The Urban Wildlands Group

Status and Variability of Mission Blue Butterfly Populations at Milagra Ridge, Marin Headlands, and Oakwood Valley

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Introduction

The National Park Service (NPS) has monitored mission blue butterflies (*Icaricia icarioides missionensis*) in various ways within its Golden Gate National Recreation Area (GGNRA) unit during the past twenty-one years. Although monitored areas at the Marin Headlands, Oakwood

Valley, and Milagra Ridge are all within the NPS system, the methodology for monitoring was not standardized between sites, nor were the annual reports produced for each site integrated to include results from all sites for the species within the GGNRA boundaries. The purpose of this report is to consolidate all survey information about mission blue butterfly on NPS property to better understand the status and variability of the species and to make recommendations on future survey efforts.

Survey data for mission blue butterflies have predominantly included transect counts conducted in the manner of Pollard walks throughout the flight period of the butterfly (Pollard 1977, Pollard and Yates 1983), which have been coupled with reports of incidental observations from off-transect. Transects have been implemented as fixed linear routes, wandering routes through suitable habitats, and, in earlier days, random walks through areas containing suitable habitat (Lindzey and Connor 2010).

Recommendations for butterfly monitoring generally suggest that any scheme include both a method to evaluate detectability of individuals and a way to record flight period and abundance (Haddad et al. 2008, Nowicki et al. 2008). The surveys of NPS property were not designed to estimate detectability, so any estimates of abundance and even flight period must rely on assumptions regarding the ability of observers to locate and identify butterflies. This is not an unusual situation, but it does highlight the difficulty of analyzing data collected by multiple methods, which is the challenge faced in this effort.

Figure 1. Mission blue butterfly (*Icaricia icarioides missionensis*) at San Bruno Mountain (T. Longcore).

Methods

Study Species

Mission blue butterfly is a small blue butterfly in the Lycaenidae (Figure 1) that has a single flight period in the spring. Like all members of the species, it specializes on lupine plants as a larval foodplant (Downey 1962), with three perennial lupines (*Lupinus albifrons* var. *collinus*, *L. formosus* var. *formosus*, and *L. variicolor*) used by this subspecies. Eggs are deposited on new growth of leaves, stems, flowers, and seedpods and hatch in 4–10 days (Downey 1957, Guppy and Shepard 2001). First and second instar larvae feed on mesophyll, then crawl to the base of the plant to diapause until the following spring. They then break diapause, resume feeding, and subsequently pupate on or near the base of the foodplant (Arnold 1983). Imagoes eclose after about three weeks (Guppy and Shepard 2001). Butterflies travel between lupine patches, but most movement by adults are <64 m, with males moving on average slightly farther than females with maximum recapture distance ~150 m for both sexes (Arnold 1983). These may be underestimates; flight distances of 400–600 m have been recorded, with 2.5 km documented (Thomas Reid Associates 1982, U.S. Fish and Wildlife Service 1996, 2010).

The largest numbers of mission blue butterflies are found at San Bruno Mountain in the preserve set aside as part of the Habitat Conservation Plan for that area (Longcore et al. 2010, U.S. Fish and Wildlife Service 2010). Important sites within the GGNRA include Marin Headlands, Fort Baker, Oakwood Valley, Tennessee Valley, Milagra Ridge, and Sweeney Ridge. Additional occupied sites are located on other Santa Cruz Mountains ridges, including at Skyline College, on private land near Milagra Ridge, and in the San Francisco Peninsular Watershed, and also at Twin Peaks in San Francisco.

Study Locations

The National Park Service's GGNRA encompasses land north and south of the Golden Gate. Within this area, mission blue butterflies are monitored in Marin County at the Marin Headlands, at Fort Baker, and at adjacent Oakwood Valley, and at Milagra Ridge in San Mateo County (Figure 2). This report reviews data from these three locations.

