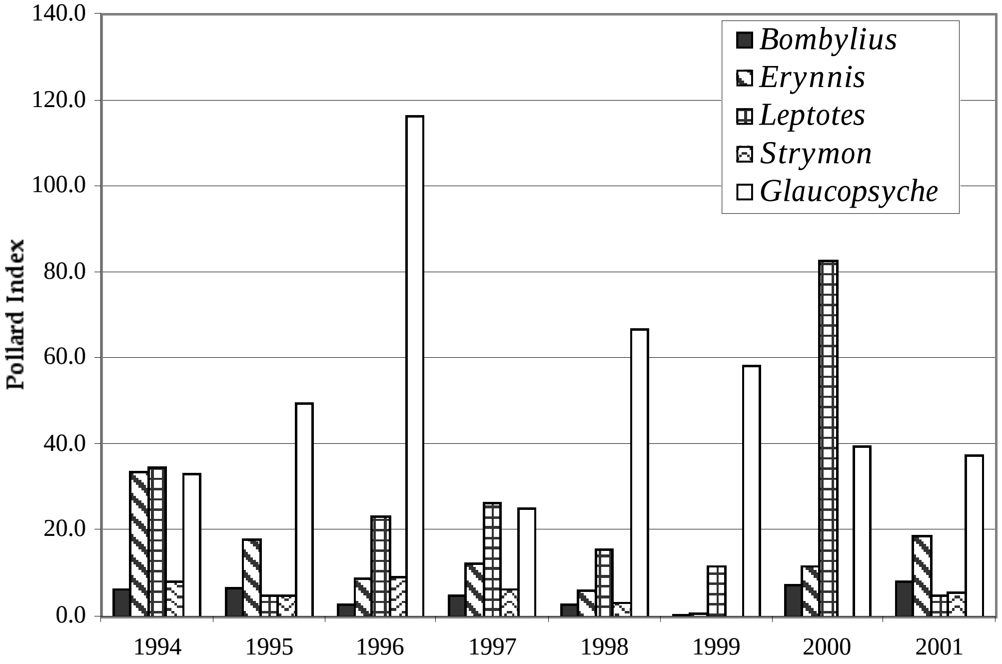


**Figure 2-5. Numbers of four butterfly species and one beefly, DFSP, 1994–2001.**

However, for each year, correlation values between the abundance of PVB, the other butterflies, and the beefly as measured by the Pollard index were largely not significant. We interpret these results to indicate that despite common response to quality habitat (shown by the preference for the same segments), each year, each invertebrate species responds to its own set of environmental parameters. Conditions that favor one species in a certain year do not necessarily favor another. The green hairstreak is not included in this analysis because of its relative rarity (maximum 21 individuals observed in 1994) and periods of absence.

**Table 2-3. Correlation of abundance of four butterfly species and a beefly species by 25 transect segments at DFSP, 1994–2001. Correlations in upper triangle, significance values in lower triangle.**

| | *Bombylius* | *Erynnis* | *Leptotes* | *Strymon* | *Glaucopsyche* |
|---|---|---|---|---|---|
| *Bombylius* | – | 0.3642 | 0.6465 | 0.4895 | 0.5618 |
| *Erynnis* | 0.07 | – | 0.7256 | 0.7292 | 0.6779 |
| *Leptotes* | <0.01 | <0.01 | – | 0.7822 | 0.6950 |
| *Strymon* | 0.01 | <0.01 | <0.01 | – | 0.5503 |
| *Glaucopsyche* | <0.01 | <0.01 | <0.01 | <0.01 | – |

For general reference on the background of the butterfly community at DFSP, Table 2-4 lists all butterflies species that likely historically occurred across the peninsula.

## Table 2-4. Butterflies and skippers of Palos Verdes peninsula, including DFSP.

| | | Migrants | |
|---|---|---|---|
| **Taxon** | **Resident** | **Regular** | **Rare** |
| *Papilio zelicaon* | x[1] | | |
| *Papilio rutulus* | x | | |
| *Papilio cresphontes* | | x | |
| *Battus philenor philenor* | | | x D |
| *Pieris rapae* | x | | |
| *Pieris protodice* | x | | |
| *Pieris beckeri* | | | x[2] D |
| *Anthocharis sara sara* | x[1] | | |
| *Colias eurytheme* | x | | |
| *Colias hardfordii* | | x[2] | |
| *Phoebis sennae marcellina* | | x | |
| *Eurema nicippe* | | x | |
| *Nathalis iole* | | | x D |
| *Coenonympha tullia california* | x[2] (ext.) | | |
| *Danaus gilippus strigosus* | | x | |
| *Danaus plexippus* | x | | |
| *Agraulis vanillae incarnata* | x | | |
| *Chlosyne gabbii gabbii* | x[2] (ext.) | | |
| *Vanessa atalanta rubria* | | x | |
| *Vanessa cardui* | x | | |
| *Vanessa anabella* | x[1] | | |
| *Vanessa virginiensis* | x | | |
| *Nymphalis antiopa* | x | | |
| *Precis coenia* | x1 | | |
| *Limenitis lorquinii* | x (ext.) | | |
| *Apodemia mormo nr.nr.virgulti ?* | x (ext.) | | |
| *Calephelis nemesis* | x | | |
| *Strymon melinus* | x | | |
| *Callophrys augustus iroides ?* | x (ext.) | | |
| *Callophrys perplexa* | x | | |
| *Lycaena helloides* | x (ext.) | | |
| *Brephidium exilis* | x | | |
| *Leptotes marina* | x | | |
| *Everes amyntula* | x D | | |
| *Hemiargus ceraunus gyas* | | | x |
| *Plebejus acmon acmon* | x | | |
| *Glaucopsyche lygdamus palosverdesensis* | x | | |
| *Euphilotes battoides bernardino* (not *allyni)* | x | | |
| *Euphilotes battoides allyni* | x U | | |
| *Polites sabuleti sabuleti* | x | | |
| *Ochlodes sylvanoides sylvanoides* | x U | | |
| *Hylephila phyleus* | x | | |
| *Panoquina errans* | x | | |
| *Paratrytone melane* | x | | |
| *Lerodea eufala* | x | | |
| *Atalopetes campestris* | x | | |
| *Pyrgus albescens* | x[1?] | | |
| *Heliopetes ericetorum* | | | x D |
| *Erynnis zarucco funeralis* | x | | |

[1] Foodplants of these species are present, but not native.

[2] Native foodplants of these species are present.

Ext., extirpated; D, species not yet recorded from DSFP, but probably was or is present, U probably never present at DFSP

## 3 Description of habitat characteristics of the Palos Verdes blue butterfly (Rudi Mattoni, Travis Longcore, and Alison Lipman)

### 3.1 Introduction

Defining the habitat necessary to support PVB requires a consideration of scale. At the micro-scale, the butterfly requires foodplants, but the natural distribution of *Astragalus* and *Lotus* is patchy within the coastal sage scrub community. Both species exploit disturbance to establish, and *Astragalus* can, but does not necessarily, persist in more mature scrub. The foodplants — *Astragalus* especially — can be found in gaps within the coastal sage mosaic so small that they are unnoticeable unless careful surveys are conducted.

The butterfly may need some critical number of foodplants and nectar sources to maintain a population, but this can be a small number if located in appropriate physical conditions in a confined area. For example, the southern blue has persisted for over ten years on about 20 deerweed in 0.4 ha at Manhattan Beach. Similar persistence is found at the Ballona dune remnant at Playa del Rey.

### 3.2 Historical habitat (south slope)

Limited data are available about the habitat characteristics of the south slope localities of the Palos Verdes peninsula. The information is based on recollections because no quantitative surveys were conducted before the PVB was extirpated. Several localities have been lost to construction or highly degraded through disking for fire control.

In 1983, the Hesse Park population was persisting on highly degraded grassland with thin soil on a shale substrate. There were a few coastal sagebrush (*Artemisia californica*) and *Astragalus* left after repeated disking, yet these conditions sustained a population for at least several years. San Pedro Hill exhibited similar conditions, with a few *Astragalus*, mostly within regularly disked grassland.

Habitat conditions at Palos Verdes Drive East and Friendship Park are similar today as when they supported the butterfly, with substantial patches of native scrub and *Astragalus* remaining, but not the butterfly.

The degraded nature of the localities where the butterfly was known to persist illustrates the dynamic nature of the habitat of the species. It is predictable that the areas where *Astragalus* — the sole south slope foodplant — was found are areas that are classified as “degraded.” *Astragalus* exploits early successional habitat and in the modern landscape those areas have been provided by human disturbance. Historically, *Astragalus* likely followed natural disturbances such as fire, landslides, and animal digging and burrowing. While some foodplant patches may have remained stable for long periods, perhaps persisting in areas where competition is limited by poor or rocky soils, the foodplant and the butterfly likely shifted their distribution in the landscape over time.

This history of disturbance-associated distribution makes interpreting the current habitat and prospects for management difficult, because the introduction of Mediterranean grasses has shifted the dynamics of post-disturbance succession. There is now severe competition in disturbances from exotic grasses. In addition, the historic natural disturbance regimes have been replaced by much more frequent anthropogenic disturbances, combined with fragmentation of the habitat mosaic.

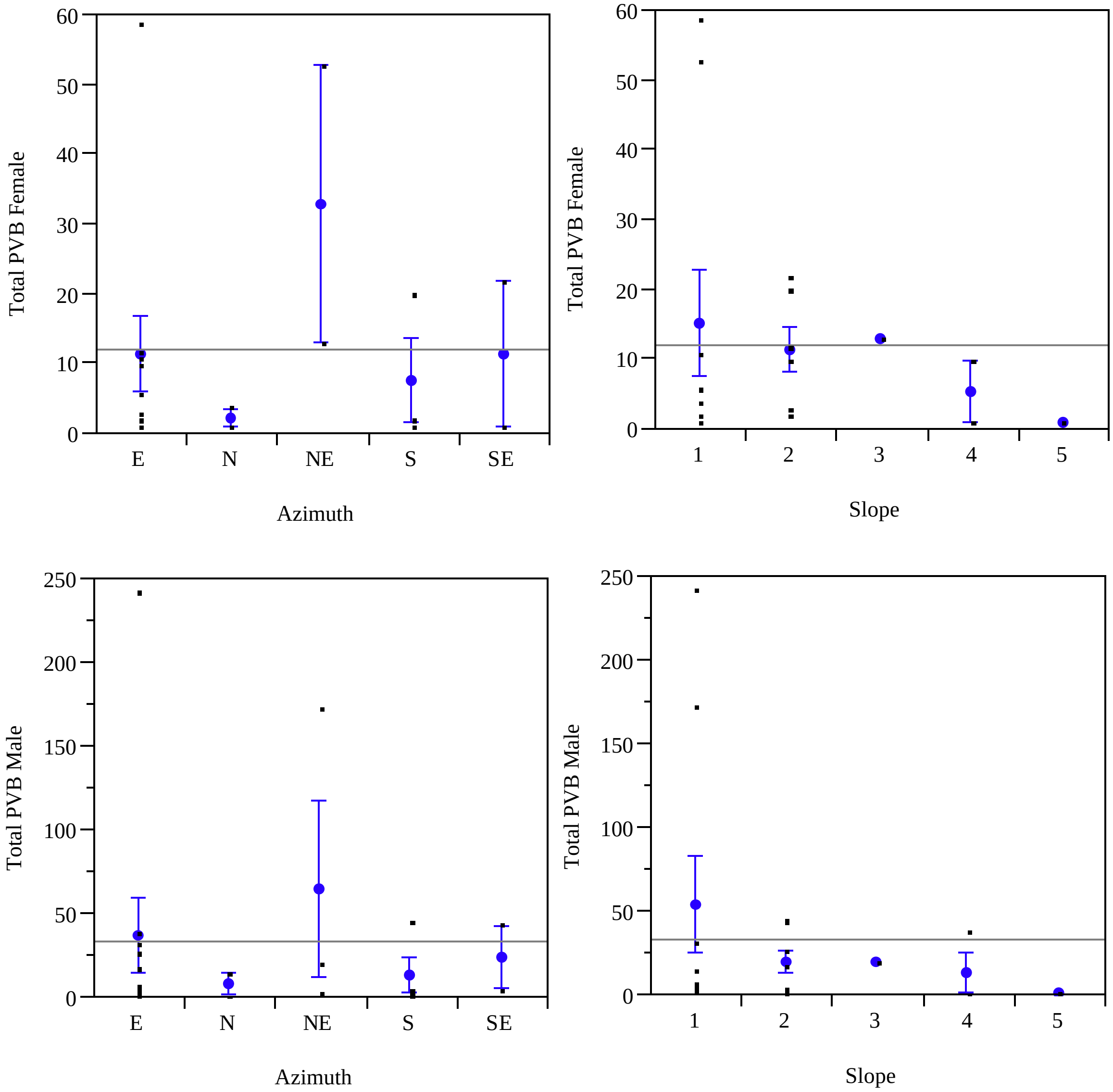


**Figure 3-1. Number of Palos Verdes blue butterflies observed relative to slope and azimuth by sex, 1994–2001.**

## 3.3 Current habitat (north slope)

To quantify the relationship between habitat parameters and PVB incidence, a study of the population monitoring transect at DFSP was completed. The transect was walked and both vegetation and topographic variables recorded, including: percent native shrub cover, number and species of native shrubs, soil history (cut, fill, native, terrace), aspect, and slope. These parameters were then used to describe conditions at occupied sites and to develop a multiple regression model to explain the number of butterflies observed along each transect sub-segment.

The model shows that the best predictors of PVB abundance at DFSP are *Lotus scoparius*, *Astragalus trichopodus*, slope, and azimuth. This model explains 50% of the variation in adult abundance (adjusted $r^2=0.495$, $p<0.0003$). Most PVB were found at intermediate slopes facing north through east (Figure 3-1) with higher numbers of *Lotus* and *Astragalus*. The large concentration of individuals along one transect segment prohibits a better fit of the model. The importance of slope and azimuth in explaining PVB abundance is consistent with the role of weather and climate in population regulation. Adult PVB seem to respond to specific topoclimatic variables, and given the yearly spatial variation discussed above, it seems that different sites provide optimal conditions in different years.

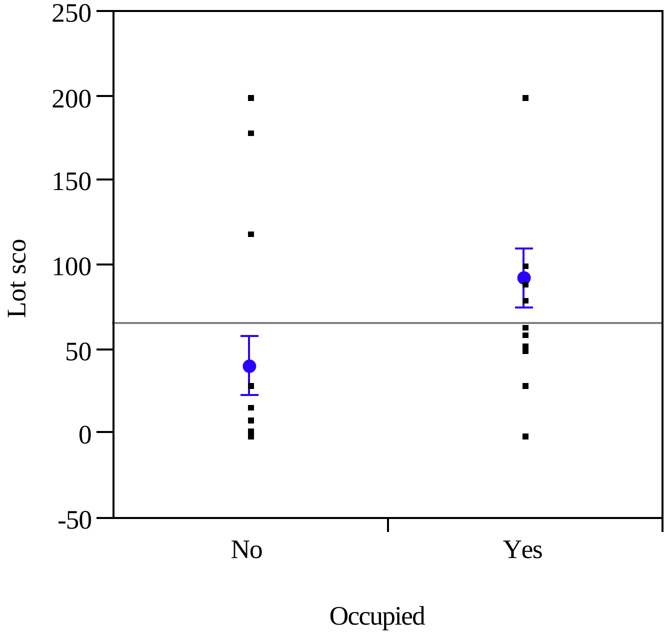


**Figure 3-2. Number of *Lotus scoparius* in transect segments occupied and unoccupied by PVB.**

Occupied transect segments have significantly (ANOVA; $p<0.01$) more *Lotus scoparius* individuals (92.9 ± 17.6 S.E.) than unoccupied segments (29.6 ± 17.6 S.E.). However not all segments with large numbers of *Lotus* support PVB (Figure 3-2). Similarly, occupied sites have more *Astragalus* individuals on average (1.92 vs 0.69; N.S.), but not all sites with *Astragalus* are occupied.

Shrub cover of occupied transects ranged 20–85%, with maximum PVB abundance on a segment with 20% shrub cover. Sites with lower and higher native shrub cover were not occupied.

Extrapolation of these results is complicated by a number of factors. First, the spatial pattern of adult abundance changes each year (Figure 2-4), different years with different vegetation and climatic conditions may show another pattern. Second, the vigor and percent cover of exotic grasses and forbs varies from year to year and remains an unexplored variable in explaining PVB habitat use. Third, these data may be unique to the northern slope of the peninsula and to areas with *Lotus* and *Astragalus* co-occurring. Nevertheless, the habitat relationship does provide specific information to guide attempts at re-creating PVB habitat elsewhere.

Other factors, as specialized predators and diseases, may be effective depending on relative isolation of suitable foodplant patches. Overall then, connectivity can be viewed as an optimum condition. Present data to not discriminate among these problems, but manipulative field experiments may provide insights.

## 3.4 Palos Verdes blue butterfly adult flight behavior

The flight and habitat usage patterns of adult PVB had not been documented prior to our report in 1999 (Lipman 1999), portions of which are reprinted here.

Quantification of PVB flight direction and distance is important to predict the possible recolonization of appropriate habitat and to determine the appropriate spatial distribution of foodplant for the purpose of habitat creation and enhancement. During the 1999 flight season, a pilot study was undertaken to quantify adult behavior during morning and afternoon periods and to test the null hypothesis that adult flight direction and duration is random. The study also addressed two behavioral questions: 1) what proportion of adult butterfly activity time is spent nectaring, basking, ovipositing, and flying, and 2) do adults recognize habitat?

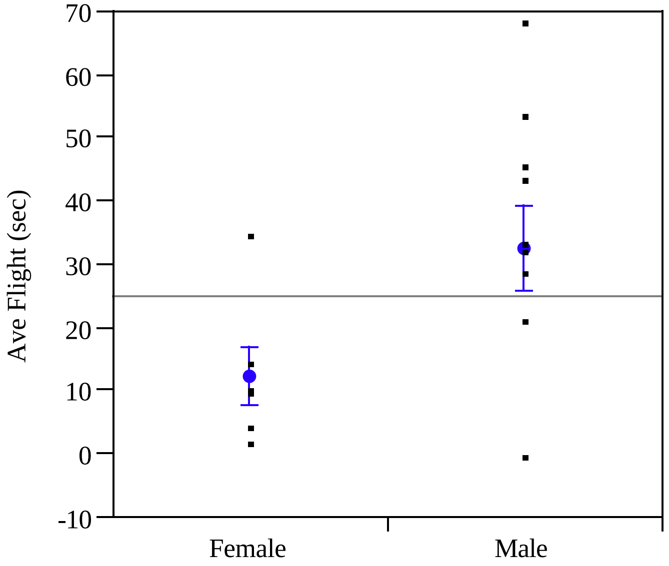


**Figure 3-3. Differences in average flight time in seconds between male and female PVB.**

In a small habitat patch (73 m X 18 m), two teams followed individual butterflies while recording, timing, and mapping all activities. Each butterfly was followed until it was lost from sight. The observations were conducted on three days during the week of March 12, 1999 in the morning and afternoon under varying weather conditions. Data were collected for 11 males and 7 females.

Females spent more time basking on cloudy (mean = 90.9 s) than sunny days (mean = 32.6 s), consistent with the need for more thermoregulation under cooler conditions. Males on average basked 49.2 s on sunny days, but no males were observed under cloudy conditions. The amount of time spent at rest — not basking with wings open — increased later in the day. Males spent a greater proportion of the time observed in flight than females, with a significantly longer average flight time (ANOVA, $p<0.05$; Figure 3-3). The longer flight time was also associated with flights that covered more distance.

Direction of flights by males and females was not random. Females were not observed leaving the food patch. Males occasionally left the patch to the north or south, in the direction of other food sources. When leaving to the east side of the patch, one male twice left the east edge of the patch and then reentered at another point. The eastern fence and the northern meadow were the most frequent directions of departure for males, but crossing these boundaries was often followed by return. Females repeatedly flew briefly and then return to the same plant, often ovipositing. These results suggest that butterflies recognize their home patch and return to it in the landscape. Such patch recognition and "homing" behavior has been shown in other Lycaenid species with relocation experiments (Keller and others 1966).

The observations of male and female flight behavior confirm that the species has a low probability of recolonizing unoccupied, distant habitats without human intervention. Under historic conditions, where the foodplant was distributed patchily in a coastal sage scrub mosaic, the greater wandering of males would increase genetic flow among populations. It is therefore likely that the concentrations of adults found at DFSP are all part of one panmictic population.

Oviposition was only observed on *Lotus scoparius*. Subjective observation suggested that females showed no preference for specific sizes or ages of deerweed.

In addition to the common behaviors observed, an instance of predation by a yellowjacket (*Vespula pensylvanica*) was recorded. A yellowjacket attacked a male PVB that was resting on a blade of grass. The PVB was knocked into a deerweed. After regaining balance, it was hit by the yellowjacket a second time. The PVB was then lost from view, but later another observer noticed a yellowjacket leaving the deerweed with a flash of white underneath, possibly the butterfly. Predation by yellowjackets had heretofore not been observed, but may be significant, given their common, and possibly increasing, occurrence at DFSP.

The observations from this pilot behavioral study are useful and suggestive. The data set was augmented by more comprehensive sampling during the 2000 and 2001 flight seasons. The more recent information supports the initial work. However, the findings represent behavior only in relation to one isolated habitat patch with *Lotus scoparius*; probable behavior in *Astragalus*-only habitat will have to be deduced. The results are similar to those reported for a rare Oregon butterfly in relation to its foodplant. The latter showed that Fender's blue butterflies (*Icaricia icarioides fenderi*) stayed within 10 m of their *Lupinus* foodplant 95% of the time (Schultz 1998). Schultz concluded that while the species could disperse between habitat patches historically less than 0.5 km apart, it was unlikely to disperse the average 3 km between patches in the current fragmented landscape. Our evidence implies that the PVB does not usually leave recognizable habitat.

## 4 Palos Verdes blue butterfly captive rearing: insurance against extinction (Rudi Mattoni and Jeremiah George)

The following section is modified from our annual report on captive rearing submitted July 3, 2001 at the conclusion of the program for the year.

The second year of low estimated population size for the Palos Verdes blue butterfly (2000, $N_t$=308; 2001, $N_t$=323) should be of concern. The numbers are even lower when the released individuals are removed from these totals, indicating total population sizes of both years below 200. Given that genetically effective population sizes, $N_e$, are substantially less, the population is clearly declining.

Although a population may now be established at the Chandler Preserve and the newly discovered population at Malaga dunes, the situation bears close monitoring. The importance of increasing captive propagation becomes urgent, as we now have a greater lab stock population than appears to exist in nature.

### 4.1 Background

The captive breeding program for the Palos Verdes Blue butterfly was instituted for four purposes: 1) to provide insurance against stochastic loss of the sole and diminished population of this species, 2) to increase size of the population at DFSP, 3) to use bred specimens for field manipulative experiments to gain insight about adaptive values in unoccupied sites, and 4) to produce sufficient numbers of individuals to attempt reintroduction of the species onto revegetated sites from which it had been extirpated. A permit from the U.S. Fish and Wildlife Service (USFWS) allows females to be removed from the field and used for egg production. Other permits were issued to allow release of captive reared individuals at DFSP in addition to revegetated areas of the Chandler Preserve.

During 2001, a second colony of PVB was discovered at the Malaga dunes by Brad Richards. The colony is quite small, likely far fewer than 100 individuals. Persistence of the colony is remarkable and its future viability uncertain. The site has degraded over the past decade with expansion of several aggressive exotic plant species. This colony should be subject to rescue efforts in the near future.

### 4.2 Prior results

Captive propagation was initiated immediately following discovery of the PVB in 1995. Between 1995 and 1998 the efforts had mixed and generally poor results. Failure of consistent production was initially the result of primitive facilities without flexible environmental controls, use of poorly designed oviposition cages, and handling neonate larvae such that high larval mortality resulted. With improved facilities and new materials and methods the situation improved. In 1999, 627 were pupae produced. This was largely the result of increased labor availability coupled with a full-time knowledgeable and observant staff biologist, Mike Vergeer.