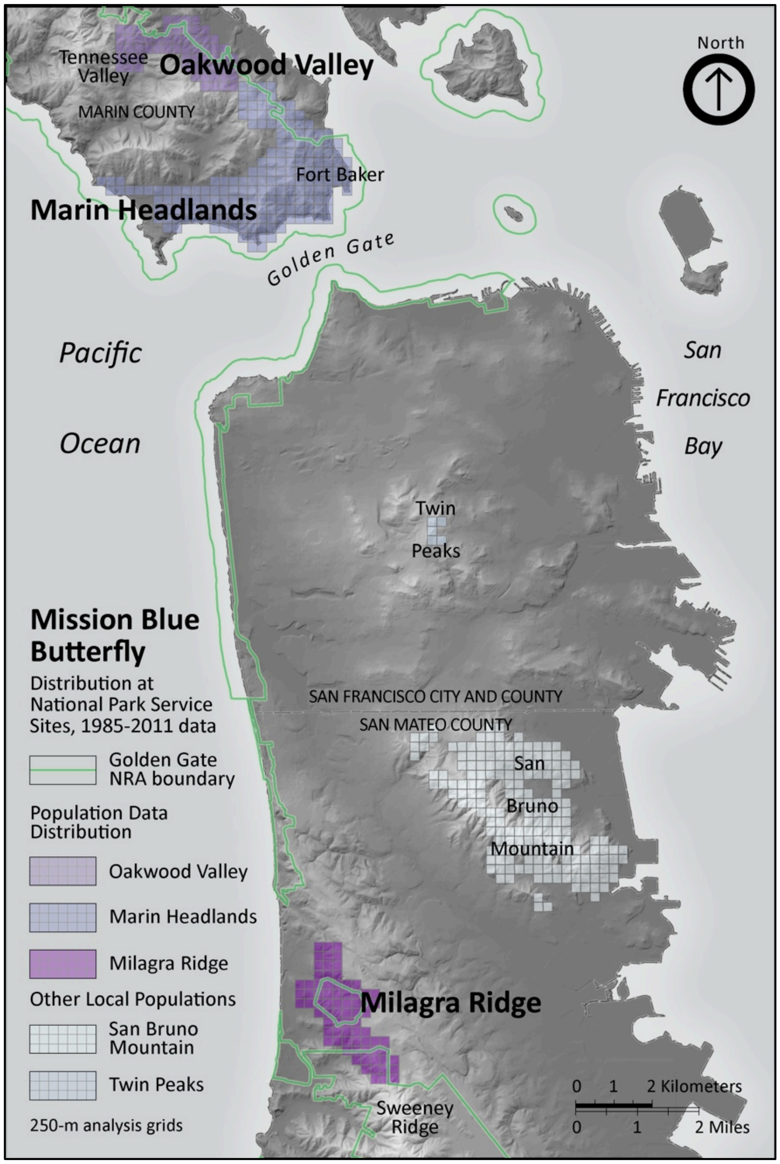

Figure 2. Distribution of Mission Blue Butterfly at National Park Service sites: Oakwood Valley, Marin Headlands, and Milagra Ridge. Additional localities are San Bruno Mountain and Twin Peaks. Analysis grids are shown for locations included in this report and for San Bruno Mountain (Longcore et al. 2010).

Data Sources

We obtained data on the observations of adult mission blue butterflies from all annual reports maps, field data sheets, spreadsheets, and database files that were available from the National Park Service and Golden Gate National Parks Conservancy (Table 1). We recognize that these data were collected and mapped based on park project locations by multiple observers with different objectives using various monitoring schemes and operating under time constraints — and that biological data are inherently uncertain.

Table 1. Data sources for GGNRA Mission blue butterfly observations. Annual reports and standalone field data sheets and maps are listed by year and location.

Year	Location	Citations
1985	Milagra Ridge	Thomas Reid Associates (TRA) 1985
1987	Marin Headlands	TRA 1987a, 1987b, 1987c
1988	Marin Headlands	TRA 1988
1991	Marin Headlands	TRA 1991a
	Milagra Ridge	TRA 1991b
1992	Milagra Ridge	TRA 1992
1993	Milagra Ridge	TRA 1993
1994	Marin Headlands	Rashbrook and Cushman 1994
	Milagra Ridge	TRA 1994a, 1994b
1995	Marin Headlands	Rashbrook and Cushman 1995
	Milagra Ridge	Shoulders 1995
1996	Marin Headlands	Rashbrook and Cushman 1996
	Milagra Ridge	DiGirolamo 1996
1997	Marin Headlands	Rashbrook and Cushman 1997
	Milagra Ridge	Hereth 1997
1998	Marin Headlands	Rashbrook and Cushman 1998
	Milagra Ridge	Lucas 1998
1999	Marin Headlands	Rashbrook and Cushman 1999
	Milagra Ridge	Newby 1999
2000	Marin Headlands	Rashbrook and Cushman 2000
	Milagra Ridge	Newby 2000
2001	Marin Headlands	Rashbrook 2001
	Milagra Ridge	Lambert 2001
2001–05	Fort Baker	Butsic et al. 2005
2002	Milagra Ridge	Lambert 2002
2003	Milagra Ridge	Wang 2003
2003–05	Oakwood Valley	Lindzey 2005a
2004	Marin Headlands	Rashbrook 2004
	Milagra Ridge	Lindzey 2004

2004–10	Milagra Ridge	Crooker and Whitty 2011a
2005	Marin Headlands	Rashbrook 2005
	Milagra Ridge	Lindzey 2005b
2006	Marin Headlands	Wang 2006
	Milagra Ridge	Lindzey 2006a
	Oakwood Valley	Lindzey 2006b
2007	Marin Headlands	Bennett 2007b
	Milagra Ridge	Bennett 2007a
	Oakwood Valley	Lindzey 2007
2008	Marin Headlands	Bennett 2008a, 2008b
	Milagra Ridge	O'Connor 2008
	Oakwood Valley	Crooker 2008
2009	Marin Headlands	Bennett 2009
	Milagra Ridge	Crooker 2011a
	Oakwood Valley	Crooker 2011b
2010	Marin Headlands	Bennett 2010
	Milagra Ridge	Crooker and Whitty 2011b, Whitty and Crooker 2011
	Oakwood Valley	Crooker and Whitty 2011b
2011	Milagra Ridge	Breheny 2011
	Oakwood Valley	Crooker and Whitty 2011c

Survey data were acquired both in spreadsheets and in a custom-designed Access database (GGNRA Mission Blue Butterfly Database) used by surveyors to record on- and off-transect observations. We received scanned copies of most original data sheets used at all locations. For Milagra Ridge, maps included with some NPS off-transect surveys within and adjacent to GGNRA property provided collateral data to locate observations that referred to sites by name (e.g., "Oceana Slope" or "Formosus Slope") rather than by proximity to a numbered transect; standardized maps created with a GIS were part of the off-transect protocol during 1999–2001. Maps drawn on topographic base maps or templates were primary sources for early data (1985–1992), including the first surveys conducted for GGNRA at Marin Headlands and Milagra

Ridge (Thomas Reid Associates 1991 a, b). Later reports included off-transect observations overlaid on high-resolution aerial imagery; data were extracted from these for Marin Headlands, Fort Baker, Oakwood Valley, Tennessee Valley, and Milagra Ridge. Some off-transect data for Marin Headlands and Milagra Ridge were provided as ArcGIS shapefiles.

Established and revised transect routes for the Marin Headlands (1994–2011; 2006), Fort Baker (2001–2005), Oakwood Valley (2003–2011), and Milagra Ridge (1994–2011) were delineated on topographic maps or overlaid on aerial imagery for reports. Mapped linear and wandering transects were compared with location information obtained as textual descriptions of latitude and longitude, as database tables and in spreadsheets, and as ArcGIS layer files of transects with start and end points derived from GPS data or input as digitized features.

Vegetation data were inconsistent because they were collected for various purposes using different methods. Lupine distribution data were obtained from maps included with supplemental files and reports and as ArcGIS shapefiles. Spatial data at an appropriate spatial and temporal scale representative of butterfly host plant distribution were acquired for Marin Headlands (1991, 2006), Oakwood Valley (2002/4, 2006/7, 2010), Tennessee Valley (2008), and Milagra Ridge (1997, 1999–2002, 2009).

Database Consolidation

We identified any errors in the Access database records (e.g., incomplete, missing record elements, records lacking details, records with conflicting details) and corrected them, either by deleting invalid records (e.g., partial entries, entries with no date or location indicated, or entries with no correspondence with on- or off-transect data) or by filling in additional data as derived from comparing with other records from the same day or from written reports, spreadsheets, or data sheets provided. Scanned copies of original field data sheets, when available, were the primary source. We performed data quality control and quality assurance procedures on three individual sets of files, identified duplicate records between the sets, and then consolidated all of the records into a single file and crosschecked them to delete additional duplicates and make further corrections. We reformatted data to shift entries from on-transect to off-transect observations when appropriate (e.g., when locations referred to "Search Areas"); made other adjustments to integrate incidental off-transect observations included only as comments in the transect portion of the database; and incorporated additional on- and off-transect data from mission blue butterfly monitoring within GGNRA.