In 2000, yet greater numbers were achieved with a yield of 968 pupae. The higher production was the presumed result of the new approach in cage design — deployment of a tent cage enclosing large foodplants in the field. Mass rearing of limitless numbers of PVB seemed within grasp.

Unfortunately success of the tent cage was illusory. Nine cages were set in the field in 2001, but only 299 pupae were recovered. We had predicted a minimum of 2,000 pupae. The difference between the actual and expected was the unforeseen consequence of apparent predation by the common European earwig, *Forficula auricularia*. Although general cage management was consistent with the success of 2000, the decreased success of 2001 resulted from the details that we discuss below.

Mass rearing of insects is subject to density independent catastrophic loss from disease and predation (parasitization) under the best of circumstances. The key factor is recognizing the non-linear complexity of biological systems with attendant issues related to high-density monocultures. The necessity of experienced management to exercise vigilance and be able to immediately identify problems and to respond appropriately cannot be overestimated. Another problem is the one-year life cycle of the PVB, which imposes a long time delay for implementing experimentation. Nevertheless, absent late season predation our results would compare favorably with other recorded efforts to rear lycaenids (Herms and others 1996).

## 4.3 Methods, materials, and results

### *4.3.1 Collection of captured wild females*

Because the PVB natural population was extremely low, no wild females were taken for oviposition. All propagation employed existing stock.

It will be recalled that the four females confined in 2000 produced only 28 eggs which yielded only 12 pupae. We had been reluctant to confine females in 2000 because only 27 females were observed that year with a total population size estimate of about 416. Given the poor yield and apparent low populations again this year, we made the decision that the benefit relative to the risk was not justified. As the PVB adult season progressed in 2001, it was quickly apparent the population would again be low. Removal could not be justified because a large captive population was available for further propagation. It seems that the captive population is larger than the wild population at DFSP.

### *4.3.2 Mating and oviposition*

Following eclosion of our captive stock in 2001, a total 595 PVB were used for propagation from a total population of 750 pupae that eclosed. The total number of mated adults, cage yield, and earwig observations are given in Table 4-1. Variables included: 1) the foodplant species enclosed by the cage, either deerweed (*Lotus scoparius)* and/or rattlepod (*Astragalus trichopodus)* and 2) cage bottom, which was either bare ground or covered with nursery ground cloth. There were no pupation media used. The number of pupae recovered is given with numbers of parental adults, and observations of oviposition and larva signs. Finally the number of European earwigs (*Forficula auricularia*) estimated within the cage confines is given. The latter had a major impact on pupal yield.

We now accept the tent cage as the preferred approach for mass rearing. However, as will be discussed below, tent cages have a serious problem with at least one predator at, or just prior to, pupation.

Tent cages are fabricated from PVC pipe frames about 1 X 1 X 1.2 m covered with plastic screen and set over large foodplants in the field. In all cases the adult mating pairs, or sets of multiple breeders, were left in the cages until their deaths. As adult butterflies died, new specimens were added. Dead specimens were not retrieved, and actually many were not seen because following death the butterflies become a resource for ants and other foragers and are quickly consumed.

**Table 4-1. Pupa recovery from the nine tent cages used for captive propagation of the Palos Verdes blue butterfly at DFSP, 2001. Number of breeding adults placed in cage, foodplant species enclosed, cage bottom, estimated egg and larval density, pupae recovered, and numbers of earwigs (*Forficula auricularia*) noted at time of recovery.**

| Cage | No. Adults | Food Plant | Ground Cover | Eggs Observed | Larvae, N & notes | Pupae | *Forficula* |
|---|---|---|---|---|---|---|---|
| 1 | 77 | L | GC | 3/17–4/20<br>>>100 | >>100 noted | 6, base of FP | >100 |
| 2 | 71 | L | CG | 3/17–4/20<br>~100 | ~100 | 5, base of FP | >100 |
| 3 | 61 | A | B | 3/17–3/25<br>poor | Few late instars *Aphis* defoliated | 12, base, w 12 in *Astragalus* pods | >100 |
| 4 | 62 | L | GC | 3/17–4/5<br>few | Few early & late instars | none | >>100 highest |
| 5 | 80 | L | B | 3/20–4/10<br>>>100 | Many, 40 late instars 4/15 | 24 | ~100 |
| 6 | 62 | L | B | 4/1–4/17<br>>300 | Many of all instars | 108 | 6 |
| 7 | 81 | L | B | 3/21–4/15<br>>100 | Many larvae, all instars | 68 | >25 |
| 8 | 66 | A | B | 3/21–4/1<br>few | None seen, *Aphis* defoliated fast | 5, w 2 in *Astragalus* pods | >50 |
| 9 | 80 | L | GC | 3/21–4/12<br>>>100 | Few noted after 4/15 | 71 | >25 |

*25 were variously lost during handling
Foodplant: L = Lotus scoparius, A = Astragalus trichopodus
Ground Cover: B = bare, GC = ground cloth

The large number of adult PVB used in the mating was a consequence of our having no other use for the specimens. Consequently adults were placed into cages as soon as they eclosed. Eclosion took place in the lab and not from pupae set out. This insured that we would not loose the fraction that did not eclose.

With these numbers we theoretically could have had upwards of 30,000 eggs (100 eggs per female with approximately 300 females). The egg population, if hatched, would have overwhelmed the foodplant. This did not happen. Observations (Table 4-1) provided sightings of many hundred eggs within the cages. Recalling the large and complex biomass within each cage, we likely saw less than 5% of the eggs actually deposited. Extrapolating the number to the best cage, many thousands of eggs were laid.

We also observed no egg parasitization by *Trichogramma*. A sample of over 100 eggs was collected by JG and no wasps emerged.

Cage number 8 contained a large rattlepod that was killed by heavy aphid infestation within two weeks of cage placement. Prior to its demise, about April 5, few eggs and no larvae were seen. In this case the dense aphid colonies seemed to discourage females from ovipositon. The aphid problem is serious, but can be solved by periodically opening the cages to predators (coccinellid beetles, true bugs) and parasitoids.

Induction of mating in the captive population is now routine. Although we had a limited success inducing mating in our earlier work, we are now confident large-scale propagation is not limited by mating failure. The key conditions are bright light (sunlight preferred) with good ventilation. Cage size is irrelevant for pair mating with multiple mating in large cages commonplace given correct environmental conditions.

### *4.3.3 Larval growth*

Rearing larvae from egg up to and possibly thorough pupation can now be accomplished for mass propagation in tent cages. One key factor is an optimal number of females so larval production does not outstrip food supply. The second key factor is prevention of foodplant consumption by aphids. To keep aphids under control the cages will be periodically opened to permit access by predators and parasitoids. To date parasitization and epizootic episodes have not been a problem with any PVB larval stage in the cages, or at least these regulators have not yet appeared.

During the 2002 season the use of defined synthetic diets will be used to rear last instar larvae. These may be removed from the tent cages for pupation in the individual creamers under laboratory conditions. Although the technique is labor intensive, the approach assures production of disease free animals without the risk of predation by earwigs.

### *4.3.4 Pupation*

The successful use of the tent cages completely depends on providing safe pupation sites. As mentioned above, we obtained >>10,000 eggs, and observed larval concentrations that were certainly >>1000, yet only recovered 299 pupae. The result contrasts with last year, when we recovered over 700 pupae from one tent cage. The 2000 result can be ascribed to removal of last instar larvae from the foodplant that was nearly defoliated. In addition, dried rattlepod pods that were scattered on the cage floor served as pupation sites for over 100 larvae.

During recovery of pupae this year we immediately noticed dense populations of the non-native European earwig. Table 4-1 shows a striking correlation with earwig density and pupa recovery. Losses were highest in cages with ground cloth floors. The finding is consistent with the preference of dark, damp spaces by the earwigs. The bare floor cages (and dry areas elsewhere at DFSP) gave lower counts.

Significantly, there were no parasitized pupae (or larvae) recovered from the tent populations, indicating that both hymenopterous and tachinid parasites were excluded by the screening. Note, however, that screening also served to limit entry of predator/parasitoids that regulate aphids, which can rapidly defoliate and kill the host plants.

### *4.3.5 Diapause and storage*

As of May 30, 2001, we had 237 viable pupae from the 2001 season, now reduced to 210. Cause of the loss is not known, although known power outages in the laboratory building could be a contributing factor. Periodic warming during refrigeration failure would result in miscues and early emergence of adults.

It is necessary to maintain humidity in the range of 50–70 % to avoid desiccation while under refrigeration. We provide the condition by maintaining stock over lava gravel that is periodically watered.

## 4.4 Conclusions and future activity

### *4.4.1 Genetic considerations*

At this time, genetic implications of maintaining a captive population are not as important as the role of the program to provide stock to buffer against stochastic demographic and environmental loss. If there is no gene pool left (extinction) adaptive processes are irretrievable. Also, possible genetic bottlenecks may well not be related to adaptive values, as Lewontin (1974) demonstrated long ago with *Drosophila* experiments. The Chandler release could provide insights to this matter if the population were to be assayed in the future. At present our focus must be on the declining population paradigm.

The actual captive propagation program is managed by a mass random mating system, with minimum of five pairs in each cage. These parents are taken at random from stock available. Given that the original genetic base was five wild females, it is unlikely that loss of any alleles will occur. As the propagation effort goes forward new stock should be introduced into the system. However, given the extremely low numbers in the wild population over the past two years, further removal is not prudent.

### *4.4.2 Ecosystem lessons from captive propagation*

The impact of European earwigs (*Forficula auricularia*) on our cage populations may be significant to understanding the low, and possibly declining, numbers in the natural population of PVB at DFSP. The earwig is one of the most abundant ground dwelling species on the site, which we previously determined from pitfall trapping studies. Distribution of the earwig is highly non-random, however, with highest population densities associated with disturbed sites and irrigated newly revegetated sites.

The differential distribution of the PVB in part may be a function of these predators, and provide insight to the question of why PVB has been absent on, and failed to recolonize, Polygon 1. Such theoretical questions are of general ecological interest and to the practical matter of augmenting the PVB metapopulation of DFSP. Invasive exotic insects are far more cryptic than many exotic plants, but doubtless exhibit profound influences on natural community structure.

Regina Skrobarczyk and Jeremiah George conducted a pilot monitoring of flying arthropods using yellow pan traps as part of a UCLA research course project. Traps were set out across three habitat types on Polygons 1B (successional stage of disturbed site with high deerweed), Polygon 7G (highest quality undisturbed climax coastal sage scrub), and Polygon 14A (just revegetated first phase coastal sage scrub) (see Figure 6-1 for polygon nomenclature). The results of this study include relative density data for the European earwig. Table 4-2 gives numbers found in the three polygons.

**Table 4-2. *Forficula auricularia* densities in yellow pan traps and collection periods among the three polygons in 2001.**

| | April 4–11 | April 11–18 | April 18–25 | April 25–May 2 | May 2–9 | May 9–16 | Total |
|---|---|---|---|---|---|---|---|
| 1 | 7 | 11 | 10 | 11 | 53 | 28 | 120 |
| 7 | 4 | 5 | 6 | 4 | 18 | 5 | 42 |
| 14 | 8 | 7 | 5 | 8 | 15 | 9 | 52 |

# 5 Release of captive reared Palos Verdes blue butterfly: manipulative field experiments (Rudi Mattoni, Michael Vergeer, Jeremiah George, and Yvonne Marlin)

## 5.1 Introduction and/or reintroduction of butterflies

A number of attempts have been made to introduce or reintroduce butterflies into natural sites. Most have taken place in Europe. The earliest attempt was with the large copper in England. The species became extinct in 1848. Larvae of a related subspecies were introduced to a former swampy habitat in 1909, but failed because the site was unsuitable. In 1913 and 1914, 400 adults were released in a more suitable habitat. These reproduced and flourished for decades. Other attempts were made using both adults and young larvae of a more closely related subspecies at other sites during the 1920s. These likewise have maintained viable populations for decades, but only with a high cost of habitat maintenance (Ford 1957). They finally failed and now depend on captive propagation to assure persistence of the colony (Webb and Pullin 1996).

Several other studies concerned with releasing butterflies into natural sites employed various approaches: Williams et al. (1984) used egg masses of *Euphydryas gillettii*, Dethier and MacArthur (1964) placed *Phyciodes harrisii* larvae in field, while Ford (1957) cites an unsuccessful attempt with adult white admirals, while the heath fritillary (*Mallicta athalia*) and the map butterfly (*Araschnia levana*) adult introductions were successful.

More recently Finnish lepidopterists relocated 10 adult Schiffermuller's blue butterflies to a restored site where they have persisted for a few years (Marttila and others 1997). Attempts to reintroduce two *Maculinea* species (the sister genus to *Glaucopsyche*) into The Netherlands met with mixed success (Wynhoff 1998; Wynhoff and others 2000). The large blue, *Maculinea arion*, has been reintroduced to restored former habitat in southern England with initial apparent success (Thomas 1989). A review of 323 reintroduction attempts in Britain found that 42% never resulted in a permanent population, and the ultimate result of another 32% was unknown (Oates and Warren 1990).

Except for the work in England, there have been no long term (greater than ten year) studies of introduced or reintroduced butterfly populations. Our initial work with PVB, although centered on increasing probability of population viability, attempted to provide ecological information on factors regulating the introduced populations.

## 5.2 Release of PVB at DFSP Polygon 1B

Although the PVB requires foodplant for survival, presence of foodplant alone is not sufficient. Since 1994 deerweed cover across part of Polygon 1 has been robust. The ~2 ha area supports several hundred healthy plants. However, PVB has never been observed at the site. In an effort to increase population size, pupae were set out in 2000 from reared stock. The procedure permitted testing the hypothesis that the butterfly did not occupy the site because of its sedentary behavior.

The availability of pupae also provided a means to test other hypotheses regarding: 1) a key assumption in our population size ($N_t$) estimate formula, 2) vagility, and 3) duration of diapause.

Release of PVB into the habitat was implemented by setting out pupae just prior to eclosion. When diapausing pupae are held at about 4º C in a refrigerator for at least four months, diapause is broken for a high proportion (~75%) of individuals with their subsequent development to adults. The eclosion of the pupae removed is synchronized within a few days. For PVB we had earlier determined that eclosion follows about three to four weeks after removal to ambient (laboratory) temperatures. Physical characteristics of the pupae include darkening with the developed wing patterns showing beneath the integument. Once darkened, eclosion is within 1–3 days. Thus we would be able to set pupae in the field at the last moment without their being subjected to predation. There would also be no possibility of imprinting of laboratory conditions.

**Table 5-1. PVB sighting at Polygon 1, DFSP, 2000. Number of PVB males (m) and females (f) seen on days sampled, Transect X, and standard transect Segment 1-2, all other transect segments, and housing area. Number of pupae and dates set out for site 1. Parentheses in standard transect column gives numbers and segment sighted.**

| Date | Transect X | Transect Segment 1-2 (S) | Other transect segments | Housing Area |
|---|---|---|---|---|
| 3/9 | 17 pupae set out | 0 | 0 | 0 |
| 3/10 | NS | 0 | 0 | 0 |
| 3/13 | 87 pupae set out | NS | NS | NS |
| 3/14 | NS | 0 | 6m (all 6) | 1m |
| 3/17 | 9m 2f<br>56 pupae eclosed | 5 m 1f | 3m 1f (all 6) | 1m 1f (f s-1) |
| 3/20 | 4m 1f | NS | NS | NS |
| 3/21 | NS | 4m 1f | 6m 3f (1-3, 1-4 7-6) | 1m |
| 3/22 | 6m 4f | NS | NS | NS |
| 3/24 | 2m 1f | 6m 2f | 12m 2f (1-4, 12-6, 1-9 | 3m |
| 3/27 | 1f | NS | NS | NS |
| 3/28 | NS | 0 | 4m 3f (1-3, 1-4, 5-6) | NS |
| 3/29 | 1m<br>9 pupae eclosed | NS | NS | NS |
| 3/31 | 0<br>38 pupae removed<br>65 PVB eclosed | 0 | 5m 4f (2-3,7-6) | 1m 1f |
| 4/3 | 0 | NS | NS | NS |
| 4/4 | NS | 0 | 3m 3f (2-3,1-5, 3-6) | NS |
| 4/5 | 0 | NS | NS | NS |
| 4/7 | 0 | 0 | 1m 1f (1-4, 1-6) | 1m |
| 4/10 | 0 | NS | NS | NS |
| 4/11 | NS | 0 | 3f (2-3, 1-5) | 2m 1f |
| 4/12 | 0 | 0 | NS | NS |
| >4/12 | 0 | 0 | 1m 1f (1-3, 1-6) | 1m |

### *5.2.1 Methods and materials*

Pupae were set into the field for eclosion after being placed inside a 7 cm diameter by 15 cm tall circle of wire screen set in sand contained in a fluted 4 oz. Lilly plastic cup. The screen cylinder provides a substrate for newly hatched adults to climb up and position themselves in a manner whereby their embryonic wings properly expand and set. The cups were set together at the base of a large coyote bush (*Baccharis pilularis*) at the center of the site in an area surrounded by dense deerweed. Seventeen pupae were set out in two containers on March 9, an additional 87 pupae were placed in four containers and set out March 13 for a total of 104 pupae. For monitoring purposes a special transect was set up (designated Transect X) consisting of 4 segments at right angles each extending about 35 m from the release point (Figure 5-1). The transect configuration included most of the high density deerweed community of the site, except for some small plants found to the north and west as indicated on the map (Figure 5-1). Note that the standard transect Segment 1-1 covered the majority of this deerweed aggregate.

Following placement of pupae, Transect X was sampled every three days through the flight period, starting March 17. Additional, but independent data were collected during the standard transect walk (Segment 1-2), usually run twice weekly, for long term monitoring of PVB at DFSP. The standard transect survey was completed by Rick Rogers. Yvonne Marlin conducted the Transect X survey.

### *5.2.2 Results*

The results are summarized in Table 5-1. Of 104 pupae set out, 65 eclosed with 38 pupae recovered for eclosion next season. On March 17, 56 pupae had eclosed, the last 9 eclosed by March 29. One pupa was partially consumed. Remains consisted of an apparent intact case with a ~2 mm hole and all contents except some wing parts removed. A minimum of 4 newly hatched adults were consumed at Chandler, with *Uta* lizard and bird dropping noted nearby with PVB wing shards. Although predation appears minimal, there is an impact, with any predation effect lowering our population estimates. Note that predation during the eclosion process, when the butterflies are most vulnerable, would be undetected: e.g. missing pupae, or pupa cases, could have been predated yet be undifferentiated from those successfully eclosed for our estimates.

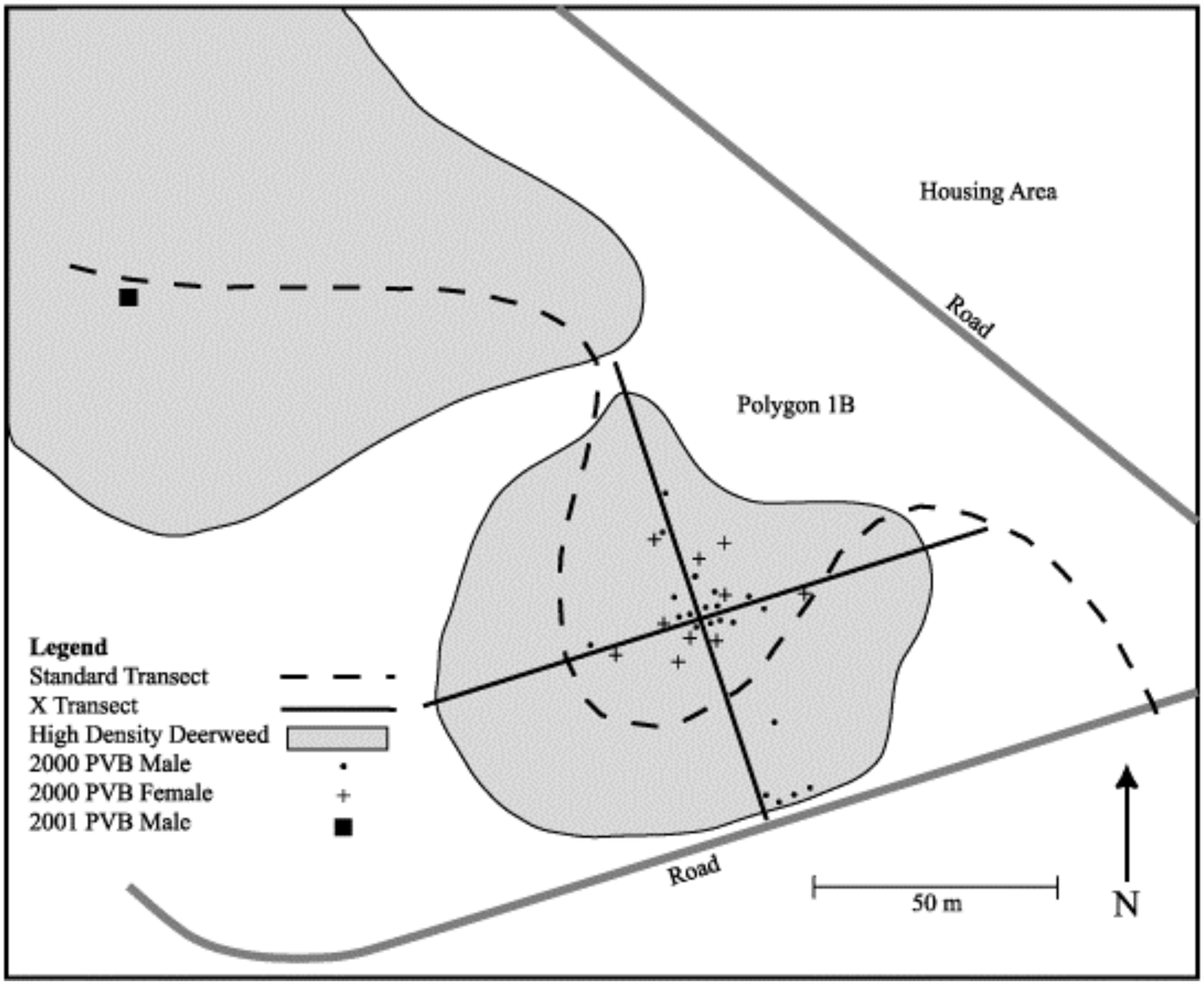
An inspection of site 1 on March 14 indicated no adults flying, an observation supported by no sightings along Segment 1 of the standard transect on the same day, although six PVB were seen on Segment 6. However, on March 16, 15 PVB were counted in the vicinity of the release point, including two copulating pairs. The following day Transect X counts were started and Transect S was run independently. The numbers of PVB sighted are given in Table 5-1, which also summarizes counts at other segments of the ST and the housing area, while Figure 5-1 shows the distribution of sightings along the X transect.

The highest count, 11 PVB, was March 17 at Polygon 1B by which date 56 pupae had eclosed of a total of 65 that would eclose for the season. The last PVB was a male sighted on March 29, after which time no further eclosion occurred. There is no record of eclosion rates between March 17 and 29.

On March 14 through March 22 several mating pairs of PVB were observed. On these and following dates many oviposition events were noted. Intense PVB activity was noted until the last individuals were seen, with butterflies always within bounds of the foodplant cover. The sighting of four individuals along the road margin (Figure 5-1) implies recognition of extrinsic barriers the butterflies appear reluctant to traverse. Nonetheless, observing an emigration event would likely be improbable given the rapidity of such an event and loss of the individual. Flight is sufficiently rapid that given motivation, a PVB could depart at the rate of 30–60 m per minute. Without an intrusive mark-release-recapture program, such movement is impossible to determine quantitatively. Such MRR techniques are not advisable because of the damage done to small butterflies by it.

In 2001 there was no reason to make counts along Transect X because no individuals were seen in early standard transects. The standard transect (S) revealed only a single male, which was sighted on Segment 1-1.

**Figure 5-1. Map of Polygon 1B showing location of sighted PVB on experimental Transect X with the standard transect position also given.**



### *5.2.3 Discussion*

Observations from other segments during the 2000 survey indicated no PVB on adjacent Segment 2, and only 5 PVB in segments 3 and 4, within 200 m of Polygon 1B. The most probable dispersant from the released individuals was a single female sighted at the northwesternmost section of the housing site, less than 100 m from the site 1 deerweed boundary. The observation was on March 17, which coincided with the maximum PVB count at site 1. The female was ovipositing on small deerweed plants.