Georeferencing

We mapped all location data that were obtained in the Access database or associated files. We used a Universal Transverse Mercator (UTM) Zone 10N projection to align with aerial imagery and digital elevation models. NPS standards for digital geospatial data (2002) indicate the standard projection for individual park units is generally UTM, NAD 1983, with measurement units in meters; a secondary reference to a regional Geographic projection with coordinates in decimal degrees also common. Each of the transect locations was overlaid on aerial photography. Transect lines received a 5-m buffer to incorporate the area defined by survey protocol. Transect data from the database were linked to these localities using unique location identification codes. Where coordinates were obviously incorrect we referred to printed maps in reports to digitize transect locations. Maps from reports or supplemental files that were used to digitize transects, butterfly presence points, or lupine patches were first georeferenced.

Off-transect data included locations with and without geographic coordinates. Points received in ArcGIS format were reprojected to a common coordinate system and then mapped points were compared with database entries to check for duplicates and accuracy. Points were also digitized from locations indicated on maps. All points were buffered by 5 m to compensate for various measurement errors. Other observations were recorded based on their location with respect to transects. For these off-transect observations we created a 15-m buffer area outside of the area included in each transect and associated these observations with those areas. Some off-transect observations could only be associated with larger areas; we assigned these locations to cells within 250-m presence/absence analysis overlay grids. Grid extent was based on 1985–2011 survey data we received for butterflies and food plants, with a one-cell buffer added.

Lupine survey data were consolidated by species by year by region. Data obtained as ArcGIS files were examined to determine field attributes and metadata, cleaned and aggregated, and projected to a common coordinate system. Additional data were obtained by digitizing field observations drawn on maps. Separate layers created from both sets of spatial data were merged within ArcGIS map documents. Data without explicit geographical locations were not used to map the distributions of host plants.

Data Analysis

With the consolidated dataset, we developed measures of occupancy and abundance that were, to the greatest degree possible, comparable across survey locations and years. To do this, certain assumptions were made.

Wandering transects through the same lupine patch as fixed transects were considered as comparable for the purpose of establishing occupancy and peak abundance for time series analysis. As an example of this, the fixed linear transects and wandering transects at Oakwood Valley and Milagra Ridge sample the same habitat patches during different years and are not so different as to obscure large trends in occupancy. As part of a larger monitoring experiment, both sites used both types in 2010 (Crooker and Whitty 2011b).

We recognize that substantially more effort was expended on wandering surveys than on fixed transects through the same lupine patch, and also realize that linear transects were not all the same length. We did not, however, adjust counts based on time or distance to standardize sampling effort, nor attempt to derive a measure of relative detectability, nor craft abundance indices better suited to different datasets. Our abundance metrics are appropriate for within-site comparisons and to evaluate relative trends between sites. Apparent anomalies in peak abundance measurements within and between sites (as for 2010) can provide useful information to inform future sampling strategies.

Off-transect data for which geographical coordinates were not provided were not included in subsequent analyses. Whenever incidental off-transect observations of butterflies could be associated with a geographic location we added them for the purpose of long-term occupancy analysis. This was not always possible.

With these decisions in place, we developed aggregate measures of abundance and distribution across the sites and years. These included maximum number of butterflies (“peak count”) observed on transects on a given day, the sum of maximum number of butterflies observed on each transect within clusters (e.g., Battery Cavallo transects 100 and 101, etc.) and within districts (Milagra Ridge, Marin Headlands, Oakwood Valley), and butterfly presence/absence along transects and summarized by cluster and region. To measure population variability we calculated the year-to-year growth as the ratio of successive years of log-transformed peak counts.

We also converted survey data to presence/absence by year within a 250-m grid overlaid over each of the areas, following our previous efforts analyzing mission blue butterfly distribution at San Bruno Mountain (Longcore et al. 2010). A grid cell was considered "surveyed" and occupancy recorded if within a given year at least 250 m of surveys were conducted within it. This roughly corresponds to minimum annual travel along a linear transect or one wandering transect. Presence/absence data assume detectability; given the nature of adult surveys, the inherent annual fluctuations of a small cryptic butterfly population, and climate variability, some cells might be recorded as absences where the butterfly was present because surveys were too infrequent, poorly timed, or conducted under adverse conditions (Longcore et al 2010). Our cell size and grid extent (324 cells: Marin Headlands, 186; Milagra Ridge, 76; Oakwood Valley, 62) allowed time-series comparisons to be drawn for individual areas across GGNRA that would identify spatial variation but were not too unwieldy. A 250-m cell will accommodate a 5–10 m error in measurement accuracy. Finer-scale (e.g., 100-m) occupancy analyses are feasible but will decrease acceptable error and increase cell numbers (by a factor of 6.25 at 100 m).

Results

Database Consolidation

Data were recorded in three different copies of the GGNRA Mission Blue Butterfly Database (Access database files). The three database files were: data from 1994–2005 (MBlue), data from 2007–2011 (MAHEMBB), and a third database (MR) for Milagra Ridge alone (2007–2011). The MBlue dataset was standalone, containing data from Milagra Ridge and Marin Headlands data, with 4,355 on-transect entries and one off-transect observation. The MAHEMBB (1,249 on- and 196 off-transect records) and MR (1,313 on- and 182 off-transect records) databases overlapped to some extent for 2007 and 2008. Consolidating these two files required elimination of duplicate entries.

The database was designed with a form-type interface for data entry. Within the relational database, information input is recorded in three tables: Events, Transects, and OffTransect. Surveyors first select whether data to be entered are on-transect or off-transect observations because the tables have a different set of fields to capture data. A field stores a single piece of information (e.g., the date, location, or the number of male butterflies observed flying) and a record is one complete set of fields. Surveyors select “Add New Record” and begin the data-entry process by filling in any field in the form. As soon as any data are entered, the record is automatically associated with a 32-character alphanumeric “EventID” which is a unique identifier for the sampling event. The database is set up to record one “event” for a given group of transects or a given set of off-transect data points on a given day, or other groupings could be recorded together as an event. Approximately 10% of the time, however, transects were entered as their own events instead of with the other transects sampled at the same time. This made it more difficult to eliminate duplicates. We kept transects in separate events when they were recorded separately, but each was checked with all other transects to determine if they were duplicates. We deleted events in the database that did not have matching transect or off-transect data (46 instances). Sometimes the same survey results were entered as more than one event. These had to be found and deleted (47 instances).

Consolidating the three databases required cross-validation to correct data entry errors. These were corrected by comparing with reports or datasheets, filling in blanks from other surveys on the same day, by the process of elimination, and other methods. Sometimes data were not internally consistent (e.g., “LocationID” and “Area/Transect” fields in the Transects table referred to different survey locations within single records) and these were corrected. Some records were duplicates that were the result of multiple entries of the same (or slightly different) data that represented the same observations and unintentional partial entries. Queries, filters, and other standard data analysis procedures were used to thoroughly crosscheck and double-check tables to identify and select data to include in the consolidated file. Events were corrected and merged first, transect records next, and then off-transect data. We maintained interim datasets that reflect edits, deletions, and additions made to original files and document the data quality control and quality assurance process. Error rates varied among the database files. The MBlue database had a 3% error rate, MAHEMBB had 13% error rate, and MR had an 8% error rate. For transect data alone, over 700 records were corrected by hand.

The Milagra Ridge dataset was most comprehensive. Reports were usually included with raw data sheets, multiple spreadsheet versions, and other supporting documentation. The 2003 and 2006 data from Milagra Ridge existed in a spreadsheet and as datasheets, but were not found in any of the three database files. These data were incorporated into the database. We added data from datasheets and spreadsheets for reconfigured "new" transects used in 2010 and 2011 and experimental "wandering" 2010 transects (Crooker and Whitty 2011b, Whitty and Crooker 2011).

Independent surveys were conducted by NPS's Park Stewardship Program (PSP) and by experienced Milagra Ridge volunteers during 2004–2011. The surveys were usually not performed on the same days, and produced different observations. The protocol for 2004–2009 was to "accept" the data from the monitoring group that observed the most butterflies during a ~7-10 day time frame. Individual observations made by the second group were added to the GGNRA database if they were from un-represented transects; this was intended to capture the spatial distribution of the population and to produce a better index of abundance (Bennett 2007a). Datasheets were sometimes merged and sometimes filed separately. We compared both sets of data and associated spreadsheets, and matched them against the database and various reports. We reviewed the draft report that compared the two data sources for 2004–2010 (Crooker and Whitty 2011a), thoroughly examined data sheets again, made side-by-side day-by-day comparisons, and concluded that different interpretations were possible. After further evaluation, we did not exclude either data set from our edited version of the database nor did we incorporate "unused" data from the separate survey groups; instead, we kept the Milagra Ridge data as originally selected by NPS to enter in the GGNRA database, made any necessary corrections, and added data for years which were not represented.