The pattern of sightings suggests that the introduced population remained remarkably sedentary during 2000 (Table 5-1). Observations along both transects X and S between March 17 and March 24 detected about 60% (using male numbers, assuming equal sex ratio) of the eclosed adults. The result indicates that most of the 65 individuals that eclosed remained within the confines of the deerweed colony. Although some sightings were doubtless of the same individuals, the 31 seen on Transect X and the 19 on Transect S indicate substantial tendency to remain confined to a small area.

The failure to see any PVB along transect Segment 1-1 during 2000 is also relevant, because deerweed distribution is nearly continuous from the release site (Segment 1-2) with a bottleneck to the northwest (Figure 5-1). Although the pattern of distribution along Transect X shows concentration near the actual release point, the Transect S observations were mostly outside the limits of Transect X. The release point clustering suggests strong birthplace fidelity.

Sex ratio is skewed with a bias identical to all prior data, namely 0.29 and 0.25 females from transects X and S respectively. This compares with 0.33 for the remainder of Transect S and 0.30 for the sum of adults since 1994. We previously determined the sex ratio of laboratory pupae used to provide our captive rearing stock at 0.46 (N=76), not significantly different from 0.50.

Longevity cannot be determined directly from these data because eclosion occurred over as many as 20 days. From the few counts of unhatched pupae, we know that 0.85 (56/66) adults emerged between March 14 and March 17, a similar pattern for synchronized diapausing pupae in the laboratory. Based on counts given in Table 5-1, average longevity would appear to be ~4–5 days, which is the value we used in prior calculations of our model.

The failure to detect PVB along Segment 1-2 in 2001 indicates that the site does not constitute suitable habitat in spite of the robust deerweed foodplant presence. The result rejects the hypothesis that PVB did not survive the introduction attempt, barring the possibility that offspring pupae all maintained diapause for future eclosion due to climatic conditions. The latter possibility will be validated after the next season.

The results imply that the success of releases based on robust foodplant presence is highly uncertain and that we do not understand the ecological factors regulating population persistence — the key factor of habitat suitability.

## 5.3 Release of PVB at DFSP Polygon 14 (Segment 9)

Polygon 14 provides another site to test for PVB habitat suitability. The polygon is a shallow barranca running north-south with a southerly orientation (see transect map, Figure 2-1 and site map, Figure 6-2). There is a patch of about 100 large deerweed plants along the bottom with another patch of over 100 small to mid-sized plants on the west facing slope nearby. The site is isolated from known occupied area by at least 600 m. Survey for PVB was started in 1996, identified as transect Segment 9. Although random inspections in 1994 and 1995 showed PVB not present, intuitively high quality habitat appearance suggested that, if not occupied, the area would serve as a trap for dispersing PVB.

PVB males were detected on the site only in subsequent years: one in 1998, two in 1999, and one in 2000. This result demonstrates that males at least have the capability of dispersing from suitable habitat, here for a distance of 600 m. However, no colony exists at the site. This result is clearly different from Polygon 1 which is much closer (~120 m) from suitable habitat and PVB had never been detected.

The site had little native plant cover except for the deerweed patches. There was also no evidence of disturbance by earthmoving activities. The predominant cover consisted of non-native grasses, mustards, radish, and chrysanthemum. These were cleared in late 2000 and a planting of about 6,000 coastal sage scrub species were set out. No deerweed were added, but about 200 rattlepod (*Astragalus*) were planted.

Because of the large number of PVB pupae available with no discernable use other than further captive propagation, the decision was made to release adults when a significant number were available within a few days. In this manner, another test of habitat suitability was possible. The reason to use adults rather than pupae was to provide further evidence of longevity in the field since we were able to determine age exactly.

### *5.3.1 Methods and materials*

We released a total of 110 adult PVB, 65 males and 45 females, as follows: 56 males and 32 females on April 12 and 13, and another nine males and 13 females on April 17. These were from eclosed stock from the laboratory collected as they hatched into small containers and kept in the dark for no more than 48 hours prior to being released.

The releases were made at the southernmost deerweed plant in the barranca. On subsequent days counts were made across the 25 m long belt transect, 10 m wide, that encompassed the entire stand of deerweed. The deerweed covered about 80%. The release was in Segment 1 of the belt transect. Counts per segment are given by day in Table 5-2. As a check on the counts, another individual (Rick Rogers) performed independent counts along the standard transect over the same time period. The standard transect runs along the same route as the experiment transect. Counts were continued until no insects were sighted.

### *5.3.2 Results*

We found the butterflies quite sedentary, with two females of the three females remaining in the segment of the transect where they had been released. The males, however, dispersed quickly. Only two males moved outside the large deerweed patch to the adjacent patch. Nevertheless, they exhibited a tendency to remain close to the release site.

This site fidelity is shown in Table 5-2 with 14 PVB remaining in the release segment (~3 X 10 m). Of the 55 PVB sighted, 31 or 0.56 remained in the first three segments. The standard transect counts were not reported with resolution that discriminates the positions with the experiment transect, but significantly the total counts are in close agreement: 49 PVB for six days sampling for the standard transect with 58 total for eight days for the experiment transect.

**Table 5-2. PVB counts on sample days along the belt transect, Polygon 14, with comparison counts on the standard transect. Adult releases: 56 males, 32 females on April 12–13, 2001; 9 males, 13 females April 17, 2001. Counts given by sampling day and per transect segment. Upper refers to the nearby deerweed patch.**

| | Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Segment | 4/13 | 4/14 | 4/16 | 4/17 | 4/19 | 4/20 | 4/22 | 4/24 | 4/25 | 4/27 | TOTAL |
| 1 | 3m | - | 3m | 1m1f | ns | 3m | 1m1f | ns | 1m | 0 | 12m 2f |
| 2 | 2m | - | - | - | | 1m | 1m | | 1m | 0 | 5m |
| 3 | - | - | 4m | 5m | | 1m | 2m | | - | 0 | 12m |
| 4 | - | 1m | 1m | 1m | | 1m | - | | 2m | 0 | 6m |
| 5 | - | - | - | 1f | | 2m | - | | 1m | 0 | 3m 1f |
| 6 | 1m | 3m | - | 2m | | - | 1m | | 1m | 0 | 8m |
| 7 | - | 1m | - | 1m | | - | - | | - | 0 | 2m |
| 8 | - | 1m | - | 1m | | - | -1m | | - | 0 | 3m |
| 9 | 1m | - | 1m | - | | - | - | | - | 0 | 2m |
| Upper | - | 1m | 1m | - | | - | - | | - | 0 | 2m |
| Total | 7m | 7m | 10m | 11m<br>2f | ns | 8m | 6m<br>1f | ns | 6m | 0 | 55m<br>3f |
| **Standard** | ns | 14m<br>1f | ns | 14m | 10m3f | ns | 4m<br>3f | 0 | ns | 0 | 42m<br>7f |

ns=not sampled

### 5.3.3 *Discussion*

We hypothesized that the extant foodplant could support a population of several hundred, with the release constituting a test of the null hypothesis that colonization will not occur — that the site is a sink. Although mating pairs and oviposition were observed, as in Polygon 1B last year, results cannot be determined before the next flight season.

It is noteworthy that the late release (mid-April) was past 90% of the flight season. Even though a large egg/larva population was established, the stress of late season plants may preclude PVB establishment. If that is the case, the experiment should be repeated in later years when pupae are available, more foodplant is established, and a robust coastal sage scrub matrix is in place.

The *Astragalus* plants set out apart from the deerweed were examined for eggs and larvae without success. Both these early stages are simple to detect on *Astragalus* because they are usually found on or in the seedpods. The same stages are cryptic on deerweed.

## 6 Revegetation: can the historic community be re-created?
(Rudi Mattoni)

### 6.1 The historic community: species aggregates

An accurate plant species list is essential to provide a qualitative baseline for revegetation that mimics the original flora. We operate under the additional presumption that the DFSP biota will serve as a source and refuge for many rare or extirpated species of the entire Palos Verdes peninsula. The site is large relative to other reserve or potential reserve sites and will likely continue under management that would assure maintenance of these species.

The historic plant community of the peninsula has not been definitively described. To do so will require reviewing extensive herbarium records and selected documents. However, even this effort will likely leave questions of overlooked species. The first, and sole published survey to date, was the work of Gales (1988). More recently Brinkmann-Busi observed, collected, and recorded flowering plants across the peninsula, providing the most thorough information set available. Lipman added quantitative information on distributions of 392 plant species from a survey of 142 open space fragments that make up most of the remaining “natural” habitats (Lipman and others 1999). This work was implemented with the goal of defining suitable habitat for the PVB (Lipman and others 1999).

A number of surveys for CEQA purposes were conducted, but added little to the above studies. However, plant species new to the region are being found as personnel from the PVB project conduct special tasks and visit various sites. This year George made three records of previously unrecorded species, the most spectacular of which was the dunes sand-food, *Pholisma paniculata*, which he found on the Malaga dunes.

A list of all known and extirpated plants of the peninsula is given as Appendix 3, based on the work of Brinkmann-Busi over a 15-year period. Species from DFSP are indicated, including likely extirpated species based on their occurrence in similar habitats nearby. A number of Palos Verdes species persist only as few individuals (e.g., *Crossosoma californica*, which is known from only two individuals at Forrestal), while a few others are questionable barring further information (e.g., coast live-oak, *Quercus agrifolia* and California walnut, *Juglans californica*). There are also a number of species restricted to specialized habitats which are not present at DFSP such as coastal bluff, dunes, and strand.

Defining the historic plant community at DFSP remains problematic because there are few prior records. Consequently some presumed historic species may not be accurately assigned, but at least they are not unreasonable. Composition of the nearby Los Angeles coastal prairie, completely destroyed several decades ago, was only recently defined from old records by Mattoni and Longcore (1997) and provides an example of the thorough analysis that should be made for the Palos Verdes region prior to restorative implementation.

Our analysis of alpha richness of higher plants at DFSP indicates that there were 85 native species extant when our work started in 1994. These included two ferns, 56 perennials, and 27 annuals. We hypothesize that 72 species were extirpated, 39 perennials and 33 annuals. The extirpations are almost all species that are present or known from the peninsula. In our attempts to revegetate the flora, we have introduced 28 perennials and 33 annuals. Three of the perennials are dominant or co-dominant at other peninsula sites (*Salvia leucophylla, Eriogonum cinerium,* and *Lupinus longifolius*). About 1,000 of each of the latter have been set out and to date have established well.

The hypothesized extinction rate of vascular plants 0.46 (72/85+72) falls within the range predicted by the species area curve (Preston 1948), given that about 90% of the DFSP habitat has been destroyed or degraded.

Difficulty in restoring the historic habitat comes into sharp focus with the impact of invasive non-native or exotic plants. We have identified 82 such species at DFSP, including 18 perennials and 51 annuals. Of this set, the perennials can all be extirpated, with continuing yet decreasing management precluding reestablishment. The annuals for the most part will never be subtracted. Achieving the goal of reestablishment of the native biota will also never be reached. Nevertheless, the goal may be approached, and the process of striving toward it may provide significant insights to applied ecology if the effort is properly directed.

### 6.2 The historic community: structure

Both the historic and present plant communities are not uniform. There are currently three vegetative communities on the site defined by dominant species: the largest is coastal sage scrub, one small (0.5 ha) patch of native bunchgrass (*Stipa* [*Nassela*] *pulchra)*, and a riparian community associated with the George F Canyon drainage. Historically, a marsh intruded onto the low elevation northeast section of the site. The marsh is now reduced in extent to nearby Harbor Park. There were also likely vernal pools on the first marine terrace, but no traces remain. A further complication is the unresolved possibility that some oak woodland, associated with the extant native walnuts, was present.

The small native grassland patch is edaphic, occurring now as Polygon 11A, on thin soil overlay on sandstone terrace substrate. The community may have been widespread across the terrace before it was disturbed for underground tank construction.

The coastal sage community, as defined in our initial studies, was almost entirely dominated by California sagebrush, *Artemisia californica*. The relatively apparent undisturbed sites of the community are restricted to portions of polygons 8, 7, and 13, polygons which had little disturbance from the varied construction activities at DFSP. The most species rich is Polygon 7E, which carries several species found nowhere else. The DFSP situation strongly contrasts to other sites on the peninsula that are mosaics of dominant patches of *Artemisia, Salvia leucophylla, S. mellifera, Rhus integrifolia,* or a mixture of these plus *Eriogonum cinerium, Encelia californica, Baccharis pilularis,* and *Opuntia* (J. Atwood, unpub. data).

The area covered with the "best" coastal sage scrub was less than 8 ha. Although additional area has been revegetated, none has yet approached what can be regarded as a climax community. Fire ecology is another management matter. Fire is a key element in both shaping and maintaining diversity if Mediterranean shrub plant communities (for recent comprehensive review see Keeley and Scott 1995). Because use of fire, even as a controlled burn, is insupportable at DFSP, there is no reason to pursue the topic. However, over the long term, some management practice must be undertaken lest the entire site become a climax with low diversity and extirpation of part of the fauna, certainly including the PVB.

## 6.3 Revegetation efforts and results

### *6.3.1 Operating principles*

Approaching the revegetation objective depends on establishing an approximation of the regional pattern of distribution and abundance of perennial species . The process requires setting out and establishing container plants over at least a two year cycle to maintain some semblance of age-stage cohorts. The use of containers is preferable to the alternatives of seeding because of the deleterious effects of site preparation for seed application. The harm to residual native biota (animals, microbes, bacteria, algae, fungi) from a "scorched earth" site preparation defies the "do no harm" principle of conservation biology.

During the covering phase of growth, careful hand weeding to reduce immediate competition as well as the non-native annual seedbanks, is required. Again, implementation demands insight, experience, and care. At the wrong time and/or with heavy hand the effort will be useless. After the second to third season, some allelopathic effects should appear, reducing non-native annuals. After some, as yet undetermined time span, no further weeding should be done to allow establishment of cryptobiotic crusts (Bowler 2000).

Finally, with establishment of 60–80% cover, hand seeding with annual stock can be started. The operation should be effected prior to seasonal rain (because many species germinate with even slight moisture and then become dormant until significant rain arrives). Of course, because many coastal sage community annuals are adapted to fire cycles for germination, the ultimate outcome of bringing back this annual component is completely unpredictable.

### *6.3.2 Stock and nursery operations*

For all species still found on DFSP, that local source was used for seed. Otherwise the closest sources are used, and the few species not currently found on the peninsula are collected elsewhere. Current seed inventory is labeled to reflect these data. Seed storage is being standardized, but little seed is cleaned.

Nursery operations have been standardize and are very efficient. For most containers we use either 10 cm squares or 6 cm deepots. Potting soil is purchased pre-mixed in quantity to a special formula initially designed by Mike Vergeer. Composition is available on request.

Except for cuttings, stock is from seed mass germinated in standard flats and subsequently transferred to the final growing container. Seedlings and fresh transfers are maintained under shade cloth with timed overhead fine spray. Stock is transferred to the open to harden prior to setting out in the field.

### *6.3.3 Field irrigation*

Prior to most field planting the treated section is first irrigated using gear driven (Hunter) emitters. These are employed in four to five unit sets (number depending on pressure) connected by flexible 1 cm black plastic tubing and set into open pipe stands. The arrays are spaced with about nine emitters covering a 0.4 ha area. The system is temporary, used over a two-year cycle.

Irrigation is initiated just prior to planting. A 24-hour cycle provides the equivalent of about a 5 cm rainfall, wetting the soil to at least planting depth (25 cm). Following each day when plants are set out, the system is at activated for several hours. Irrigation starts in November (depending on plant availability) and activated as needed following planting (e.g., when plants reach the wilt stage). Irrigation is rainfall dependent, but in any case is extended until late April and then terminated until the next planting cycle in the second year. With establishment of the second planting the system is removed for use at the next polygon.

Irrigation is thus minimal and not used following the completed planting schedule for any polygon. The system is inexpensive and can be recycled for at least six years. We estimate material costs at about $300 per 0.4 ha in addition to about two man days for fabrication and installation.

### *6.3.4 Planting*

The mechanics of setting container plants out is straightforward. The emphasis of the process is minimal substrate disturbance, although a berm is usually formed around each plant. A major departure from normal practice is use of newspapers for mulch. Several layers, open, are placed on either side of the plant with small tears around the stem to provide overlap. Thus an approximate four square foot area is covered. The hypothetical advantages of the papers are to 1) retain soil moisture, 2) increase the C:N ratio and 3) retard weed growth and competition in the area covered. Only the latter is clearly beneficial by observation. A key factor is use of newsprint that uses vegetable, non-toxic, dye. The papers are held in place by dirt clods from the preparation and they usually biodegrade by the second year. The mulch is inexpensive and easily transported to field sites.

The current planting scheme is for a three-year cycle, setting out container plants in two cohorts during the first and third years. Thus some age variance thus will be introduced into the system.

For seed broadcast, which has been limited and on special small plots (e.g. Polygon 11A, the grassland), the seed is broadcast preferably before or immediately following the first fall rain. Seed is broadcast by individual species (not a mix) by hand. The resultant erratic distribution mimics natural seed rain patterns. Hydroseeding has been suggested, but the approach results in low germination, unknown adverse effects to native arthropod communities, and little control over seed location..

### *6.3.5 Weeding*

Control of non-native plants (weeds), barring their subtraction from the biota altogether, is necessary to reduce competition with the native flora . In general weed plants occur in two categories perennial and annual species. The former, except the bulb *Oxalis*, can be eliminated from the community, although periodic removal efforts are necessary to address residual propagules. Tree species, including two palms, two peppers, several eucalypts, and acacia are invasive, but can be simply removed by cutting and local herbicide application. Other serious invasive shrubs and herbaceous species, such as castor bean, iceplant, fennel, arundo, myoporum, and horehound, are likewise simply controllable. To date we have removed about 90% of the iceplant cover from the polygons in which we have performed work.

**Table 6-1. Revegetation, Chevron Pipeline, DFSP, 1996 and 1999, % native shrub cover (%nsh cov), numbers of dominant shrubs (key below), and numbers of PVB sighted. The number of each plant species and percent cover are estimates along the transect segment and not polygons.**

| Seg. | % native shrub cover | *Lot sco* | *Ast tri* | *Art cal* | *Enc cal* | *Bac sal* | *Bac pil* | *Cor fil* | *Cro cal* | *Sal mel* | *Sal leu* | *Eri cin* | *Eri fas* | *Hap eme* | PVB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1996** | | | | | | | | | | | | | | | |
| 1-2 | 5 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2-1 | 1 | 0 | 40 | 0 | 0 | 1 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2-2 | 10 | 6 | 60 | 1 | 40 | 8 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 3-1 | 80 | 100 | 0 | 20 | 100 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 0 | 1 |
| 3-2 | 80 | 150 | 0 | 15 | 100 | 2 | 1 | 7 | 90 | 0 | 0 | 0 | 85 | 0 | 6 |
| 4-1 | 75 | 20 | 0 | 3 | 20 | 6 | 10 | 0 | 10 | 0 | 0 | 0 | 150 | 0 | 3 |
| 4-2 | 60 | 20 | 0 | 20 | 40 | 20 | 10 | 10 | 0 | 0 | 0 | 0 | 100 | 2 | 6 |
| 4-3 | 50 | 60 | 10 | 20 | 60 | 50 | 0 | 10 | 0 | 0 | 0 | 0 | 20 | 0 | 11 |
| 5-1 | 50 | 40 | 20 | 40 | 10 | 30 | 10 | 20 | 30 | 0 | 0 | 0 | 2 | 0 | 20 |
| 5-2 | 60 | 80 | 15 | 200 | 20 | 10 | 40 | 40 | 15 | 0 | 0 | 0 | 5 | 0 | 35 |
| 6-1 | 25 | 30 | 0 | 0 | 0 | 0 | 5 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 10 |
| 6-2 | 35 | 20 | 0 | 0 | 7 | 2 | 0 | 4 | 50 | 0 | 0 | 0 | 0 | 0 | 14 |
| 6-3 | 50 | 100 | 10 | 4 | 0 | 2 | 0 | 16 | 10 | 0 | 0 | 0 | 0 | 0 | 24 |
| 6-4 | 1 | 30 | 6 | 8 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 4 |
| **1999** | | | | | | | | | | | | | | | |
| 1-2 | 10 | 120 | 0 | 6 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2-1 | 1 | 1 | 1 | 0 | 20 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2-2 | 20 | 3 | 8 | 8 | 40 | 8 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3-1 | 50 | 200 | 0 | 15 | 100 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 5 |
| 3-2 | 80 | 200 | 0 | 6 | 100 | 0 | 3 | 7 | 60 | 0 | 0 | 0 | 25 | 0 | 1 |
| 4-1 | 85 | 0 | 0 | 6 | 20 | 10 | 20 | 0 | 10 | 0 | 0 | 0 | 150 | 0 | 1 |
| 4-2 | 70 | 50 | 7 | 40 | 40 | 40 | 20 | 10 | 0 | 0 | 0 | 0 | 100 | 2 | 1 |
| 4-3 | 60 | 80 | 0 | 30 | 60 | 50 | 0 | 10 | 0 | 0 | 0 | 0 | 20 | 0 | 7 |
| 5-1 | 50 | 10 | 0 | 40 | 10 | 20 | 10 | 20 | 30 | 0 | 0 | 0 | 2 | 0 | 0 |
| 5-2 | 60 | 60 | 2 | 200 | 20 | 10 | 40 | 40 | 15 | 0 | 0 | 0 | 5 | 0 | 3 |
| 6-1 | 30 | 53 | 10 | 20 | 4 | 0 | 50 | 0 | 23 | 13 | 6 | 2 | 0 | 0 | 4 |
| 6-2 | 40 | 30 | 15 | 5 | 7 | 2 | 0 | 4 | 50 | 1 | 2 | 4 | 0 | 0 | 2 |
| 6-3 | 50 | 120 | 10 | 21 | 0 | 2 | 0 | 16 | 8 | 7 | 10 | 6 | 0 | 0 | 15 |
| 6-4 | 5 | 20 | 2 | 15 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |

Key: Lot sco, *Lotus scoparius*; Ast tri. *Astragalus trichopodus*; Art cal, *Artemisia californica*; Enc cal, *Encelia californica*; Bac sal, *Baccharis salicifolia*; Bac pil, *Baccharis pilularis*; Cor fil, *Lessingia filaginifolia*; Cro cal, *Croton californicum*; Sal mel, *Salvia mellifera*; Sal leu, *S. leucophylla*; Eri cin, *Eriogonum cinerium*, Eri fas, *E. fasciculatum;* Hap eme, *Haplopappus emeryi*; PVB, Palos Verdes blue butterfly

Control of annuals by weeding is less certain and presents a major challenge to all revegetation projects where soil disturbances are involved, which is certainly the case at DFSP. Weeding was overly vigorous when we first started revegetation (e.g., soil scraping was performed). We are now convinced that minimal energy should be expended because our observations show that no amount of physical and/or chemical energy will remove invasive non-native annual plants for more than a season or two (see manipulative experiments below).

The primary purpose of weeding is to 1) remove biomass and 2) reduce the seed bank of non-native annuals. Removal of biomass both reduces nutrients and competition. The latter function, together with reduction of the target seedbank, depends on timing of the weed removal operation. We initially weed (we refer to this as "clearing") an entire site that is to be planted. Following planting, we attempt to perform weeding in early spring when the annual grasses (chiefly bromes and oats) are first forming seed. Implementation is by using a hand weed whacking machine. The cuttings are lightly hand raked into stacks or windrows where the residue is left to compost. We assume that the heat of composing kills most of the seed.

The second weeding is performed about 4 weeks following the last rain, at which time the grasses (and mustards) have largely completed growth. In this manner competition for light and water is substantially reduced enabling the set out plants to establish and further mature prior to summer dormancy. The second rakings are added to the stacks formed by the initial clearing.

### *6.3.6 Monitoring*

Plant monitoring consists of establishing a permanent transect in each polygon, with a minimum of one transect per 0.4 ha. The transects are selected at random with the constraint that each must lie within planted areas and not extend into infrastructure. Each transect is marked at each end of a 50 m length using a 1 cm rebar, 1.5 long, driven into the soil.

We measured plant community composition with the point-intercept method. A 50-m tape was stretched between the permanent metal rods at each transect and the open space or plant mass that the tape intercepts was recorded to the nearest centimeter. The plant species intercepted is noted, and only perennial species are recorded. The annual "understory" plants are not noted. In this manner percent cover and cover by species is immediately available. Data collected in this manner is available for the first two years plantings and is given in Table 6-2.

Prior to 2001, monitoring was done by visual estimation, such as was performed for the PVB density/vegetation pattern determinations in 1996 and 1999 (Table 6-1). Other cover data, given in Table 6-4 were visual.

Results to date (Table 6-2) indicate steady progress toward the goal of 50% minimum native cover. The five transects for Polygon 9 indicate cover of 31–63%, even without the second cohort having been planted. With a rate of about 1,200 plants set out initially, the objective will doubtless be reached without further plantings. The additional 1,200 plants per 0.4 ha to be set out in 2001–2002 should reach the cover objective with the added benefit of age variation. Shrub cover levels can be achieved more quickly, but this would entail planting shrubs more closely than they should be, which would crowd them and impair their proper development.

The 10 transects sampling polygons 12, 13E, and 14 give the results of first year growth, showing 5–35% cover. The lowest value, in Transect 14, reflected a lower planting density (~800 per 0.4 ha) in a poor location.

It should be noted that the 2001–2002 plantings will be based on increased clustering of species that are distributed in the cluster pattern. Thus, *Artemisia* and the *Salvia* spp. will be placed as nearest neighbors to established individuals of the same species thereby creating a more natural mosaic pattern. In addition to these mosaics, a more highly diverse assemblage of species will be employed.

**Table 6-2. Vegetation transects of revegetated polygons, sampled 2001.**

| **Transect** | **% Native Cover** | | **% cover** | **N individuals** |
|---|---|---|---|---|
| **Polygon 14** | **(planted 2001) 3 transects** | | | |
| **14 T1** | **8.46%** | ***Artemisia californica*** | **2.52%** | **2** |
| | | *Eriogonum cinerium* | 2.10% | 1 |
| | | *Eriogonum fasiculatum* | 1.60% | 1 |
| | | *Gnaphalium bicolor* | 1.16% | 1 |
| | | *Salvia leucophylla* | 0.68% | 1 |
| | | *Galium angustifolium* | 0.40% | 1 |
| **14 T2** | **20.16%** | | | |
| | | *Artemisia californica* | 7.76% | 4 |
| | | *Encelia californica* | 6.62% | 2 |
| | | *Eriogonum cinerium* | 2.24% | 1 |
| | | *Galium angustifolium* | 1.48% | 1 |
| | | *Verbena lasiostachys* | 1.24% | 1 |
| | | *Mimulus longiflorus* | 0.82% | 1 |
| Note *Curcubita* coverage (~12 m) not planted N. end of transect | | | | |
| **14 T3** | **4.74%** | | | |
| | | *Galium angustifolium* | 1.74% | 2 |
| | | *Stipa pulchra* | 1.00% | 1 |
| | | *Salvia leucophylla* | 0.96% | 1 |
| | | *Artemisia californica* | 0.58% | 1 |
| | | *Mimulus longiflorus* | 0.46% | 1 |
| **Polygon13E** | **(planted 2001) two transercts** | | | |
| **13F T1** | **8.24%** | | | |
| | | *Lotus scoparius* | 3.14% | 2 |
| | | *Astragalus trichopodus* | 1.38% | 1 |
| | | *Lessingia filangifolia* | 1.22% | 1 |
| | | *Phacelia cicutaria* | 0.80% | 1 |
| | | *Salvia leucophylla* | 0.76% | 1 |
| | | *Mimulus longiflorus* | 0.42% | 1 |
| | | *Horkelia cuneata* | 0.34% | 1 |
| | | *Opuntia prolifera* | 0.18% | 1 |
| | Note full transect in sand fill | | | |
| **13F T2** | **16%** | | | |
| | | *Lupinus longifolius* | 7.10% | 2 |
| | | *Lotus scoparius* | 4.44% | 1 |
| | | *Lessingia filangifolia* | 1.92% | 1 |
| | | *Mimulus longiflorus* | 0.94% | 2 |
| | | *Verbena lasiostachys* | 0.68% | 1 |
| | | *Stipa pulchra* | 0.44% | 1 |
| | | *Galium angustifolium* | 0.34% | 1 |
| | | *Opuntia prolifera* | 0.14% | 1 |
| | Note 2/3 of transect on native soil high success, last 1/3 poor | | | |

**Polygon 12 (planted 2001) five transects**

| | | | | |
|---|---|---|---|---|
| **12 T1** | **22.02%** | | | |
| | | *Lotus scoparius* | 13.88% | 9 |
| | | *Astragalus trichopodus* | 3.58% | 3 |
| | | *Phacelia cicutaria* | 3.18% | 1 |
| | | *Epilobium canum* | 1.06% | 1 |
| | | *Mimulus longiflorus* | 0.32% | 1 |
| **12 T2** | **12.66%** | | | |
| | | *Encelia californica* | 3.60% | 1 |
| | | *Salvia mellifera* | 2.88% | 1 |
| | | *Lessingia filangifolia* | 2.40% | 2 |
| | | *Rhus intergrifolia* | 1.12% | 1 |
| | | *Artemisia californica* | 1.60% | 2 |
| | | *Ericameria palmerii* | 0.54% | 1 |
| | | *Verbena lasiostachys* | 0.52% | 1 |
| **12 T3** | **17.48%** | | | |
| | | *Artemisia californica* | 5.20% | 2 |
| | | *Encelia californica* | 2.76% | 3 |
| | | *Keckiella cordifolia* | 2.08% | 2 |
| | | *Lupinus longifolius* | 1.60% | 1 |
| | | *Astragalus trichopodus* | 1.54% | 2 |
| | | *Mimulus longiflorus* | 1.22% | 1 |
| | | *Lotus scoparius* | 1.12% | 1 |
| | | *Phacelia cicutaria* | 1.00% | 1 |
| | | *Horkelia cuneata* | 0.96% | 1 |
| **12 T4** | **35.86%** | | | |
| | | *Phacelia cicutaria* | 23.12% | 8 |
| | | *Artemisia californica* | 3.58% | 1 |
| | | *Mimulus longiflorus* | 3.56% | 3 |
| | | *Leymus condensatus* | 1.96% | 2 |
| | | *Lotus scoparius* | 1.86% | 1 |
| | | *Encelia californica* | 0.90% | 1 |
| | | *Mirabalis californica* | 0.88% | 1 |
| **12 T5** | **23.92%** | | | |
| | | *Lotus scoparius* | 11.06% | 7 |
| | | *Lupinus longifolius* | 4.02% | 2 |
| | | *Phacelia cicutaria* | 3.94% | 3 |
| | | *Baccharis pilularis* | 3.10% | 1 |
| | | *Horkelia cuneata* | 0.68% | 2 |
| | | *Mirabalis californica* | 0.62% | 1 |
| | | *Stipa pulchra* | 0.50% | 1 |

**Polygon 9 (planted 2000) four transects**

| | | | | |
|---|---|---|---|---|
| **9 T1** | **36.32%** | | | |
| | | *Atremisia californica* | 19.70% | 8 |
| | | *Salvia leucophylla* | 6.12% | 2 |
| | | *Encelia californica* | 2.28% | 1 |
| | | *Leymus condensatus* | 3.12% | 1 |
| | | *Salvia mellifera* | 2.80% | 1 |

| | | | | |
|---|---|---|---|---|
| **9 T2** | **33.50%** | | | |
| | | *Artemisia californica* | 22.00% | 6 |
| | | *Salvia leucophylla* | 5.40% | 2 |
| | | *Baccharis pilularis* | 3.50% | 1 |
| | | *Leymus condensatus* | 2.18% | 1 |
| | | *Opuntia prolifera* | 0.42% | 1 |
| **9 T3** | **31.54%** | | | |
| | | *Lotus scoparius* | 12.44% | 6 |
| | | *Artemisia californica* | 11.02% | 4 |
| | | *Croton californica* | 3.46% | 1 |
| | | *Epilobium canum (Zauscheria)* | 3.08% | 1 |
| | | *Verbena lasiostachys* | 0.80% | 1 |
| | | *Salvia leucophylla* | 0.74% | 1 |
| **9 T4** | **63.38%** | | | |
| | | *Artemisia californica* | 15.86% | 5 |
| | | *Lotus scoparius* | 14.10% | 4 |
| | | *Salvia mellifera* | 11.70% | 3 |
| | | *Salvia leucophylla* | 8.74% | 2 |
| | | *Eriogonum cinerium* | 5% | 2 |
| | | *Eriogounum fasiculatum* | 3.50% | 1 |
| | | *Galium angustifolium* | 2.86% | 1 |
| | | *Opuntia littoralis* | 1.62% | 1 |

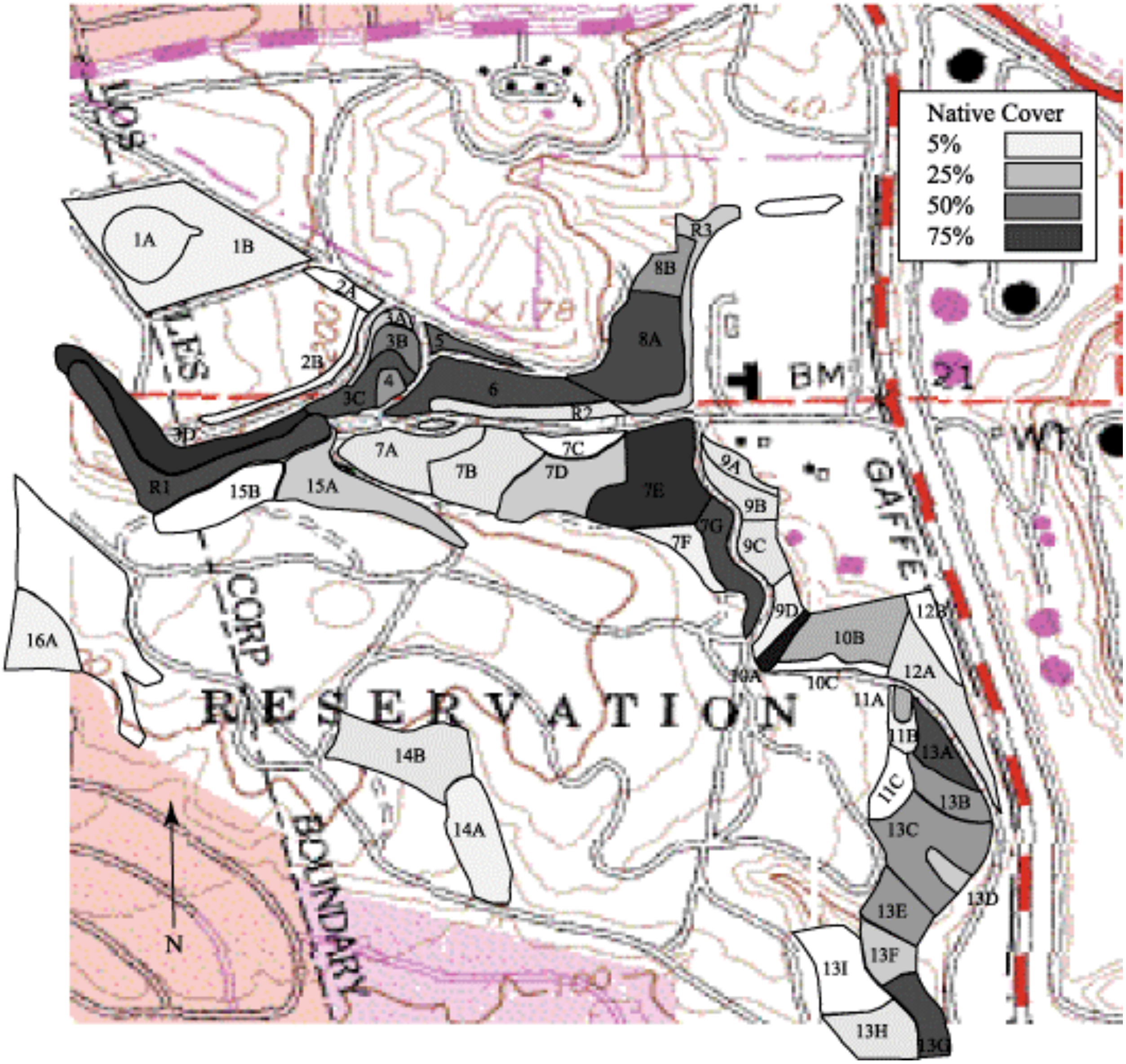
To provide more meaningful data in the coming season, we propose to design a program to monitor rate of soil change with revegetation. Insight may be gleaned through estimating establishment of non-native invasive annual species in the immediate understory/shadow of dominant shrubs that have been set out.

### 6.3.7 Manipulative experiments

Scientists first derived understanding of processes in plant ecology from observations of patterns of distribution and abundance, correlating these with variable environmental parameters. However, deduction of process from pattern is not testable without experimentation (Leps 1989; Leps and others 1999). Our earliest work in 1995–1996 included two manipulation experiments on Polygon 1. These were initially completed by Lipman and reported at the time.

The first experiment attempted to partition effects of irrigation, solarization, and herbicide (Roundup®) on the establishment of dominant perennial native shrubs on Polygon 1A. Two blocks each of 32 randomized 3-m square cells were marked and treated with irrigation, solarization, Roundup, and scraped soil. The plots all were then both seeded and planted. After the first growing season there were substantial differences in the invasive annual populations. However, after three years, all plots were visually identical, overgrown with brome, *Erodium*, and mustard. The only survivors were the few set out container dominant shrubs (*Encelia, Artemisia*), that have survived until 2002. There was no apparent germination from the seeds broadcast, and no recruitment is yet apparent from the established plants.

**Figure 6-1. Map of DFSP showing nomenclature for polygons in natural areas. Native plant cover in 1994 shown on a continuous gray scale gradient.**



The second experiment was similar, except the objective was to test solarization, Roundup, and scraping on establishment of a community of annuals and one bunchgrass. Two blocks of 12 randomized 3-m square cells were used, and after the treatments all were seeded with a mix of *Festuca myuros, Orthocarpus densiflorus* (PV stock), *Lupinus bicolor* (PV stock), and *Stipa pulchra-cernua* (PV stock). The first year showed striking differences in non-native growth and display of the seeded species (none of which occurred naturally on the experimental arena). After the third year, however, most differences disappeared and the almost total cover by the non-natives resumed. There is no evidence any of the initial propagules provided recruitment beyond the immediate treatments.

The third experiment, also in Polygon 1A,was designed to determine optimal approach to iceplant removal, testing solarization and Roundup herbicide. There was no difference, except solarization was about 20 times as expensive. Very little recruitment of iceplant on the cleared sites has occurred; the few new seedlings or resprouted fragments were removed when noted. Iceplant, once removed, can easily be kept under control.

The two hard lessons from these early experiments are: 1) non-native Mediterranean annual plants are impossible to regulate using simplistic physical or chemical control, and 2) founder native shrubs persist once introduced, but introduction is only certain with container plants. These conclusions have been reiterated many times over from observation of many seed broadcast and planting trials across all sites treated.

### *6.3.8 "Restoration"*

Establishing a plant community of shrubs and herbaceous perennials approximating the historic model is the first phase of revegetation. States approaching true restoration will require far greater time, thought, and energy. Our initial observation on allelopathy is encouraging. However, we recognize that the key factor of a coastal sage scrub community — fire — is perforce excluded at DFSP, which will present an significant long-range challenge. Virtually all Mediterranean scrub communities appear to be dynamic non-equilibrium ecosystems dependent on a fire mosaic (Keeley and Scott 1995). Had use of fire been an option, our efforts would likely have been somewhat different, but this is untestable.

Practically, the fire constraint need not be addressed for decades if we are able to create at least a partially regenerative and diverse floral aggregate. To provide a more comprehensive community it will be necessary to augment the few small vertebrates and many arthropods that are missing. This action again need not be addressed until native shrub cover is increased and some success achieved with annual plant species.

Topics mentioned here as crucial to claiming "restoration" do not constitute a plan of action. These factors are generally and unfortunately overlooked in the immediacy of confusing revegetation with "restoration."

### *6.3.9 History of revegetation, by polygon*

Revegetation of DSFP started shortly following discovery of the PVB in 1994. At that time other studies of the site biota were underway for purposes associated with occurrence of the then recent listing of the California gnatcatcher under the federal Endangered Species Act. Two breeding pairs of the bird were present (Atwood and others 1998), with none observed since 1998. With regard to the gnatcatcher, as well as several small rodent species that should be present, DFSP probably should be currently viewed as a "sink" of unsuitable or hostile habitat. The habitat is degraded by a population of feral domestic cats, erratic feral dog packs, and predominance of exotic rats. Amelioration of these conditions would render DFSP much more amenable to sensitive vertebrate species.

**Figure 6-2. Map of DFSP showing native plant cover in 2001 on a continuous gray scale gradient.**

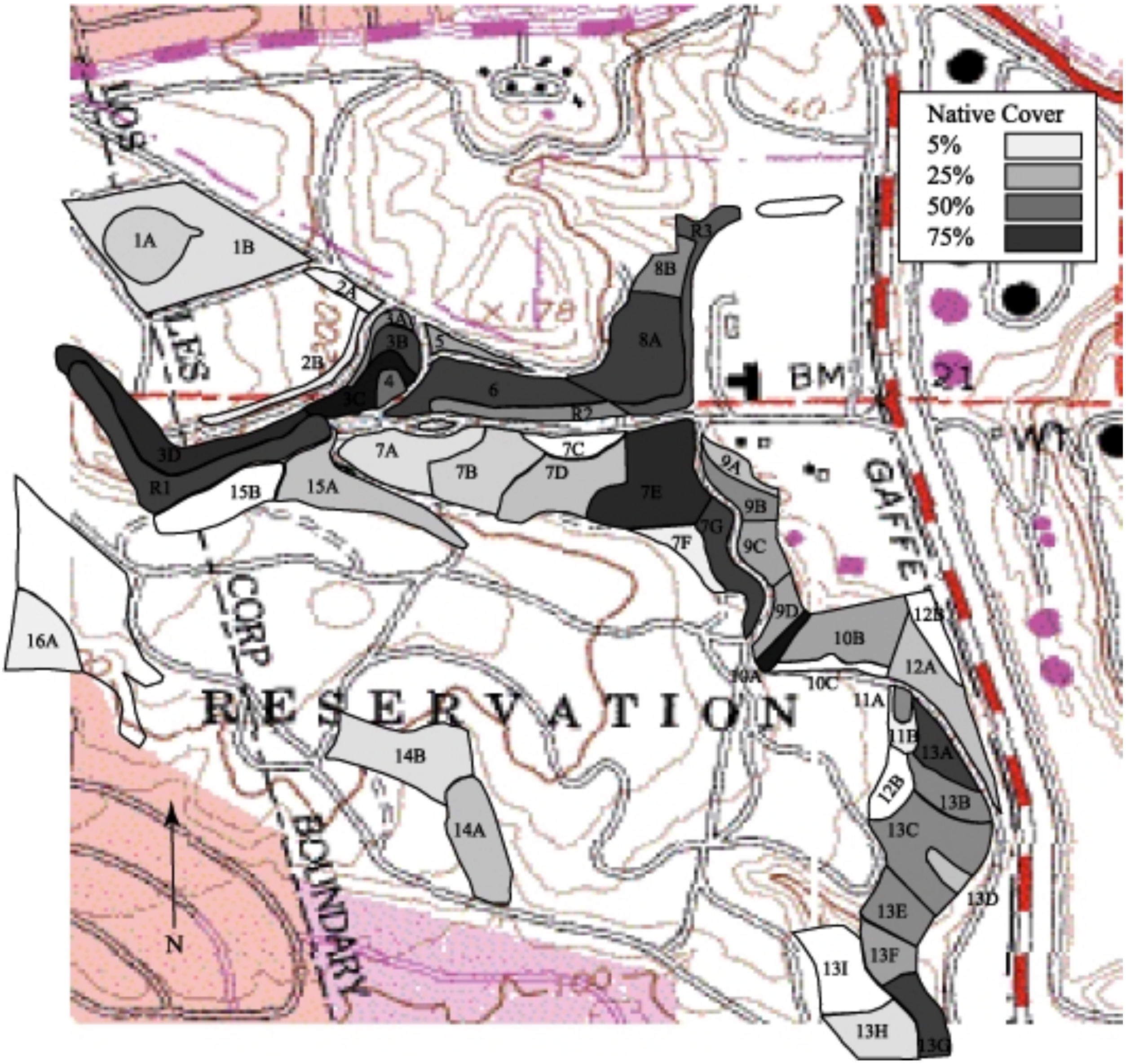
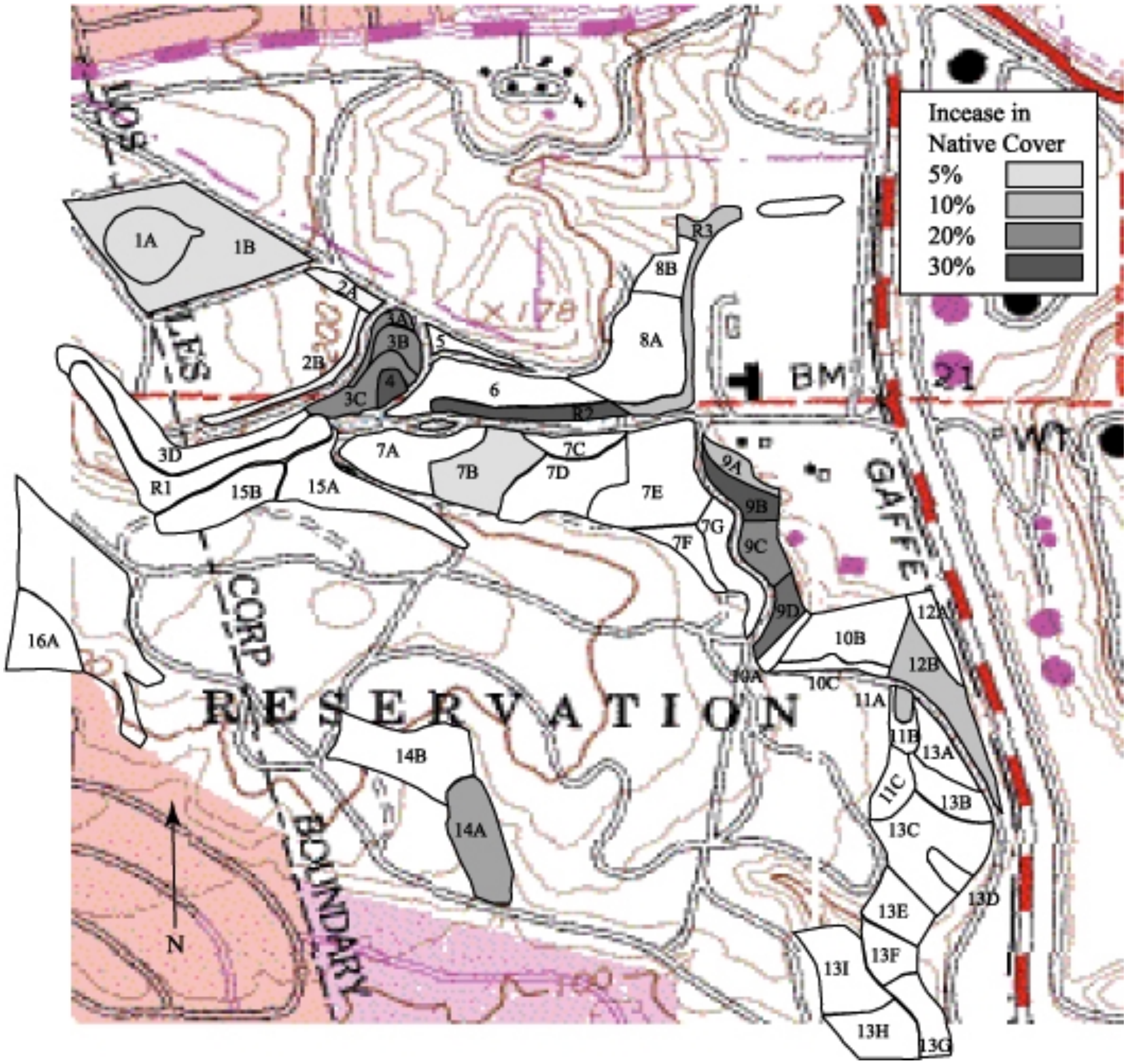


Table 6-3 summarizes the physical characteristics of the 40 polygons we have delineated for purposes of identifying approximately homogeneous sites for study and effort. Estimates of native plant (perennial shrub) cover for 1994 and 2001 are stated. The following section presents a narrative of revegetation effort. Establishment of native plant cover is an essential first step to achieving the goal of ecosystem restoration.