Oakwood Valley data were intentionally not entered into the database by surveyors because monitoring methods were not Pollard transects as first established at Marin Headlands and

Milagra Ridge (Crooker 2008). We extracted all Oakwood Valley survey data from spreadsheets and reports for 2003–2011 and entered them into the database (both linear and “wandering” surveys).

The majority of off-transect data in the consolidated database had not previously been entered into the database. Many entries (1,044) were derived from field datasheets, spreadsheets, maps, reports, and other sources. Some were data entered as incidental observations in the comments field of Events or Transect tables but not transferred (94 instances); each became its own event and one or more off-transect records. Some surveys at Fort Baker during 2001–2005 were in “Search Areas” and essentially off-transect observations, however, all data were recorded together as on-transect events. Some had multiple designations (e.g., for transects, Baker-FG = Baker203, and for areas, Baker-FG = Baker-C). On- and off-transect data were split, events created, and records were reassigned (217 instances). Shifting information between on- and off-transect tables was not entirely straightforward because data are aggregated differently (e.g., the off-transect fields include the number of butterflies observed, activity, and sex, while the on-transect numbers are input to a combined sex and behavior field, as in “female flying”; on-transect weather observations did not transfer to the off-transect table but their averaged values were entered in Events table fields).

All National Park Service surveys for mission blue butterfly are now consolidated into a single database, which has 1,756 events that include 6,424 transect records and 1,762 off-transect records (162 from comments in the transect database, and 58 points digitized from maps). An additional 442 digitized points not included in the database represent 1985–1992 observations at Milagra Ridge and Marin Headlands.

Georeferencing

Three different files were available with geographic information for the transect data. The first was from the MBlue database. This was correct for the 13 original Milagra Ridge transects but not for the 17 original Marin Headlands transects; monitoring began on both sets in 1994. We received a second location file in the 2007–2011 MAHEMBB Marin Headlands database, but it was not corrected; rather, all but three transects had been deleted. The correct transect coordinates were obtained in a separate spreadsheet. Oakwood Valley location data were received for both "wandering" (2003–2010) and linear transects (2010–2011). Geographic coordinates were obtained for Milagra Ridge transect revisions, realigned (2010) linear transects, and new wandering transects. We also received transects as ArcGIS layer files. At Fort Baker, in the Marin Headlands District, additional survey locations were used by a different group during 2001–2005 along with established Battery Cavallo and Battery Duncan transects (Butsic et al. 2005); seven transects were digitized from maps in the GGNRA database. New Marin Headlands transects for 2006 only were based on lupine presence (Wang 2006); these were provided as ArcGIS files and lupine data were digitized from supplemental maps. All linear and wandering transect lines were surrounded by a 5-m buffer zone, and on-transect observations were associated with that area.

The datasets contained off-transect survey data. Ideally, the off-transect data and the GIS data would match, with individual points in associated GIS layers corresponding to each observation reported in the dataset. The points were not consistent, however; sometimes one event was represented by one point that represented one butterfly. Other times, one point represented several butterflies. In other instances a point could also represent two males flying and a female resting on vegetation. Other times the same data would be reported with three separate points.

Data in GIS files varied from points with no associated attributes to comprehensive entries that matched the database. GPS data collection and data export to a GIS are acquired skills; fields and projections changed often and data quality improved over time. GPS data collected with the device set to a UTM projection with measurements in meters were generally accurate. Almost all decimal degree coordinates were corrected, some minimally, by adjusting the decimal point in the latitude measurement before projecting them to a common coordinate system (UTM Zone 10N). Projected points were mapped and various inconsistencies were resolved by comparing each point in a GIS layer to the associated report and datasheet and the corresponding record in the Access database. Several hundred points were corrected by hand in this manner. We received butterfly data from Milagra Ridge for 2005–2007, and from Marin Headlands for 2008–2011. Some required substantial editing (e.g., for Marin Headlands, 101 entries were made in the off-transect database for 2008, but 122 of 149 GIS points received were valid; for Milagra Ridge, off-transect entries made for 2008–9 included a "point number" but there were no GIS data). We digitized all observations prior to 1993 from points drawn on georeferenced maps. All points were buffered at a 5-m radius to adjust for various types of error.