Revegetation activity and status within the 40 polygons are summarized in Table 6-4. In an earlier report on correlating PVB counts with vegetation (see Section 3, above) density of all perennial shrubs within a 10 m wide belt along the PVB transect were given. This report was prepared to describe the Chevron mitigation effort and is available. Table 6-4 gives the date primary clearing was performed, indicating whether this was partial or complete; the date irrigation was installed, operated and removed; the date container plants were first set out, and how many were planted; estimated 2001 native cover; the date weeding was performed; and the date annual seed were broadcast. Counts of species set out are available. Native plant cover in 1994 is shown in Figure 6-1, while cover in 2001 is shown in Figure 6-2. Increase in native plant cover is illustrated in Figure 6-3.

**Figure 6-3. Increase in native plant cover at DFSP resulting from revegetation activities.**



Information on each polygon follows, describing attempts, failures, and lessons learned. It cannot be overstated that the process of design and implementation of revegetation and related efforts at DFSP to date has provided invaluable insights to carry a successful program into the future.

**Polygon 1A.** Substrate is fill excavated from construction of Navy Housing, mostly sandstone-clay with poor nutrition and no surface soil development. The flora consists of many depauperate appearing deerweed with extensive iceplant. Limited iceplant removal has taken place and the shrub layer has apparently slightly expanded between 1994 and 2001. The weak annual understory results from the poor soil status. One male PVB was noted in 2001, the first ever seen. If support becomes available the site could provide an arena to test establishment of native annuals because of apparent low competition for light. There are no plans for plantings in the near future.

**Polygon 1B.** Substrate appears native, a very thin soil layer over the sedimentary marine terrace sandstone that is barely disturbed. Iceplant covered about 60% in 1994, with cover reduced to about 10% in 2001 due almost entirely to volunteer activity. Several hundred *Stipa* (*Nasella*) bunchgrass were set out in 1995 and limited experimental shrubs set out in 1995–1996 (reported in Section 6.3.7). Removal of iceplant at least doubled the number of deerweed with limited recruitment of *Lessingia* and *Ericameria palmerii*. Annual grasses, mustard, and *Erodium* have also replaced the iceplant. The PVB release experiment in 2000, with only one butterfly noted in 2000, strongly supports the conclusion that some factor other than foodplant limits the population. There are no plans for plantings in the near future, although iceplant removal will continue by volunteer effort.

**Polygon 2A.** The substrate may or may not be native, because the site is adjacent to the underground tank excavations. The site had few *Lessingia* and *Stipa* in 1994. Irrigation was placed out in 1996. Two successive plantings with about 400 *Astragalus* and seed broadcasts of mixed native annuals were made in 1996 and 1997. The *Astragalus* did not survive beyond 1998, although a single plant was found in 2001 in addition to about 20 *Eschscholzia* from the original seed broadcast. The site originally was covered with iceplant and the common non-native annuals (1% native). The iceplant was eliminated, but the site now is covered mostly with the non-native annuals (2% native). Robust growth of the exotic annuals implies greater soil depth than at Polygon 1. The lesson is that short-lived herbaceous perennials cannot persist on sites heavily contaminated with the common non-native annual aggregates.

**Polygon 2B.** The substrate is likely not native, having been deposited from the adjacent underground tank excavations. However, there are sections with dense old growth, including a few *Salvia mellifera*, *Heteromeles arbutifolia*, and the only native *Rhus imtegrifolia* on DFSP. The polygon was approximately half cleared in 1998, but neither irrigated nor planted.

**Polygon 3A.** Most, if not all, of the soil is disturbed, in part from construction of the road bordering the curved north side of the polygon and in part from a concrete bunker. The northeast portion was one of the first sites clearing in 1995 and 1996 with subsequent weeding. Over 200 *Astragalus* were set out at the time and the site heavily seeded with annuals. The first year produced a rich stand of *Orthocarpus purpurescens, Plantago erecta, Camissonia micrantha, Lupinus bicolor*, and *Descurainea pinnata*. None persisted beyond 1998 and the site became overgrown (~80% cover) with *Encelia* and a few deerweed and coyote bushes. The western section reverted to the common non-native annual aggregate with less than 10% native shrubs. The result reiterates the pattern of founder shrubs persisting while exotic annuals outcompete native annuals and resist shrub germination on disturbed substrates.

**Polygon 3B.** Most of the soil is apparently native, at least across the south facing slope that remains densely covered with *Encelia* and *Artemisia.* The west facing portion of the slope may be part fill from road construction and was originally covered with iceplant (removed) and a mat of the common non-native annuals. Limited plantings of native shrubs were made in 1997. These plantings should be augmented.

**Polygon 3C.** The substrate appears to be almost entirely native slope soil, except possibly the westernmost quarter. The entire polygon is densely (90%) covered with native shrubs, as it was since 1994. There is a small marsh created by filling part of the drainage. The area above the marsh was cleared and heavily seeded with several annuals in 1996, and at least *Descurainea* persists. Willows and mulefat have naturally established from wind blown propagules providing a small but rich wildlife habitat. We periodically fill the marsh in summer to maintain the habitat. There is a rich stand of old *Artemisia californica, Encelia californica, Baccharis pilularis* and *Heteromeles arbutifolia* over about half the polygon. Most significantly, we set out 12 *Crossosoma californica* in 1996. At least eight individuals flourished and flowered and set seed in 2000. We irrigate only the marsh and otherwise believe the site requires no further attention.

**Polygon 3D.** Substrate origin is not clear, but in part appears native. There are some large concrete pieces on the site. Some fill soil may have originated from the road bordering the north side. The polygon is densely covered (90%) with *Encelia californica, Opuntia littoralis,* and some *Artemisia californica* and *Baccharis pilularis*. There are no PVB foodplants on the polygon. We have cleared some iceplant, but otherwise have not impacted the polygon and have no plans to do so. The dense patch of *Encelia* suggests that the plant community has not reached a climax typified by sagebrush.

**Polygon 4.** The substrate is almost entirely sand, likely a lens in the terrace sediment formation. There is little evidence of past disturbance. The plant community of this small polygon (<0.2 ha) has several unique components, including the only *Filago californica* at DFSP. Common non-native annuals are sparse, likely because of edaphic selection. We broadcast several native annuals of which a few *Descurainea pinnata, Chaenactis gabriuscula*, and *Orthocarpus purpurescens* have persisted. Cover is low, about 40%, but essentially all natives, again likely an edaphic regulation. The cover is typical for exposed sand dune communities. Clearing and weeding are minimal, and we discourage any traffic on the area because of sensitivity. This polygon should be left untouched.

**Polygon 5.** The substrate has a high proportion of disturbed subsoil, turned up from initial pipeline construction (pipeline R-O-W), and again disturbed with the replacement in 1997. The soil in the immediate pipeline reach formed dense clay, which has been difficult to plant, although a predominant deerweed stand is gradually recruiting by natural process. The portion to the west of the pipeline was earlier disturbed by a series of covered bunkers. The site originally provided about 80% cover of *Encelia, Eriogonum fasciculatum, Lotus scoparius,* and *Artemisia.* As part of the pipeline mitigation, the disturbed area was planted and is now largely deerweed covered. The western section was cleared, planted and weeded, with a mix of annuals (see 3A) broadcast. A few have persisted. Overall there is about 70% native shrub cover, but the community is a mosaic.

**Polygon 6.** The substrate is almost entirely fill from Navy housing construction. The westernmost ~75% is covered with a pure stand of *Eriogonum fasciculatum* (70% cover) that appears to be an ecotype not typical of the Palos Verdes region (we assume this was likely hydroseeded). The substrate of this portion is almost barren of organic matter. Part is a soil dump. The easternmost section that borders the pipeline R-O-W is a mixed stand of *Encelia, Eriogonum fasciculatum,* and deerweed. The latter portion was irrigated and heavily planted and seeded in 1998 as part of the Chevron mitigation. Deerweed is dense and the PVB increasing in the area but none of the annuals has established. Irrigation has been withdrawn. We planned to set out a foodplant node for PVB along the riparian border, and in time replace the presumed exotic buckwheat with an appropriate community of coastal sage perennials.

**Polygon 7A–G.** This contiguous set of polygons are all on natural soil substrate except for some waste concrete, etc. dumping along the southern border. Other than 7F and 7G, the whole area has a high priority for revegetation, especially to provide PVB habitat. Overall the area has highest plant diversity at DFSP.

**Polygon 7A.** The substrate is essentially native slope soil, although cover was about 60% iceplant in 1994. The bottom of the polygon is eroded sand. Prior construction of a large bunker involved excavation and replacement with subsoil. Less than 10% has native cover and no planting has been performed, although the slope was cleared of iceplant and heavily seeded with deerweed and *Artemisia* in 1998. The polygon was cleared by volunteer labor over the period 1998 to date, iceplant being removed as it resprouted. The polygon should be planted with an appropriate coastal sage aggregate.

**Polygon 7B.** Soil is essentially native slope. The lower parts had some iceplant cover in 1994, but this was cleared between 2000 and 2001. An upper 0.2 ha was cleared, irrigation installed in early 2000, and about 500 shrubs set out. In May 2001 a 0.2 ha section on the southeast corner was irrigated and planted with 600 deerweed, but only six plants survived. The deerweed plants were irrigated for one month following planting, but the late planting did not provide establishment even given that the stock was healthy. The failure emphasizes the importance of the seasonal window for setting out container plants. Beyond some date, root system development and physiological preparation for dormancy is not reached and the individual dies. The critical point depends on species, life cycle stage, and container size. Lacking this information for most perennial species that we handle demands that planting be completed by mid-March. The lesson is clear that successful field planting is increasingly less likely the later in the season that the planting is performed.

**Polygon 7C.** Substrate history is questionable. The polygon straddles a large bunker and the soil has all been disturbed although samples show it is a sandy soil that would be expected from the position in the canyon alluvium. There are no native residuals, however. The polygon would appropriately be used to (re?) establish a prairie community. The site is routinely mowed for fire safety.

**Table 6-3. Polygons suitable for revegetation giving abiotic parameters and native shrub cover in 1994 and 2001.**

| Polygon | Slope | Azimuth | Soil | History | %cover 1994 | %cover 2001 | Treated |
|---|---|---|---|---|---|---|---|
| 1A | 2 | E | fill | placed excavated fill | 10 | 15 | 0 |
| 1B | 1 | E | terrace | native marine sediment soil | 5 | 10 | 1 |
| 2A | 1 | E | terrace | " | 1 | 2 | 2 |
| 2B | 3 | SE | terrace | " | 5 | 5 | 1 |
| 3A | 1 | SE | fill | excavated from construction | 20 | 40 | 2 |
| 3B | 3 | S | fill | " | 50 | 70 | 2 |
| 3C | 3 | SE | native | old native scrub | 70 | 90 | 2 |
| 3D | 4 | S | native | terrace slope | 80 | 80 | 0 |
| 4 | 1 | SE | native | " sand outcrop | 20 | 50 | 1 |
| 5 | 1 | E | fill | placed excavated fill | 60 | 60 | 2 |
| 6 | 2 | S | fill | placed excavated fill | 70 | 70 | 0 |
| 7A | 4 | N | native | part disturbed | 10 | 10 | 1 |
| 7B | 4 | N | native | part disturbed | 10 | 15 | 1 |
| 7C | 0 | E | fill | mowed ?prairie | 0 | 0 | 0 |
| 7D | 4 | N | native | part disturbed | 20 | 20 | 0 |
| 7E | 4 | N-E | native | old native | 80 | 80 | 0 |
| 7F | 0 | N | alluvium | part mowed | 5 | 5 | 0 |
| 7G | 3 | E | native | old native | 70 | 70 | 0 |
| 8A | 3 | E | native | 80% old native scrub | 70 | 70 | 1 |
| 8B | 3 | E | native | part (40%) fill, pt old native | 40 | 40 | 1 |
| 9A | 0 | N | alluvium | mowed <1995 | 10 | 20 | 2 |
| 9B | 3 | E | native | part disturbed | 10 | 40 | 2 |
| 9C | 3 | E | native | part disturbed | 10 | 30 | 2 |
| 9D | 4 | E | native | part disturbed | 5 | 30 | 2 |
| 10A | 4 | NE | native | barranca | 90 | 90 | 0 |
| 10B | 5 | N | cut | sediment/lens/layers | 30 | 30 | 0 |
| 10C | 0 | E | terrace | mowed routinely | 0 | 0 | 0 |
| 11A | 0 | E | terrace | old prairie | 30 | 40 | 1 |
| 11B | 0 | E | terrace | mowed <1997 | 5 | 5 | 0 |
| 12A | 5 | E | native |  | 10 | 20 | 2 |
| 12B | 0 | 0 | ? | mowed | 0 | 0 | 0 |
| 13A |  |  | native |  | 70 | 70 | 0 |
| 13B |  |  | native |  | 40 | 40 | 0 |
| 13C |  |  | native |  | 80 | 80 | 0 |
| 13D |  |  | native | disturbed in part | 20 | 20 | 0 |
| 13E |  |  | native |  | 80 | 80 | 0 |
| 13F |  |  | fill | *Myoporum*/iceplant | 20 | 30 | 2 |
| 13G |  |  | native |  | 70 | 70 | 0 |
| 13H |  |  | cut | graded | 10 | 10 | 0 |
| 13I |  |  | fill |  | 0 | 0 | 0 |
| 14A |  |  | native | part alluvium | 5 | 20 | 2 |
| 14B |  |  | terrace? | part graded? | 10 | 10 | 0 |
| 15A |  |  | native | part graded | 20 | 20 | 0 |
| 15B |  |  | fill |  | 0 | 0 | 0 |
| 16A |  |  | native | extensive clearing/degraded | 5 | 5 | 0 |
| R1 |  |  | native | rubble | 70 | 70 | 0 |
| R2 |  |  | alluvium | graded/mowed<98 | 10 | 40 | 2 |
| R3 |  |  | alluvium | graded/bermed | 20 | 30 | 1 |

Slope: 1=0–5%, 2=5–10%, 3=10–20%, 4=20–30%, 5=>30%. Cover by visual estimate. Treatment: 0=none, 1=some. 2=extensive.

**Table 6-4. Overview of treatment history of polygons treated in some manner at DFSP, 1994–2001 by year.**

| Polygon | Date cleared | Date install irrigation | Planting dates | N planted | Dates weeded | Estimated cover 2001 |
|---|---|---|---|---|---|---|
| 1A | 99–01 part | | | | | 15 |
| 1B | 94–01 part | 96, r 99 | 95–00 | 200 | 99 | 10 |
| 2A | 95 | 96, r 99 | 96, 97 | 400 | 97, 98 | 2 |
| 2B | 96 part | - | - | 100 | - | 5 |
| 3A | 95 | 96 | 96, 97 | 400 | 96 | 40 |
| 3B | 96 | 96 | 96, 97 | 500 | 97 | 70 |
| 3C | not req | 96 marsh | 96, 97 | 200 | 97 | 90 |
| 3D | - | - | - | - | - | 80 |
| 4 | not req | 96 | 96, 97 | - | 97, 98 | 50 |
| 5 | 97 | 97 | 97 | 800 | - | 60 |
| 6 | 97 pt | 97, r 99 | 97 | 300 | - | 70 |
| 7A | 98–01 | - | - | - | - | 10 |
| 7B | 00 pt | 00 pt | 00–01 pt | 700 | 01 | 15 |
| 7C | mowed | - | - | - | - | 0 |
| 7D | - | - | - | - | - | 20 |
| 7E | not req | - | - | - | - | 80 |
| 7F | mowed | - | - | - | - | 5 |
| 7G | not req | - | - | - | - | 70 |
| 8A | not req | 01 pt | 99– | 300 | - | 70 |
| 8B | not req | 01 pt | 97– | 200 | - | 40 |
| 9A | not req | 96 r 99 | 95–01 | seed | 96–01 | (20 prairie) |
| 9B | - | 98–99 | 96–01 | 400 | 96–01 | 40 |
| 9C | 99 | 99 | 99–02 | 2000 | 00–01 | 30 |
| 9D | 99 | 99 | 99–02 | 2000 | 00–01 | 30 |
| 10A | - | - | - | - | - | 90 |
| 10B | - | - | - | - | - | 30 |
| 10C | mowed | - | - | - | - | 0 |
| 11A | not req | - | - | 200 | 97–99 pt | (40 *Stipa*) |
| 11B | mowed <97 | - | - | - | - | (5 *Stipa*) |
| 12A | 01 | 01 | 00–03 | 4000 | 01 | 20 |
| 12B | - | - | - | - | - | 0 |
| 13A | not req | - | - | - | - | 70 |
| 13B | - | - | - | - | - | 40 |
| 13C | - | - | - | - | - | 80 |
| 13D | - | - | - | - | - | 20 |
| 13E | not req | - | - | - | - | 80 |
| 13F | 01 | 01 | 00–03 | 4000 | 01 | 30 |
| 13G | not req | - | - | - | - | 70 |
| 13H | mowed | - | - | - | - | 10 |
| 13I | mowed | - | - | - | - | 0 |
| 14A | 00–01 | 00-01 | 00–01 | 5000 | 01 | 20 |
| 14B | mowed | - | - | - | - | 10 |
| 15A | mowed | - | - | - | 99–01 pt | 20 |
| 15B | - | - | - | - | - | 0 |
| 16A | 01 part | 01 part | 02 pt | 3000 | 01 | 0 |
| R1 | not req | - | - | - | - | 70 |
| R2 | not req | 99 part | 99 pt | 400 | 99–01 | 40 |
| R3 | not req | 00 part | 00-pt | 200 | 00-01 | 30 |

pt = part done, N = approximate number of container plants set out, r = irrigation removed, est % cover = native shrub or *Stipa* cover.

**Polygon 7D.** Substrate is mostly native slope soil with old coastal sage cover on the lower (northern) half. Two deep barrancas are found one with a natural seep with old willow growth. The lower portion has several large elderberry and toyon and a dense annual growth of *Claytonia* in the spring. The polygon is suitable for appropriate coastal sage community cover. We had no plan for revegetation prior to 2003–2004.

**Polygon 7E.** The substrate is an all-native slope and most of the polygon is covered with coastal sage scrub dominated by *Artemisia californica.* The polygon has the highest plant diversity of any polygon, including the unique *Calystegia piersonii,* a few ferns, and several annuals not otherwise found at DFSP. We refer to the site as the "pristine" polygon, although that is not strictly true because of a section of about 0.5 ac with heavy non-native brome cover. We had periodically set out a few rare species, as *Ribes, Delphinium,* and *Ranunculus,* but otherwise have done little. The high conservation value of the polygon dictates minimal disturbance, even for scientific purposes. There is no irrigation.

**Polygon 7F.** The substrate appears to be relatively natural terrace with thin soil and a number of old *Stipa* bunchgrass, some *Isocoma palmerii, Astragalus,* and deerweed. There is no irrigation and we had no plan for planting for at least another season. The polygon would present an excellent site for PVB foodplant because no coastal sage species occur, implying deerweed and *Astragalus* would be at some competitive advantage.

**Polygon 7G.** Similar to Polygon 7F, this polygon is virtually all natural with minimal disturbed area. The diversity is not as high, a possible effect of lower aspect variance and niche conditions. We have set out over 200 plants along the road border to the east in addition to completing some seeding. There is no irrigation and periodic planting is undertaken during wet periods.

**Polygon 8A.** Mostly native substrate, native slope soil that is deep and supporting mature old stand coastal sage scrub with 90% cover across about 80% of the polygon. We have set out about 200 plants across the eastern border to the riparian (R3) polygon and have this portion irrigated. There is a disturbed area of about 0.2 haon the northwest corner of the polygon that we have cleared. There is a deep eroded barranca created by water concentrated by the paved area and underground tank on the east border. The polygon is suitable for revegetation with appropriate coastal sage scrub species on the disturbed portion.

**Polygon 8B.** Approximately 40% native slope deep soil across the eastern half of the polygon. The western section is excavated spoil from the underground tank construction immediately to the west. The latter is non-nutrient low organic substrate that has not developed shrub cover since construction of the tank nearly 60 years ago. Most of the disturbed area was covered with iceplant that was removed by volunteers. About 0.4 ha is now irrigated for a deerweed and *Astragalus* node for PVB. The eastern border is also irrigated, and along with riparian R3, has been planted with about 100 plants to increase diversity.

**Polygon 9A.** The substrate is a shallow slope of deep alluvium that originated across the terraces and from the historic discharge of George F Canyon. The site was routinely mowed prior to 1995. Since then we have removed all of a sparse iceplant cover and periodically weed. We have seeded the site over several years with a variety of annual broadcasts. The soil is unsuitable for the dominant scrub species (*Artemisia, Encelia,* etc.), but a sparse cover of deerweed and *Lessingia* has expanded since 1994. The dominant invasive annual is storksbill that we have been unable to control. We have also attempted to establish *Astragalus.* This effort has not succeeded. *Astragalus* plants flourish for 2–3 years and seem to have large seed sets. However, they then senesce without recruitment. There is nevertheless high diversity, and the presence of small stands of *Dichlostemma* indicates the soil is historically native. The only known individual of *Heterotheca sessiliflora* for the peninsula occurs on the site. Since 1996 we have established propagation beds for annuals across the polygon, but even with dense seedsets, including doubtless high residuals even with harvest, there is rare recruitment. This is another powerful lesson in the recalcitrant characteristics of annual plants in restoration.

**Polygon 9B.** The substrate is mostly deep native terrace slope soil. The polygon was covered with about 50% iceplant that was removed in 1995–1996, and the slopes planted with over 400 shrubs from 1996 to the present. These now provide about 50% cover. The irrigation system was removed except for one line serving about 0.2 ha.

The older plantings are now five years old and have provided allelopathic areas around the shrub bases (*Artemisia, Salvia leucophylla, S. mellifera,* and *Eriogonum fasciculatum*). This has provided the clearest on-site lesson of the approach to naturally selecting against the non-native annual complex. The situation presents an opportunity to perform manipulative experiments for establishing native annuals, or at least investigating differential co-adaptation of such species under these circumstances.

**Polygon 9C.** The substrate is the same as Polygon 9B. This was the first entire polygon we cleared, irrigated, planted, and weeded in one season. The first year cohort now provides about 30% cover, including a mix of diverse shrub species that have all survived two years. The second cohort planting plan concentrates the same species as nearest neighbors to the surviving shrubs. Thus the beginning of small same-species concentration mosaics may be achieved, which is a more natural pattern. Irrigation was used only for the first year plantings, extending for one month after the last seasonal rainfall. The survivors were robust and continued growing well the following season in spite of no weeding. The pattern to date provides an important insight into how to best implement revegetation of coastal sage scrub plant communities.

**Polygon 9D.** The situation is identical to that for Polygon 9C, above.

**Polygon 10A.** The substrate is deep terrace slope that is a step sided barranca eroded by runoff focused by the road pattern. The vegetation is dense mature scrub with large mulefat (*Baccharis salicifolia*). The community is mature and requires no attention.

**Polygon 10B.** The substrate is mostly raw cut that has been partially terraced for erosion control with some planting of low growing *Myoporum* that has largely succumbed to the harsh conditions. There is a robust scattered stand of deerweed and a usually high concentration of PVB, noted since 1994. A drainage system was engineered to control runoff, but is now largely superfluous with the revegetation of the slope. Cover is low, but is expanding as organic matter builds. Consequently, there is a sparse common non-native annual aggregate, which provides an opportunity for introducing a native annual community. The western 10% of the area is scrub-covered where the original slope was not cut. The line of demarcation to both east and west is very sharp where the raw cut forms a border.

**Polygon 10C.** The substrate is approximately thin native terrace soil. There is some *Stipa* cover with a few *Dichlostemm*a and *Bloomeria,* indicating the soil is undisturbed, even though the polygon is routinely mowed for fire control.

**Polygon 11A.** The substrate is almost entirely native very shallow terrace soil. The dense native *Stipa* bunchgrass cover is unique, sensitive, and rare. It may be the only such remaining stand across the peninsula. Adjacent Polygon 11B has similar soil and patches of dense bunchgrass, but has been mostly degraded by disking. The only subshrubs are *Lessingia* and *Isocoma palmerii* in addition to two lilies and the only stand of *Lotus heermanii* on the peninsula. We have performed minor weeding and have broadcast several sets of common annuals that should occur. The latter have made poor shows, but rainfall patterns have been suboptimal since the El Niño rainfall in 1998. The polygon must be carefully sequestered from damage.

**Polygon 11B.** Similar to Polygon 11A except only small patches of bunchgrass occur. The polygon should be densely planted with bunchgrass and seeded. Over time the polygon should revert to a native grassland. The adjacent terrace to the west shares some features.

**Polygon 12A.** Substrate is native terrace slope that appears deep. There were several clumped stands of sage and a large stand of perennial rye until planted in 2001. The slope is quite steep and, except for the few natives, was densely covered with radish. We set out a node of about 500 deerweed on the south end of the polygon.

**Polygon 13A.** Substrate is partial native terrace slope, mostly shallow soil. The northern ~100 m along the road border is cut with sedimentary strata showing. The almost pure native cover is complete but the plants are small, a likely result of poor nutrient availability. There are a number of deerweed plants and PVB are usually present during the flight period. We had planned no effort except to remove exotic pepper trees and possibly set out a more diverse assemblage at some future date.

**Polygon 13B.** Substrate is native terrace slope with fairly deep soil. There are a few cholla (*Opuntia prolifera*) along the deep barranca that channels water from the terrace, and many sage are quite old, indicating the site has not been disturbed. A few exotic pepper trees have been cut, and an earlier small stand of *Astragalus* that was found 1994–1996 has disappeared, and the small PVB colony with it. The polygon should be weeded and a diverse appropriate assemblage set out to enrich the community. There is a large strand of tree tobacco (*Nicotiana glauca*) on the site.

**Polygon 13C.** Substrate is native terrace slope with soil of varying depth. The cover is mostly old dominant *Artemisia* with low diversity, but dense cover. There is a small amount of deerweed along the western edge, but the site, although native, does not appear to be used as PVB corridor (see Polygon 13F below). Limited weeding and set out of container plants for diversity should be undertaken.

**Polygon 13D.** Substrate appears to be native terrace slope soil, but cover is almost entirely non-native tree tobacco and pepper trees, all of which should be removed and the site cleared and planted with an appropriate assemblage. We have expended no effort on the polygon.

**Polygon 13E.** The substrate is similar to Polygon 13D, except there are a few sand lenses and thin soil over portions of the site. The lenses have some of the annuals found on Polygon 4 (such as *Filago* and *Apiastrum*). The polygon appears relatively undisturbed and is densely covered with native plants (~80%). We have expended no effort and have not inventoried the plant community during spring bloom.

**Polygon 13F.** Substrate is broken sedimentary fill excavated from deep layers on the terrace for tank construction and moved to fill a former barranca. There is virtually no soil formation. There was about 20% native cover of mulefat (*Baccharis salicifolia*), *Artemisia,* and deerweed in 1994, but planting of iceplant and low growing *Myoporum* covered most of the site. A small PVB population occurred on the polygon until 1998 when it disappeared. We consequently deemed this a high priority polygon to revegetate, which was implemented in 2000–2001 with clearing, irrigation, and setting out of over 100 plants including a dense deerweed stand. The planting extended onto Polygon 13G.

**Polygon 13G.** Substrate is native terrace slope with fairly deep soil and high native shrub cover of mature dominant *Artemisia* and understory of *Stipa*. The site requires no effort other than possible weeding along the periphery with planting of diversity assemblages.

**Polygon 13H.** Substrate appears to be a cut terrace on graded sedimentary stone. Cover is almost entirely the common non-native annual community, which is routinely mowed. The site should be cleared and planted as coastal sage scrub with an *Astragalus* and deerweed node. No effort has been expended and none is planned in the near future.

**Polygon 13I.** Substrate is broken sedimentary fill, the new topography forming the top of the 13F slope discussed above. The whole site is covered with the common non-native annual community which is routinely mowed. No effort has been expended on this site.

**Polygon 14A.** The polygon is a large (~1.6 ha) shallow barranca with substrate a combination of terrace slope and alluvial sand base. There is a dense stand of about 200 large deerweed in the base with another stand on the northeast slope. The slopes had some (~5%) native cover including *Artemisia* and *Heteromeles arbutifolia*. Stands of *Dichlostemma* imply that the site historically was not disturbed to any extent. The site was cleared, irrigated, and planted 2000–2001 with about 3,000 plants set out. A set of PVB adults were released in 2001 (see above Section 5.3), because the site appears suitable.

**Polygon 14B.** The polygon appears to have native terrace soil cover with a sparse native shrub cover. A diverse coastal sage scrub assemblage may be appropriate for revegetation in this polygon. Future study may demonstrate otherwise, depending on edaphic parameters that may suggest grassland as the more likely climax community.

**Polygon 15A.** The polygon combines both terrace and slope. The terrace portion is partially degraded, but with shallow soil and a grass and deerweed aggregate. The portion is routinely mowed because of proximity to a storage tank. The slope is mostly native terrace slope soil covered predominantly with mature *Artemisia*. Volunteers have weeded a dense stand of castor bean in an erosion barranca caused by concentrated water flow from the terrace. No planting has been undertaken and there are no plans for further treatment in the near future.

**Polygon 15B.** The substrate appears to be entirely excavated subsoil from tank construction that forms a steep slope dropping into the R1 riparian zone. The slope is covered with dense radish and totally lacking any native elements. We have performed no work on the polygon and regard the site as an end-game project for revegetation. When the latter is planned a coastal sage aggregate would be appropriate.

**Polygon 16A.** The substrate may be largely native soil, but there are virtually no native shrubs present. The site is degraded from old infrastructure and apparent disking. We cleared a ~0.5 ac section in late 2001 for establishment of an all *Astragalus* node to test PVB reintroduction in such an isolated case (see above). An irrigation system is being put in place and between 600–1000 container plants will be set out. Otherwise, the polygon is completely isolated from sites with any natural values and ecologically functions as an island within the DFSP arena.

**Polygon R1.** The polygon is about 70% covered with mature riparian vegetation, native willow (*Salix* spp.) and mulefat (*Baccharis salicifolia*). The soil is alluvial with steep sides cut into the sedimentary terrace soil. There is substantial rubble from broken concrete and other trash. The canyon is the lower reach of George F Canyon and portions may contain old contaminated debris. However, the site has substantial wildlife value for birds and the only population of tree frogs (*Hyla* sp.) noted at DFSP. Nothing has been done on the site, nor is any work planned. There are some non-native *Arundo* patches and pepper and myoporum trees interspersed that should be removed.

**Polygon R2.** The substrate is alluvium of various depths, in some places shallow above sedimentary strata. There is a small mature stand of willow in the western section. Since 1994 riparian elements have expanded following our efforts to clear. Planting on a casual basis since 1998 has expanded cover over the lower 50% of the site with added diversity using species introduced from upper George F Canyon. A partial irrigation system installed.

**Polygon R3.** Substrate is entirely alluvium of varying depth above the underlying sedimentary strata. The hydrology of the polygon was modified by construction of a berm that contains the old streambed on the east border. This has changed the underground flow pattern causing varying water depth, which increases uncertainty of maintaining a riparian assemblage of trees over portions of the area. The north section was well watered when the upslope Navy housing was occupied and the landscaping irrigated. Since the irrigation was terminated in 1999, the larger willows died. Irrigation has been installed across the southern reach, which has permitted setting out a diverse shrub bank community. Observations over the next few years will determine whether a riparian tree assemblage can be maintained naturally.

## 7 Invertebrate community composition as an indicator of restoration success (Travis Longcore[1])

### 7.1 Introduction

Ecological restoration properly should have the goal of re-creating the entirety of an ecosystem (National Research Council 1992), including the invertebrate fauna (Longcore and others 2000; Longcore 1999). The recovery of the invertebrate fauna on restored sites has been used to assess the performance of restorations (Andersen and Sparling 1997; Greenslade and Majer 1993; Jansen 1997; Mattoni and others 2000; Parmenter and MacMahon 1990; Peters 1997; Wheater and others 2000; Williams 1993). Such attempts, however, depend on the ability to compare the site to reference conditions adjacent to or near the site if the previous condition of the site being restored is unknown (White and Walker 1997).

Reference sites are used to describe the conditions — species composition, abundance, diversity — of the natural habitat that is the goal of a restoration project. Comparison with such conditions allows an evaluation of the progress of the restoration. The site for the measurement of these conditions is usually not the restoration site itself, because it is presumably already degraded, unless surveys prior to degradation were made for some reason. Rather, it is most often a nearby, undisturbed habitat. The reference site may be measured simultaneously with the restoration with which it is to be compared, or measurements may be taken and established during previous years. For the purpose of defining reference conditions for arthropods, the high yearly variation in abundance exhibited by this phylum in areas of Mediterranean climate recommends where possible that comparisons of arthropod communities at restorations and reference sites be conducted with data collected during the same period, under the same climatic conditions (Longcore 1999). Alternatively, a long-term dataset (30 years) could be used because it would incorporate the full range of climatic variation. Few such datasets exist but shorter datasets collected at reference sites during previous years can be used to define a range of variation exhibited by arthropod communities (Samways 1990; Wolda 1992) and to identify species that may be good indicators because their responses to habitat conditions transcend yearly variation. I (Longcore 1999) used the results of a five-year monitoring effort to describe the composition of pitfall-trapped arthropods in coastal sage scrub and their interannual and seasonal variation.

While establishing reference conditions for restorations is attractive in that they provide a goal for the restorationist to achieve, they generally fail to provide for assessment of alternative outcomes of the restoration project. That is, reference conditions provide a definition of the ideal outcome of restoring a community untouched by anthropogenic disturbance. Equally useful for purposes of evaluating restorations is to describe a range of conditions with which to compare the restoration. For example, a restored habitat may be similar to a native habitat that has been undergoing succession without interference. For this reason, I used the concept of "comparison sites" that exhibit a set of different conditions with which to compare the restoration. This

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[1] This chapter is modified from a doctoral dissertation by Travis Longcore (1999) and has been submitted for publication elsewhere.

differs from the usual definition of reference conditions, which does not include disturbed habitats.

This chapter develops quantitative methods to compare unreplicated restorations based on the results of arthropod monitoring with pitfall traps. This goal requires investigation of the relationship between vegetation characteristics and arthropods for two reasons. First, the structure of arthropod communities at restored sites may be influenced by a number of ecological factors. Studies of old field succession have shown a positive relationship between plant species and structural diversity and arthropod diversity (Hawkins and Cross 1982; Murdoch and others 1972; Parmenter and MacMahon 1987; Parmenter and MacMahon 1990; Southwood and others 1979; Stinson and Brown 1983). Second, plant community characteristics are those used to measure success of restorations in a regulatory context.

The literature suggests some methods of comparing unreplicated restoration attempts. Arthropod guild structure could be important, and a good indicator of a successful restoration should be rare, predatory arthropods (Peters 1997). Because other studies of guild structure during succession use more comprehensive sampling measures (*e.g.*, sweep netting, vacuuming) than the present study (pitfall trapping), the guild proportions shown in those studies (Hendrix and others 1988; Moran and Southwood 1982; Teraguchi and others 1977) are not likely to be replicated by pitfall trapping. However, comparison of guild structure among sites should be illustrative.

Exotic arthropods will also likely be an indicator of restoration success or failure. Argentine ants (*Linepithema humile*) have received the most attention as invaders in Mediterranean ecosystems (Cole and others 1992; Erickson 1971; Holway 1995; Holway 1998; Human and Gordon 1997; Kennedy 1998; Suarez and others 1998; Suarez and others 2000; Ward 1987; Way and others 1997), but several other species (*Armadillidium vulgare*, *Porcellio* spp., *Forficula auricularia*, and *Dysdera crocata*) are likely also important (Barthell and others 1998; Bolger and others 2000; Langston and Powell 1975; Paris 1963; Paris and Pitelka 1962).

Based on this literature, the null hypotheses to be addressed in this chapter are:

- Restored and comparison sites have identical terrestrial arthropod communities, as measured by composition, abundance, and richness.
- Restored and comparison sites exhibit similar abundance and species richness of exotic arthropods.
- Terrestrial arthropod community structure in restored and comparison sites is not explained by plant taxonomic or structural diversity.
- Exotic species have no effect on overall arthropod species diversity.

Monitoring sites in the present study were chosen to minimize the effects of size and isolation. All of the restoration sites and most of the comparison sites are contiguous with undisturbed habitat blocks.

## 7.2 Methods

### 7.2.1 Study localities and sites

The comparison localities are those described as "disturbed" and "undisturbed." The undisturbed comparison localities provide "reference" conditions *sensu* White and Walker (1997).

**Defense Fuel Support Point (DFSP).** DFSP is the only currently known locality for the federally endangered Palos Verdes blue butterfly. While much of the 120-ha installation was disturbed during the 1940s to construct underground fuel tanks, a contiguous area of approximately 11 ha of coastal sage scrub was left undisturbed. The integrity of these areas is indicated by the presence of mature *Opuntia prolifera* and intact cryptobiotic crusts. Six localities were sampled within the facility. **DFSP-Office-Polygon 8 (*undisturbed*).** This area is undisturbed with high native cover of mature coastal sage scrub**. DFSP-Disaster Shelter-Polygon 6 (*undisturbed*).** This area has high native plant cover, but is not diverse. **DFSP-Locoweed-Polygon 13A (*undisturbed*).** This area has high native plant cover, some invading pepper trees. **DFSP-South End-Polygon 14A (*disturbed*).** This area is in early succession following disturbance for the construction of a drainage channel and subsequent mowing. Mowing stopped in the early 1990s and recolonization of native shrubs was allowed. **DFSP-Hill-Polygon 1A (*disturbed*).** This is an area in early succession on fill left from a construction project in 1987.

**Landslide Area.** Geologically unstable soils have prevented the development of a large area on the southern slope of the Palos Verdes peninsula. Consequently, significant tracts of coastal sage scrub remain and are currently the subject of a comprehensive conservation planning process (California Department of Fish and Game 1999). Several localities with mature coastal sage scrub were sampled along the public right of way through this area: **Kelvin Canyon** (*undisturbed*), **Portuguese Canyon (*undisturbed*)**, and **Klondike Canyon (*undisturbed*)**. **Fennel Hill (*disturbed*)** is a highly disturbed locality in the landslide area, dominated by exotic species. The disturbance was likely some combination of grazing or dry farming during the early part of the 20th century through at least the 1950s. It has been left fallow — perhaps occasionally disked — and has been colonized by exotic fennel (*Foeniculum vulgare*).

**Inspiration Point (*undisturbed*).** This locality has high native shrub cover on a coastal bluff. It was farmed in the 1920s but is now part of a public park. Because of the long time since disturbance and high native cover, this locality was considered an undisturbed site.

**Malaga Canyon (*disturbed*).** This locality is adjacent to a golf course and a predominantly riparian area, but with significant coastal sage scrub components. It was disturbed by a public engineering project in 1996.

**Crystal Cove and Pelican Point (*restoration*).** Two localities in the Crystal Cove State Park were included in the study: Pelican Point and Crystal Cove. Both sites are on a coastal bluff in an area with a history of agricultural exploitation, and it is likely that both sites were dry farmed. They are however, contiguous with the bluff face, which has never been substantially disturbed and should have provided a refuge for the terrestrial arthropod community. According to records provided by park staff, Pelican Point was both seeded and planted in 1984 and Crystal Cove was seeded in 1985. The revegetation effort at the Park has been documented (Hillyard 1990).

**Ocean Trails (*restoration*).** The Ocean Trails West Bluff preserve was revegetated as compensatory mitigation for the construction of a golf course on a coastal bluff. The 1.8-ha site is adjacent to undisturbed bluff face. The site had been used for agriculture through the first half of the 1900s and had lain fallow with some reestablishment of some native shrubs for at least 30 years prior to revegetation. The locality was heavily covered with invasive exotic plant species, including fennel (*Foeniculum vulgare*) and mustard (*Hirschfeldia* sp.). The revegetation protocol included mowing followed by disking and seeding, then another round of disking and seeding and the final planting of container stock. Final planting was completed in the fall 1994.

**DFSP-Restoration-Polygon 9B.** This locality is part of an ongoing revegetation effort focused on providing habitat for the federally endangered Palos Verdes blue butterfly (Mattoni 1994). Because of its location on property used as a military installation for the last 50 years, it has not been actively used for agriculture, although land use prior to the construction of the installation is unknown. It was likely disturbed in the last ten years by the construction of a small runoff channel through the site. During 1997 the site was cleared of exotic species (mostly Mediterranean grasses) by hand and planted with native shrub species. Although irrigated during shrub establishment during the fall of 1997, it was not irrigated during the study period.

### *7.2.2 Sampling methodology*

**Pitfall Trapping.** I sampled terrestrial arthropod communities at each restoration and comparison locality with pitfall traps monthly during 1998. This continued monitoring for comparison sites that had been begun in 1994. Pitfall traps consisted of two cylindrical one-quart plastic containers each 10 cm across and 13 cm deep, nested together and buried so that the rim of the inner container is flush with the soil. Each trap was covered with a 20-cm square 0.5 cm thick plywood lid supported about 2 cm above the rim by wooden legs. Traps were filled to a depth of 2 cm with ethylene glycol (commercial antifreeze) as preservative, and trap contents were collected monthly into 200-ml snap top plastic vials and returned to the laboratory for sorting. Each locality was sampled at 2–3 trapping “sites” separated by 20 m as topography and vegetation allow, which is sufficiently distant to avoid sampling bias (Ward and others 2001). More traps in close proximity previously had been shown to be duplicative in a coastal dune environment (Mattoni and others 2000).

Data were entered into *Biota*, a relational database designed explicitly for biodiversity data and collection management (Colwell 1996). The program *EstimateS* (Colwell 1997) was used to calculate species diversity measures, including Fisher’s alpha, which was chosen as the appropriate measure based on the observed species abundance pattern.

Sampling for the restorations at Crystal Cove State Park (Crystal Cove/Pelican Point) was started three months later than the other restorations, so nine months of samples (April through December) were used for analyses that compared sites at the restoration localities with sites at comparison localities. Sites with more than one unsuccessful trap month were excluded from analyses involving comparisons of restorations with reference sites. This is necessary because of the observed seasonal variation in arthropod abundance (Longcore 1999). Use of data from other years or different numbers of successful samples would not provide an accurate comparison of the community at each site. However, the use of the shorter time span for analysis does decrease the ability to discriminate patterns. Some relationships that have shown to be significant using more samples are still evident but with less statistical certainty with the use of fewer samples. Analysis that involved only the comparison sites used twelve months of data.

Each species was assigned to a guild based on available reference materials (Arnett 1993; Borror and others 1989; Borror and White 1970; Hogue 1993; White 1983). The guilds were phytophage, predator, scavenger, ant, and parasite.

**Vegetation Sampling.** Vegetation characteristics surrounding each of the 2–3 pitfall traps (sites) at each locality were measured by placing a sampling pin at 30 random locations from a 10-m diameter circle around the trap. The 2-m sampling pin was marked at 20-cm intervals. For the first 10 pins, the number of touches of each plant species in each of the 10 height classes was recorded. For the remaining 20 locations all species touched by the pin were recorded. From these data, a plant spatial diversity was quantified using the technique described by Hendrix *et al.* (1988). The height index is used as a measure of structural complexity (Gibson and others 1987; Hendrix and others 1988):

$$\text{height index} = \frac{\sum_{i=1}^{N}\left(h_i \times n_i\right)}{\sum_{i=1}^{N}\left(n_i\right)}$$

where $h$ = the midpoint of each height class $i$, $n$ = the number of touches at height class $i$, and $N$ = number of height classes represented by the sample (Hendrix *et al.* 1988). Plant species touches from all 30 locations were used to calculate native species richness, Shannon-Wiener diversity, and the percent native cover.

### *7.2.3 Statistical techniques*

**Analysis of Variance.** Differences in arthropod and vegetation parameters between sites were compared using analysis of variance in which reference and disturbed sites (*sensu* White and Walker 1997) were each treated as one group and compared to each of the restoration sites separately. All pairs were compared using the Tukey-Kramer Honest Significant Difference (HSD) test (Kramer 1956). For arthropod data, Student’s t was used to compare diversity (Fisher’s alpha), number of species, and number of individuals. Vegetation parameters compared were diversity (Shannon-Wiener), number of touches, height index, number of native species, and percent native cover.

**Multiple Regression.** Relationships between vegetation and arthropod parameters were tested for each of the arthropod variables by building a stepwise multiple regression model with forward entry of vegetation measures. Vegetation measures (number of native plant species, Shannon-Wiener diversity, height index, number of touches) were used to create models for arthropod diversity (Fisher’s alpha), number of species, and number of individuals. Models were created for reference and disturbed sites alone, and for all sites together, to investigate whether arthropod communities in restoration sites responded differently than other sites. To identify the effect of exotic arthropods on overall arthropod diversity, a model was also created to explain arthropod diversity using abundance of exotic arthropod species.

**Cluster Analysis.** Ward's method of agglomerative clustering was used to produce dendrograms based on the abundance of arthropod species. Similar site level analyses were conducted based on plant species abundance and vegetation structure using number of touches per height class as input data.

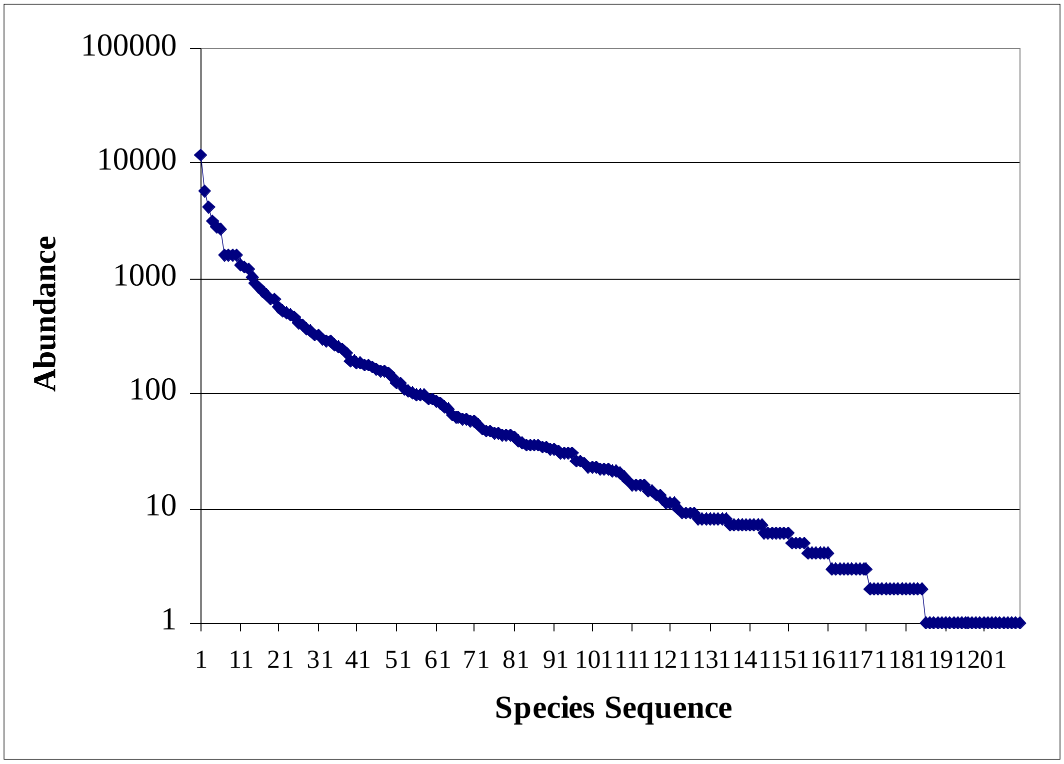

**Figure 7-1. Number of individuals per species (rank abundance curve) for all collections, 1994–1998. Species are arranged in decreasing abundance along the x-axis. Note that the y-axis is on a log-10 scale.**

**Correspondence Analysis.** All specimen numbers for the period with complete sampling, April–December 1998, were log transformed to normalize their distribution. Sites and arthropod species were ordinated using detrended correspondence analysis (ter Braak 1987–1992; ter Braak 1996; ter Braak and Prentice 1988). This method assumes an underlying normal distribution of the data in response to environmental variation and reduces the variation to several unrelated axes. Normal response to temporal variation in environmental parameters was evident in an analysis of seasonal abundance (Longcore 1999), so the assumption of a normal response curve to spatial variation is supported. The localities are assigned scores and can then be plotted on two axes.