Other off-transect observations were recorded based on proximity to an established transect, with their location given either in the "nearest transect" field in the off-transect data table or as a description. These were located by reviewing all the comments in the database, where information was provided (e.g., "male between T108 and T110"). These were associated with15-m polygon buffers around the associated transect. Finally, some off-transect observations could only be assigned to larger areas (e.g., when data indicated that a butterfly was observed within the "Gun and Bunker Zone" at Milagra Ridge or the "Battery Cavallo 100 and 101 Area" at the Marin Headlands); these were assigned to cells within the 250-m overlay grids used for presence/absence analysis.

We recognize there are likely substantial differences in the geographical accuracy of the off-transect data. When the relative accuracy of source information can be assessed, data points can be buffered at various distances to reflect their comparative locational uncertainty. This source of error can be integrated into analyses and symbolized on maps using, for example, different sizes of circles, where larger circles indicate greater uncertainty. Biological datasets that rank data on multiple criteria and incorporate a "distance" component for error are disseminated by several agencies (e.g., California Department of Fish and Game California Natural Diversity Database, U.S. Fish and Wildlife Service GIS Division); their buffer zones for comparable butterfly data range from less than 10 m to greater than 4 km. We made the assumption that all data were of equally high quality, once errors or inconsistencies in coordinates or projections were fixed, and used the same 5-m buffer distance for all observations. For points, the 5-m buffer zone is a comparatively small radius that avoids overstating grid-cell occupancy, coincides with the division between on- and off-transect data, and is considered rule-of-thumb accuracy for GPS technology, consistent with the U.S. Department of Defense GPS Standard Positioning Service (SPS) Performance Standard (2008).

The off-transect butterfly presence data and the lupine distribution data were the most variable components used in this analysis. We developed a geographically-referenced dataset representative of lupine host plant distribution at an appropriate spatial and temporal scale for this investigation. Spatial habitat data were supported by anecdotal data for all sites, and included reports, on- and off-transect monitoring datasheets, and an analysis of vegetation on butterfly monitoring transects.

At Marin Headlands, mission blue butterfly habitat described as "quite extensive" was divided into geographical regions and systematically surveyed in 1991, with *L. albifrons* distribution mapped concurrently with adult butterfly observations during a two-month flight season; additional lupine surveys were made to verify locations and map more remote sites, and then topographic field maps were compiled into a master distribution map (Thomas Reid Associates 1991a). We digitized this map. Wandering transect routes drawn in 1987 (Thomas Reid Associates) align with these vegetation patches. Linear survey transects created by NPS in 1993–1994 were established within the same areas in undisturbed or restored lupine habitat (Rashbrook and Cushman 1994). Subsequent butterfly survey reports noted lupine quantity and quality declined during 1998–2000 (Rashbrook and Cushman 1999, 2000) but no spatial data were provided.

During 2001–2005, at Fort Baker in the eastern Marin Headlands, GGNRA established new transects within existing and restored habitat and initiated "area searches" within *L. albifrons* habitat not previously monitored (Butsic et al. 2005) but lupines apparently were not mapped. West of Highway 101, lupines described as healthy, widely-dispersed, and abundant were surveyed and mapped to site short-lived transect bands based on host plant presence within different microclimates (Wang 2006). We obtained this data as maps and GIS files. GIS metadata for 2009 lupine mapping at Milagra Ridge state that a comparable effort to map host plants was made at Marin Headlands, but we have no additional data. The Marin Headlands annual report (Bennett 2009) noted that the 1991 map was found in storage and its butterfly data were digitized, and that while the "historic" representations might not be completely accurate, an anecdotal comparison of 1991 data with 2009 data indicated "most areas were similarly supportive of mission blues," with some discrepancies. Lupine data were not specifically mentioned.