All statistical tests were performed using JMP statistical software (SAS Institute 1997). Correspondence analysis was completed with CANOCO (ter Braak 1987–1992).

**Table 7-1. Summary statistics for arthropod diversity and abundance by category (mean±S.E., standard error uses a pooled estimate of error variance). Summary vegetation statistics by site history (mean±S.E.). Superscripts indicate significantly different groups ($p<0.05$).**

| | Disturbed | Reference | DFSP-Restoration | Ocean Trails | Crystal Cove/ Pelican Point |
|---|---|---|---|---|---|
| Number of sites | 7 | 19 | 3 | 3 | 4 |
| **Arthropods** | | | | | |
| Fisher's alpha | 9.56±1.27 | 9.49±1.49 | 8.75±1.39 | 7.16±0.88 | 5.75±0.61 |
| Total species observed | 34.14±5.27 | 32.93±5.47 | 42.00±6.08 | 26.00±2.00 | 29.00±3.92 |
| Mean specimens | 43.13±22.19 | 38.02±17.64 | 124.77±27.69 | 31.34±5.14 | 105.46±38.29 |
| **Vegetation** | | | | | |
| Shannon-Wiener diversity | 1.74±0.11$^{a}$ | 1.62±0.09$^{a}$ | 2.27±0.02$^{b}$ | 1.61±0.08$^{a}$ | 1.85±0.09$^{a}$ |
| Number of native species | 2.00±0.44$^{a}$ | 4.79±0.41$^{b}$ | 6.00±0.58$^{b}$ | 3.67±0.33$^{ab}$ | 6.83±0.70$^{b}$ |
| Proportion native cover | 0.19±0.05$^{de}$ | 0.73±0.04$^{abc}$ | 0.38±0.03$^{bcde}$ | 0.52±0.02$^{cd}$ | 0.86±0.05$^{ab}$ |
| Number of touches | 146.57±23.81$^{ab}$ | 173.74±9.14$^{b}$ | 75.333±12.17$^{a}$ | 120.67±6.84$^{ab}$ | 131.67±7.34$^{ab}$ |
| Height index | 43.22±8.00$^{ab}$ | 48.38±2.36$^{b}$ | 21.13±1.48$^{a}$ | 34.84±3.39$^{ab}$ | 51.68±4.33$^{b}$ |

## 7.3 Results

### *7.3.1 Arthropod data*

The 1,293 successful collections averaged 45.99±40.38 S.D. specimens of 9.11±3.65 S.D. species. The distribution of specimens per collection was not normal because of large specimen counts in some collections. Log transformation normalized the number of specimens per collection.

The rank species abundance curve for the entire collection indicates that the distribution of species follows a log normal distribution (Figure 7-1) (Magurran 1988). Individual site rank abundance curves revealed a log series distribution. Based on this species distribution, Fisher's alpha was chosen as the appropriate measure of arthropod diversity, because it assumes an underlying log series distribution. Fisher's alpha has the added advantage of a low sensitivity to sample size (Magurran 1988; Taylor 1978).

Using Fisher's alpha as the appropriate measure of arthropod diversity, the diversity of arthropods at undisturbed reference sites was greater than the two older restoration sites, Ocean Trails ($p<0.1$) and Crystal Cove/Pelican Point ($p<0.05$). DFSP-Restoration was not significantly different. When twelve monthly samples were used for the Ocean Trails comparison, confidence increased ($p<0.05$). The differences in species number were insignificant, with DFSP-Restoration recording the maximum number of arthropod species and the other two restorations with the fewest. DFSP-Restoration and the combined Crystal Cove/Pelican Point restoration localities had significantly more individuals than all other sites (Table 7-1).

### *7.3.2 Vegetation data*

Results from vegetation sampling show few differences between disturbed, reference, and the restoration sites (Table 7-1). DFSP-Restoration was significantly more diverse than the reference sites, and it had significantly fewer plant touches than did any of the other categories. The disturbed sites had significantly fewer native plant species than did the reference sites, the Crystal Cover restorations, and DFSP-Restoration. DFSP-Restoration had a significantly lower height index than the reference sites, but not the other categories. The Crystal Cove restorations had a significantly larger percent native plant cover than disturbed sites or the other two restorations, while the reference sites had significantly larger percent native cover than disturbed sites and DFSP-Restoration.

**Table 7-2. Multiple regression results: explanation of arthropod species richness by vegetation parameters for reference and disturbed sites combined.**

| Model ($r^2$) | Variable | Coefficient | Standard Error | T score | Prob |
|---|---|---|---|---|---|
| I. Arthropod species richness, all sites by vegetation (0.48) | Intercept | 47.25 | 2.96 | 15.96 | <0.0001 |
| | Number native plant species | 1.12 | 0.35 | 3.19 | 0.004 |
| | Vegetation height index | -0.17 | 0.05 | -3.24 | 0.004 |
| II. Arthropod diversity, all sites by vegetation parameters (0.66) | Intercept | 12.05 | 0.92 | 13.03 | <0.0001 |
| | Touches 40–60 cm | 0.09 | 0.03 | 3.47 | 0.0022 |
| | Vegetation height index | -0.08 | 0.02 | -4.88 | <0.0001 |
| | Percent native cover | 2.06 | 0.87 | 2.37 | 0.027 |
| III. Arthropod diversity, comparison sites, by exotic arthropod abundance (0.29) | Intercept | 13.13 | 0.49 | 26.97 | <0.0001 |
| | *Forficula auricularia* | -1.89 | 0.61 | -3.10 | 0.005 |
| IV. Arthropod diversity, all sites, by exotic arthropod abundance (0.48) | Intercept | 10.73 | 0.46 | 23.25 | <0.0001 |
| | *Dysdera crocata* | -2.61 | 1.46 | -1.79 | 0.085 |
| | *Linepithema humile* | -1.03 | 0.31 | -3.34 | 0.002 |

### *7.3.3 Vegetation-arthropod relationships*

Two vegetation factors significantly explained the number of arthropod species found at disturbed and reference sites combined: 1) a positive relationship with the number of native plant species ($p<0.004$) and 2) a negative relationship with vegetation height index ($p<0.004$) (model $r^2=0.48$) (Table 7-2). The number of arthropod individuals had three predictors: 1) vegetation Shannon-Wiener diversity, 2) number of native plant species, and 3) number of touches. This relationship is largely an artifact of the superabundance of a few species of exotic arthropods. These results were not explored further because of the large effect of exotic arthropods on total arthropod individuals. Arthropod diversity was predicted by: 1) the number of 40–60 cm height class touches ($p<0.002$), 2) vegetation height index ($p<0.0001$), and 3) percent native cover ($p<0.027$) (Table 7-2).

For reference and disturbed sites, the model for arthropod diversity based on exotic species included one species, the European earwig (*Forficula auricularia*), which explained 29% of the variation in overall arthropod diversity (Table 7-2). The model including all sites showed significant predictive value for abundance of 1) Argentine ants (*Linepithema humile*), and 2) the sowbug killer (*Dysdera crocata*) with an overall model explanation of 48% (Table 7-2).

**Table 7-3. Mean percentage of arthropods by guild and nativity. Guilds are ants (Ant), phytophages (Phyt), predators (Pred), parasites (Para), and scavengers (Scav).**

| Locality | Exotic Ant | Exotic Phyt | Exotic Pred | Exotic Scav | Total Exotic | Native Ant | Native Para | Native Phyt | Native Pred | Native Scav |
|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | | | | | | | | | | |
| DFSP-Office | 28.3% | 0.1% | 0.5% | 14.2% | 43.1% | 0.8% | 0.4% | 8.3% | 29.5% | 17.9% |
| DFSP-Locoweed | 24.5% | 0.0% | 0.4% | 15.7% | 40.6% | 0.4% | 0.7% | 9.8% | 18.4% | 30.1% |
| DFSP-Disaster | 17.3% | 0.0% | 0.4% | 11.0% | 28.8% | 0.5% | 1.3% | 9.4% | 18.7% | 41.4% |
| Kelvin Canyon | 13.1% | 0.0% | 1.0% | 27.6% | 41.7% | 0.7% | 0.2% | 4.0% | 27.7% | 25.7% |
| Klondike Canyon | 22.6% | 0.1% | 0.6% | 16.7% | 40.0% | 0.1% | 0.8% | 5.4% | 11.8% | 41.9% |
| Portuguese Canyon | 20.7% | 0.0% | 0.4% | 10.0% | 31.1% | 0.7% | 0.5% | 7.6% | 24.9% | 35.2% |
| Inspiration Point | 7.0% | 0.2% | 0.7% | 19.9% | 27.9% | 0.1% | 0.6% | 3.8% | 27.7% | 39.8% |
| **Disturbed** | | | | | | | | | | |
| Fennel Hill | 23.2% | 0.0% | 0.8% | 27.1% | 51.1% | 0.1% | 0.8% | 3.2% | 11.1% | 33.8% |
| Malaga Canyon | 14.1% | 0.0% | 0.4% | 4.4% | 18.9% | 0.4% | 0.1% | 11.6% | 25.8% | 43.3% |
| DFSP-Hill | 7.1% | 0.0% | 0.2% | 19.7% | 27.0% | 0.3% | 0.6% | 5.5% | 14.7% | 51.9% |
| DFSP-South End | 5.9% | 0.0% | 0.2% | 12.0% | 18.1% | 15.9% | 0.2% | 2.0% | 21.1% | 42.7% |
| **Restoration** | | | | | | | | | | |
| Pelican Point | 54.3% | 0.0% | 1.4% | 28.5% | 84.2% | 0.0% | 0.0% | 8.1% | 5.1% | 2.5% |
| Crystal Cove | 40.6% | 0.0% | 0.4% | 22.8% | 63.8% | 2.7% | 0.3% | 7.7% | 12.6% | 12.8% |
| Ocean Trail | 21.0% | 0.0% | 1.2% | 13.0% | 35.3% | 0.0% | 0.4% | 3.4% | 41.0% | 20.0% |
| DFSP-Restoration | 15.3% | 0.0% | 0.1% | 38.2% | 53.6% | 12.4% | 0.4% | 2.5% | 9.2% | 21.8% |

### *7.3.4 Arthropod guild composition*

The Argentine ant dominated the exotic species and guild structure (Table 7-3), ranging from 5.9–54.3% of individuals at sites. Sites with lower percentages of Argentine ants had correspondingly larger proportions of native scavengers. All guilds were represented, but the trapping methodology resulted in a majority of ants, predators, and scavengers, rather than phytophages. Percentage native predators ranged from 5.1–41.0%. The extremely high value for predators at Ocean Trails resulted from an abundance of spiders. Mean percentages for each native guild were lower in restorations than reference sites. The lower percentages of native guilds is especially apparent for native scavengers, which were less prevalent at restored sites. With the exception of spiders at Ocean Trails, native predators constituted a significantly smaller proportion of captures at restorations than reference sites.

### *7.3.5 Cluster analysis*

Cluster analysis of sites using vegetation height class data produced three distinct clusters of short, medium, and tall vegetation (Figure 7-2). Sites from the same locality did not cluster together, and samples from restoration, disturbed, and reference sites clustered with each other and did not produce exclusive groups.

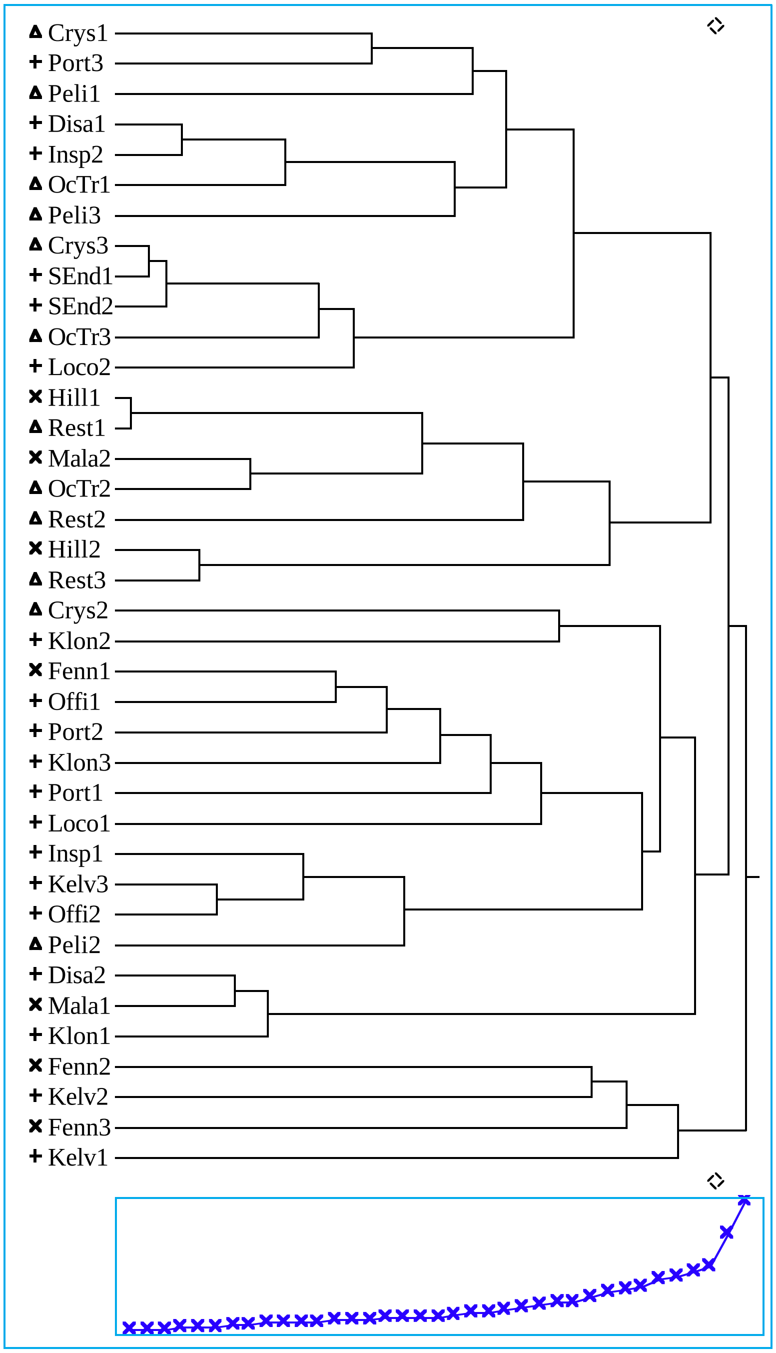

**Figure 7-2. Cluster analysis (Ward's method) of restoration and comparison sites based on vegetation structure as measured by touches per height class. Note that the clusters formed include restored, disturbed, and reference sites with each other. The plot beneath the dendrogram has a point for each cluster join. The y-axis is the distance that was bridged to join the clusters at each step. Symbols at left indicate reference (+), disturbed (X), and restoration sites (Δ).**

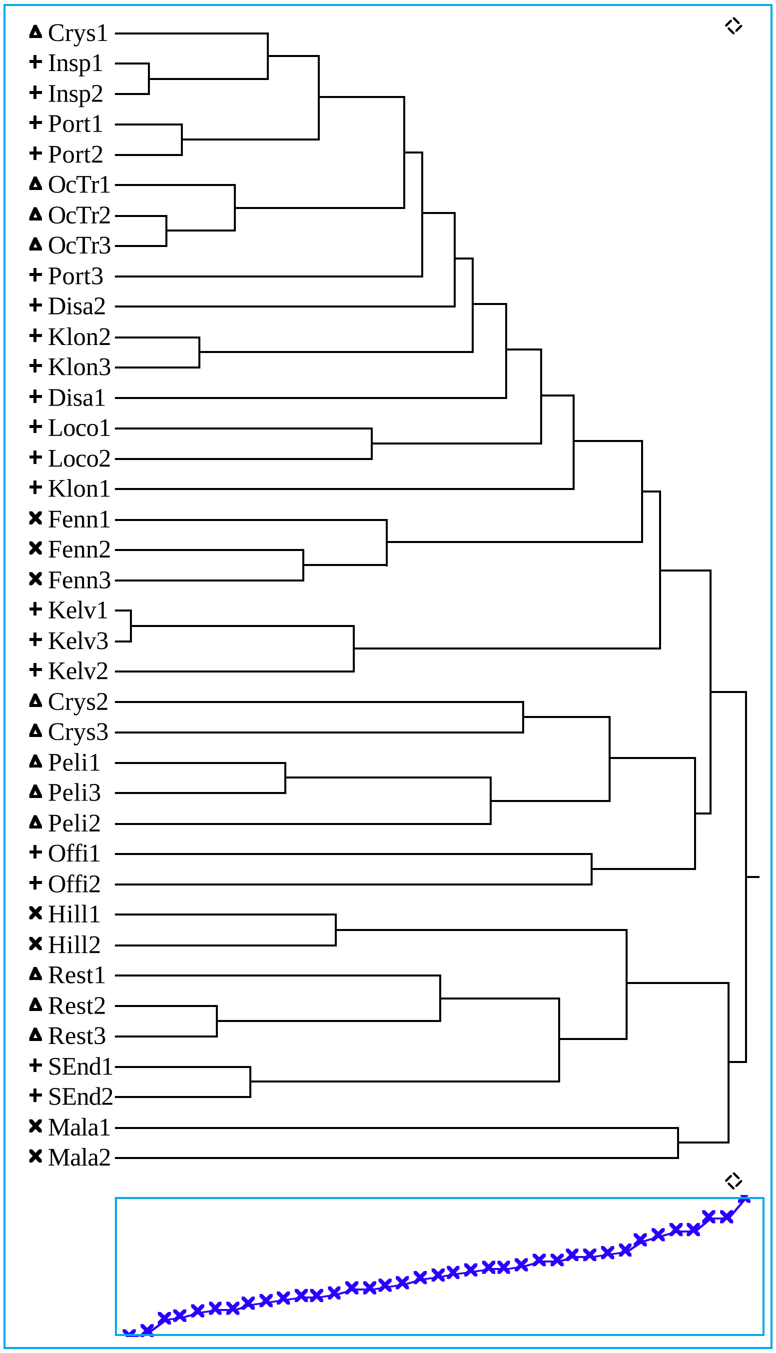

**Figure 7-3. Cluster analysis (Ward's method) of restoration and comparison sites based on log-transformed number of touches for each plant species. Note increased cohesion between sites at a locality when compared to structural diversity, but also clustering of restorations with reference and disturbed sites. Symbols at left indicate reference (+), disturbed (X), and restoration sites (Δ).**

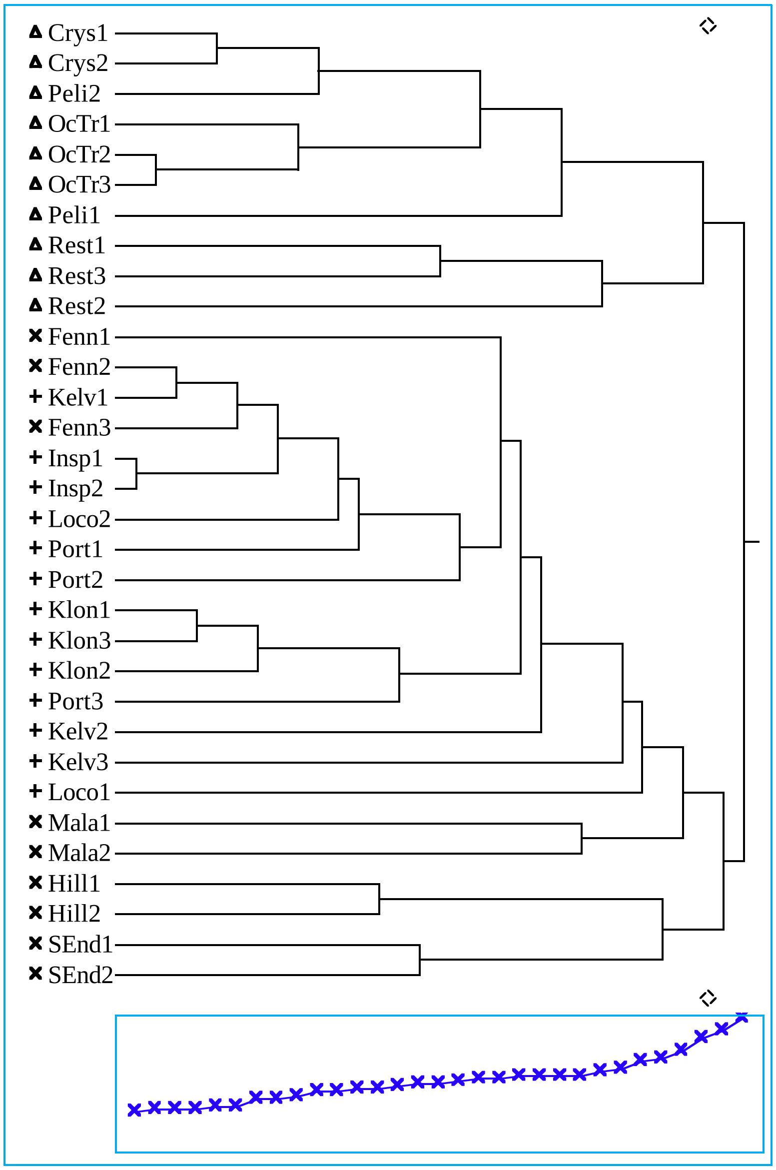

**Figure 7-4. Cluster analysis of restoration and comparison sites based on arthropod species and abundance. Sites with missing months of data are omitted. Note that all restorations are separated from other sites at first division. Symbols at left indicate reference (+), disturbed (X), and restoration sites (Δ).**

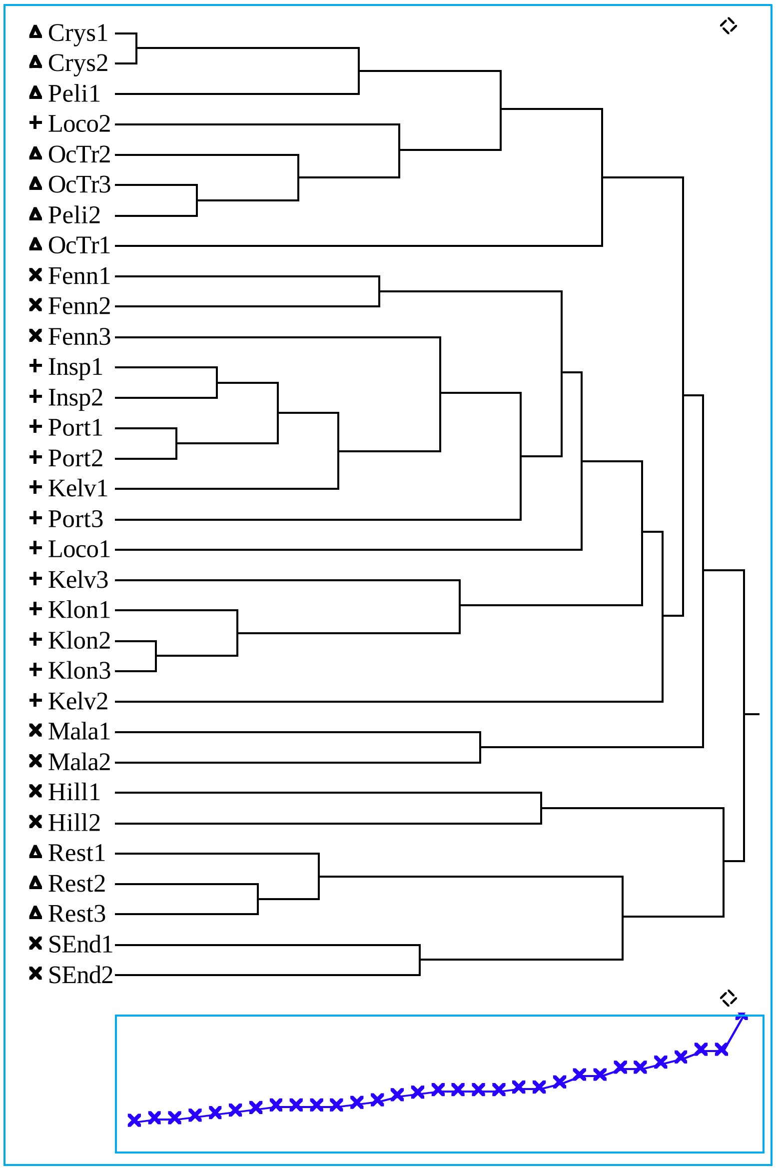

**Figure 7-5. Cluster analysis of restoration and comparison sites based on abundance of native arthropods only. Symbols at left indicate reference (+), disturbed (X), and restoration sites (Δ).**

The dendrogram produced for plant species did show cohesion among samples from the same site; all terminal pairs contained samples from the same site and 8 of 15 sites formed exclusive clusters (Figure 7-3). DFSP-Restoration clustered with the disturbed sites at the first level, with the other restoration sites interspersed with the reference sites.

Cluster analysis of sample sites based on arthropod species forms three large clusters: 1) DFSP-Hill and DFSP-South End, 2) all three restorations, and 3) all other sites (Figure 7-4). Seven of 14 sets of sites from the same locality formed exclusive clusters and all terminal pairs but one were sites from the same locality. Of the disturbed sites, Fennel Hill clustered in with reference sites. The height of vegetation at Fennel Hill influences its arthropod community. As shown below, the non-restoration sites are separated by differences in vegetation height.

When exotic arthropods were removed from the clustering analysis, the distinctions between restorations, disturbed, and undisturbed sites largely remained. The two interesting differences were: 1) DFSP-Restoration sites clustered with the other disturbed sites at DFSP, rather than with the other restorations, 2) DFSP-Locoweed 2 clustered with the restorations at Crystal Cove.

**Table 7-4. Detrended correspondence analysis of arthropod communities.**

| Axes | 1 | 2 | 3 | 4 | Total inertia |
|---|---|---|---|---|---|
| Eigenvalues | 0.388 | 0.190 | 0.120 | 0.083 | 2.866 |
| Lengths of gradient | 2.660 | 2.199 | 1.833 | 1.668 | |
| Cumulative percent variance of species data | 13.6 | 20.2 | 24.4 | 27.6 | |

### *7.3.6 Detrended Correspondence Analysis*

The log-transformed arthropod abundance data were used in detrended correspondence analysis. Detrended correspondence analysis (Table 7-4) separated restoration from reference and disturbed sites on the first axis (Figure 7-6). Restorations had significantly ($p<0.01$) higher scores on the first axis than reference and disturbed sites; and although not as pronounced, disturbed sites had significantly ($p<0.05$) higher scores than reference sites. A linear regression showed the first axis to be significantly negatively correlated with arthropod diversity ($r^2=0.46$, $p<0.0001$) and positively correlated with most exotic species. The second axis separates early succession disturbed sites from other reference sites along a height gradient. The axis is significantly correlated with the height index of the vegetation ($r^2=0.54$, $p<0.0001$).

## 7.4 Discussion

Of the three restoration sites sampled, none had developed an arthropod community that resembled that of undisturbed or disturbed native coastal sage scrub (Figure 7-6). Restoration sites, in general, exhibited lower arthropod diversity and a preponderance of exotic arthropod species. The time elapsed since revegetation effort had no discernable effect on arthropod community structure; there was no gradual return of the community over time to a more natural structure. In fact, the oldest revegetation — Crystal Cove State Park — was dominated by exotic arthropods and exhibited extremely low arthropod diversity.

Vegetation parameters explained a substantial portion (48–66%) of the variation in arthropod communities in reference and disturbed sites. The one relationship found that is consistent with succession theory is that between arthropod diversity and vegetation height and complexity. Southwood *et al*. (1979) described increasing insect taxonomic diversity while plant taxonomic and spatial diversity increase, followed by a decrease in insect taxonomic diversity with even higher spatial diversity but decreasing plant taxonomic diversity. Southwood *et al*. (1979) described this relationship as an arch in insect taxonomic diversity with respect to succession over time. When including the disturbed sites on the continuum of height indexes documented in the study, there is an arch in arthropod species diversity with the height of vegetation. The subsequent model to describe arthropod diversity by site class data further illuminated this relationship with respect to terrestrial arthropods measured by pitfall trapping.

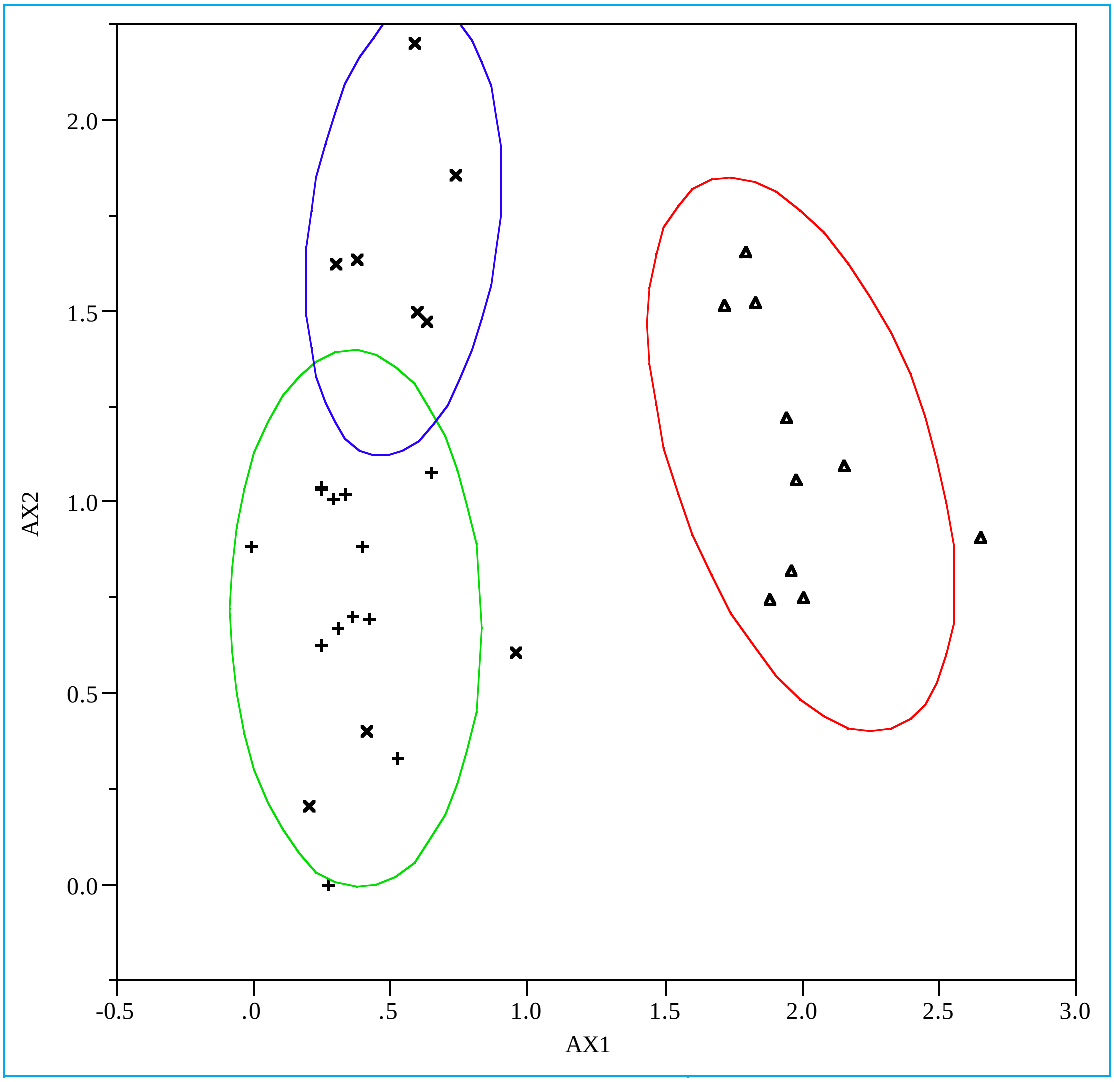

**Figure 7-6. Detrended correspondence analysis of arthropod species and site data. Bivariate ellipses show clusters based on first two axes. Symbols indicate reference (+), disturbed (X), and restoration sites (Δ).**

Increased plant touches (*i.e.*, greater complexity) at 40–60 cm above the ground is correlated with higher arthropod diversity, while complexity at greater heights (and a correspondingly greater height index) was correlated with lower arthropod diversity. This relationship is not spurious, because height index and touches at 40–60 cm are positively, not negatively, correlated. Southwood *et al.*'s (1979) other predictor, plant diversity, was not found to have a significant relationship, but rather percent native cover emerged as a significant predictor of overall arthropod diversity at native coastal sage scrub sites.

For restoration sites, the percent native cover or the number of native plant species was not correlated with increased arthropod species richness or diversity. To the contrary, because of the high native cover of the Crystal Cove restorations and their equally low arthropod diversity, the relationship was the opposite of that expected. Furthermore, all of the restoration sites supported plant communities similar in species incidence and abundance to comparison sites. Vegetation at the DFSP restoration was similar to the early succession disturbed sites. However similar their vegetation to comparison sites, the restoration sites did not support similar arthropod communities. The cluster analysis and DCA strongly support this result as well.

The importance of exotic species in determining arthropod communities cannot be overstated. However, this effect was not uniform among reference, disturbed, and restoration sites. For reference and disturbed sites, one exotic species, *Forficula auricularia*, explained 28% of the variance in arthropod diversity. However, for all sites combined, two exotic species, *Dysdera crocata* and *Linepithema humile*, could explain 48% of the variance in overall arthropod diversity. First, this illustrates that the negative correlation between exotic species abundance and overall arthropod diversity is much stronger in restoration sites. This response is probably not the result of the invasion itself, but rather the site conditions that promote the overwhelming abundance of exotic species. Because even the most diverse of the reference sites had been invaded by exotic species, the difference in community structure between them and the restoration sites cannot be attributed to the presence alone of the exotics. Rather, it is likely that a history of intense disturbance and the absence of any remnant native arthropod community allows exotic species to dominate the habitat. The abundant presence of exotic arthropods inhibits invasion of the restoration by native arthropod species from adjacent source areas. This scenario is consistent with the application of “assembly rules” by which different stable communities depend on the order of species invasion (Diamond 1975). By contrast, the relatively high native arthropod diversity at the DFSP restoration in the face of rather high exotic species abundance reflects both its history of light disturbance and the avoidance of restoration techniques that would disrupt the native arthropod community.

Other measured variables cannot account for the distinctness of the arthropod communities at Ocean Trails and Crystal Cove/Pelican Point. The effect of regional changes in species composition (beta diversity) was eliminated from the dataset by dropping species found at fewer than three localities from the analysis. Distance to source areas was eliminated as a variable because each restoration was adjacent to native habitat, coastal bluff scrub in the case of Ocean Trails and Crystal Cove/Pelican Point and remnant coastal sage scrub at DFSP. Results from these localities illustrate that creation of a native plant community does not necessarily result in the re-creation of a native arthropod community. Site disturbance history, assembly rules, and restoration technique remain as probable explanations of their depauperate character.

In addition to the overall differences in arthropod diversity and exotic species abundance between native and restored sites, several species were found only at reference sites, and these may serve as indicator species. The likely candidates for indicator species are the charismatic megafauna of the arthropod world, viz., large predators such as scorpions. Indeed, of the scorpion species found during the study, the burrowing scorpion (*Anuroctonus phaiodactylus*) and common scorpion (*Vejovis* sp.) were limited entirely to reference sites at Kelvin, Klondike, and Portuguese canyons. Stripe-tailed scorpions (*Paruroctonus silvestrii*) were predominantly found at reference sites but were also found in small numbers at each of the restorations.

Another unique predator, the trap door spider (*Aposticus* sp.), was found almost exclusively at reference sites, but with a few records from the restoration at Pelican Point. For other predators, no psuedoscorpions or assassin bugs were found at restoration sites but were found at reference sites. In addition, although not a predator, the sand roach (*Arenivaga* sp.) was found almost exclusively at reference sites, with only one individual found at the Ocean Trails restoration.

Despite the number of predator species missing from the sampled restorations, the restorations do have predators, but the pattern of predator abundance is not uniform among restorations. At Ocean Trails, 41% of the individuals captured were predators, mostly lycosid spiders. At Crystal Cove, 12.6% were predators, but only 5.1% were predators at Pelican Point. The DFSP restoration had 9.2% predators. The abundance of individuals of small predator species (spiders) may be the result of the absence of larger predators (*e.g.*, scorpions). Polis and others have described the dynamics of interference, usually predation, among potentially competing species (intraguild predation) (Holt and Polis 1997; Polis and McCormick 1986; Polis and others 1989). In experimental manipulations, removal of scorpions resulted in a doubling in spider number (Polis and McCormick 1986). Release from intraguild predation is a promising explanation for spider abundance in restoration sites. Similarly, the lack of intraguild predation likely explains the abundance of spiders found at old, isolated scrub fragments by Bolger and others (2000). Lack of population regulation by scorpions is a complementary hypothesis to their suggestion that a more productive detrital food web explains high spider abundance in old, isolated fragments (Bolger and others 2000).

The results support the overall objective of assessing restoration sites undertaken at different times with different methodologies using terrestrial arthropods. The arthropod species are distributed normally and exhibit sufficient variation to be used as metrics to evaluate restoration projects. In this respect, the study joins a number of other studies using arthropods to evaluate restoration projects. The clustering of replicate traps together in cluster analysis also reinforces the adequacy of the experimental design. Restoration sites had lower arthropod diversity than undisturbed reference sites. This difference was also evident in cluster analysis based on those data and could not be attributed to differences in vegetation at the sites. Detrended correspondence analysis also separated restoration sites from all others. The differences between restoration sites and their natural analogues were closely related to higher abundance of exotic arthropods at restoration sites. Rare predatory species are absent or present in significantly lower abundance at restoration sites.

While ecological restoration is used for compensatory mitigation (i.e. for replacement of natural communities lost through human activity), care should be taken to ensure that arthropod communities are re-created as well. For the restoration sites in this study, none supported an arthropod community similar to reference conditions. However, because of the largely native plant community and percent cover, each would have been considered sufficient under most current regulatory schemes. Restoration standards must be expanded to include measures of arthropod community structure or diversity or land managers and regulators risk the long-term erosion of native diversity through the replacement of native habitats by depauperate imitations.

## 8 Volunteers and outreach (Rudi Mattoni)

Because of the opportunities afforded at DFSP as an important case study for conservation biology and practice, all volunteers are given brief lectures on conservation biology. Many come away with fulfillment, knowledge, and the positive view of their experience with desire to return. The limiting factor is that the principal investigator and entire technical staff must actively participate in the events or program credibility is lost. The programs require a personal touch for success.

### 8.1 Rhapsody in Green

The past seven years has seen extensive involvement with volunteers. Rhapsody in Green was the first organization called and arrived a few months after the PVB was discovered. Volunteers began work on the obvious needs to clear weeds. Rhapsody in Green has provided an average of 35 volunteers on the first Sunday of each month since 1994. These individuals devote about 1,000 hours per year in nursery operations, clearing, and planting.

The driving force of Rhapsody in Green is the couple of Jon Earl and Ellen Petty. They originally started working with Rudi Mattoni on the El Segundo dunes restoration project in 1987, and were instrumental in clearing ~12 ha and planting over 10,000 plants. Innovative programs such as “adopt an acre” at that site combined with Earl’s public relations abilities were inspirational. The bottom line is that conservation organizations need hands-on personal involvement by principals if volunteers are to believe in the value of work undertaken.

### 8.2 Audubon YES!

The Audubon YES! (Youth Environmental Service) provided various sized groups of teenage students from local schools for a total of another 1,000 plus hours to the same tasks. The program was established by Jess Morton, a leading conservationist in San Pedro who also has been involved with the DFSP studies since the beginning. In addition several local colleges have sent students to participate in our activities.

### 8.3 UCLA Graduate School of Education & Information Studies

The UCLA teacher training program in science had three field courses at DFSP utilizing the “Butterfly Dreams” concept, developed by Mattoni, to focus on butterflies as a teaching tool for general and conservation biology. DFSP has been instrumental as a venue where direct involvement with field material — including the excitement of an endangered butterfly — is right at hand.

### 8.4 UCLA Department of Geography and The Urban Wildlands Group

When work at DFSP began in 1994, contracts for revegetation and PVB studies were administered through the UCLA Department of Geography, and implemented by a group of students and faculty interested in conservation known as the Urban Wildlands Group. (This organization since incorporated as The Urban Wildlands Group in 1999.) The Urban Wildlands Group has provided volunteer scientific and technical expertise since that time. Both Mattoni and Longcore have taught courses at UCLA and provided students with the opportunity of volunteering at DFSP. Also under the direction of Mattoni, DFSP has been valuable as a site for individual instruction in applied ecology. Several advanced students from UCLA Department of Geography have carried out special research projects to satisfy course requirements in research, Geography 199. Alison Lipman did work on one of the first projects, described above, studying manipulative effects on revegetation under controlled pesticide, solarization, and irrigation regimes, in addition to establishment of container and seed plants. Others have made monitoring surveys. Finally a 12-student course in field methods, Geography 159E, was instructed during spring 1998, with each student working on individual projects from DeWij competition experiments to various field manipulations. Seven of the 12 students conducted special project studies related to DFSP on topics related to conservation biology. Their studies covered the following topics:

Maura Heintz: Comparing the success of *Orthocarpus* in association with various host plants for conservation purposes at DFSP;

Christian Herrmann: Undermining success rates of a non-native plant through competition with a native grass;

Robb Hertz: Effect of mowing on native and non-native grasses in a disturbed *Stipa* grassland fragment at DFSP (Polygon 11A grassland);

Scott Goldberg: Managing a native bunchgrass community to decrease density of non-native invasive species (Polygon 11A grassland);

Raja Lahti: Population viability analysis, a lesson in scatology;

Kristeen Penrod: Analyzing the effectiveness of treatments for restoration of California grasslands;

Yin Lan Zhang. Estimation of competition between selected pairs of native annual plants under standard conditions in pots.

# 9 Summary of lessons, solutions, and future directions
(Rudi Mattoni)

## 9.1 PVB monitoring

PVB monitoring along the standard transect has been the cornerstone of the project. We anticipate that the program will continue indefinitely to provide quantitative data on the PVB and all other identifiable flying insects during the PVB flight period. Deviation from current implementation would jeopardize the ability to track population trends over time, which is the central purpose of the monitoring effort.

## 9.2 Adaptive monitoring

Adaptive monitoring refers to specialized surveys for monitoring new habitat and manipulative experiments. Key factor analysis may be considered, although such efforts have not been budgeted because substantial staff time would required.

## 9.3 PVB captive rearing

Captive rearing problems should be under control. The tent cage system will be continued with 1) removal of mature larvae to the lab before pupation and maturation on diet and 2) limited attempts to exclude earwings and use of pupation medium in the field. We are now investigating appropriate matrices.

## 9.4 PVB manipulative field experiments

The introduction of PVB to Polygon 1B appeared successful, but the population did not persist. The conclusion is that although foodplant was abundant, there is some limiting key factor at play. The attempted introduction Polygon 14A cannot be evaluated until the end of the 2002 season. A negative result could be due to the release of adults late in the season. The observation that *Astragalus* has decreased at DFSP may be tested in part. Other experiments need to be designed to test other explanations for the apparent decline of PVB.

## 9.5 Revegetation: plant community selection

We have concentrated on setting out dominant shrubs in addition to generally increasing plant diversity. Future augmentative planting of Polygon 7, 9, and 14 should concentrate on clustering the plants around established individuals of the same species . This action will provide mature mosaics rather than random sets. Subsequent new polygons should be planted following a cluster model.

## 9.6 Revegetation: nursery operations

Nursery operations have been very successful within the limitation of the Mediterranean seasonal offset paradigm. We can now provide N plants of most perennial species in an array of containers. This season will be limited because of the delay in relocating the nursery, but that is not a technical constraint. There is limited area for producing annual seeds, which will be a problem until the move is completed. However, lack of annual seeds will not be a critical issue for several years, except for the more aggressive species that can be set out under the current clear-irrigate-plant protocol. These include only *Lupinus succulentus, Amsinckia* and *Clarkia.* In the meantime seeds of all relevant species should be as they are available and within time constraints.

## 9.7 Revegetation: monitoring and success criteria

During 2001, a revegetation monitoring protocol was implemented. Evaluation is based on point intercept recording of all shrubs along a set of permanent 50-m transects across treated polygons. The percent cover measurement provides annual quantitative data. During the coming season a photo record should be added using digital photography on a number of set points to be determined. We have a limited photo record made sporadically since 1994, but these records have not been organized for repeatable data gathering.

The use of restoration as compensatory mitigation has resulted in the development of a rather cosmetic criterion for success, that of a certain percent native plant cover. This criterion is superficial, because it can be attained without re-creating a native community. This is shown quite clearly in Section 7, where it is demonstrated that several "restored" sites with native plant cover fail to support arthropod communities found at native sites. Similarly, sites revegetated to achieve percent cover goals quickly often crowd native shrubs, resulting in dense cover, but stunted individuals and a structurally artificial system. The argument that some native cover is better than none may or may not be correct depending on subsequent soil evolution, establishment of fine grain diversity, and appropriate animal aggregates (see Bowler 2000). Nevertheless, the native cover criterion is used by regulatory agencies, even though more sophisticated measures of restoration success are available.

## 9.8 Revegetation: rare plants

A major objective of our goal is establishment of known and probable extirpated plant species. To date 28 perennial and 14 annual presumptive extirpated species have been set out. Several dominants (*Cleome, Salvia leucophylla, Lupinus longifolius*) have grown well, but have yet to recruit. The most striking success has been establishment of 12 *Crossosoma californica* which are now eight years old and are flowering and setting fruit. In addition to reintroductions we are attempting to increase all plant species represented by only a few individuals with the objective of carrying them into the future. Exemplifying success here has been setting out over 100 *Rhus integrifolia*, represented by only two individuals, and about 500 *Salvia mellifera,* with only five present in 1994. Both exhibit large local dominant stands across the peninsula.

## 9.9 Ecosystem montoring: umbrellas and arthropod community structure

The PVB/spring flying insect transect data provide some insight of ecosystem (biodiversity effect) functioning. Minimal effort arthropod trapping at selected sites should be reconsidered to provide possible indicators of overall ecosystem health. These studies are cheap and effective (see Section 8). At some point limited vertebrate surveys could be considered, but available observation strongly supports the hypothesis that DFSP is more a sink for such species (eg California gnatcatcher, absence of expected small rodents), and such surveys cannot be justified by comparative costs.

### 9.10 Inventory

Since 1994 the biota of DSFP has been partially sampled. Records of the higher flora, although likely complete except for rare annual species, must be codified with voucher specimens. The plant voucher collection is only partially complete and must be completed with duplicate sheets deposited in a permanent herbarium. The arthropod collection from all trapping has been retained, but substantial material must be curated and the key collection brought to date with the many unknowns identified. Further collections should be made to provide information on groups not sampled by trapping (e.g., miners and soil dwellers). Given the efforts to date on revegetation this information will be invaluable for describing fine scale changes over time and with habitat enhancement.

### 9.11 Limitations to further effort

As the tasks related to mechanics of producing and setting out plants, monitoring fixed transects, and captive rearing PVB are standardized, personnel time will be increasingly available for the more thorough database management, experimental, and curatorial efforts mentioned above. The latter efforts provide the incentive and opportunity for achievement that can attract skilled and qualified staff for a scientifically meaningful program that maximizes the probability of recovery for the Palos Verdes blue butterfly and the unique and irreplaceable natural habitats at DFSP.

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