An additional report provided complementary information about Marin Headlands vegetation with different levels of geographic and ecological precision. Bennett (2008b) tracked changes in habitat quality over time; results were aggregated by transect by year and provided as a tabular compilation and an analysis of overall trends observed over the period 1995-2008. Data collected along butterfly monitoring transects measured various vegetation classes (including "host plant") as a percentage of absolute cover; these data reside in an NPS "Restoration Database" (Bennett 2008b) we do not have.

At Oakwood Valley, lupine distribution mapped in later years corresponds closely with the "Marin City" wandering transects drawn on a topographic base map (Thomas Reid Associates 1987c). Initial *L. formosus* mapping was done in 2002, with other patches identified in 2004 and 2005 (Lindzey 2005a, Crooker 2008). GIS metadata for 2006/7 indicate lupines were first flagged in the field and then GPS coordinates were acquired; these late-season surveys may have underestimated distribution (Crooker 2011b). We obtained GIS data for 2004, 2006 and 2007. Distribution for 2010 was digitized from the map in the Oakwood Valley report (Crooker and Whitty 2011c). Upper Tennessee Valley is immediately west of Oakwood Valley but surveyed by Marin Headlands staff. Potential habitat and adult butterflies were assessed and mapped in 2008;

we digitized *L. albifrons* distribution from the map in the Marin Headlands report (Bennett 2008a).

At Milagra Ridge, early survey reports discussed host plant mapping but methods and results indicate only adult butterfly locations were recorded (Thomas Reid Associates 1991b, 1992). Lambert (2001) referred to vegetation data collected on transects, similar to the Marin Headlands data, and to an analysis that suggested a relationship between the percent cover of host plants and butterfly abundance for 1995–1998 and 1998–2001, but we do not have vegetation transect data for Milagra Ridge. We acquired GIS data created from Milagra Ridge lupine surveys in 1997, 1999, 2001, 2002, 2004, and 2009. Patch size and location within GGNRA for *L. albifrons* and *L. variicolor* were mapped in 1997 and separate patch-density data were collected in 1999. Patches of *L. formosus* adjacent to North Ridge (on "Formosus Slope") but outside GGNRA were also mapped (Lambert 2001). Although not on NPS property, this location and other areas south and east of Milagra Ridge were regularly surveyed for host plants and butterflies, and data were included in off-transect observations and in reports (Lambert 2001, 2002, Lindzey 2004). GIS files were added in 2001–2004 that contained new attributes, including the number of individual plants per patch, an assessment of their health, and presence of nearby invasive species, but early GIS files do not include metadata and exact survey methods are unknown. We received a lupine distribution map drawn on a topographic base map with the off-transect data sheets for 2004, rather than with its associated report (Lambert 2002). Captioned "Mission blue host plants in Milagra Ridge Vicinity 3/26/02," it indicated locations of isolated lupine plants and "substantial patches large enough to support individuals"; when georeferenced, it was aligned with 2001–2004 GIS data. In 2009, all Milagra Ridge host plants were mapped using a GPS to capture locations of flagged lupine patches (Crooker 2011a). Field methods were thoroughly documented with detailed GIS attribute data and metadata provided.

Status

We used maximum number of butterflies observed on a transect during a year as the most reliable measure of abundance. Peak counts correlate highly with other transect-based estimates of population size (Pickens 2007, Longcore and Osborne 2011). At Marin Headlands, Rashbrook (2005) found peak numbers on any single survey day were highly correlated (R^2=0.91, p=0.0001) with 1994–2005 annual totals.

At the level of the three districts (Marin Headlands, Milagra Ridge, and Oakwood Valley) the sum of these maximum counts shows the long-term status of mission blue butterfly (Figure 3). Oakwood Valley is apparently the most significant population on NPS property, albeit a shorter time-series, while Milagra Ridge has accounted for the fewest butterflies. Direct comparisons may seem problematic given Oakwood Valley mainly used wandering surveys, while Milagra Ridge primarily used fixed transects. Recently, however, well-documented near-identical monitoring schemes were evaluated at both sites (Crooker and Whitty 2011b). For 2010, fixed and wandering transects were used at Oakwood Valley for the "relatively robust, and possibly increasing" population (Crooker 2011b). Wandering and established and reconfigured fixed transects were used for the "relatively small" Milagra Ridge population (Crooker and Whitty 2011b. In 2011, transects were fixed (Breheny 2011, Crooker and Whitty 2011c). All data were included in the sum of peak counts. Substantial differences exist between the two populations.

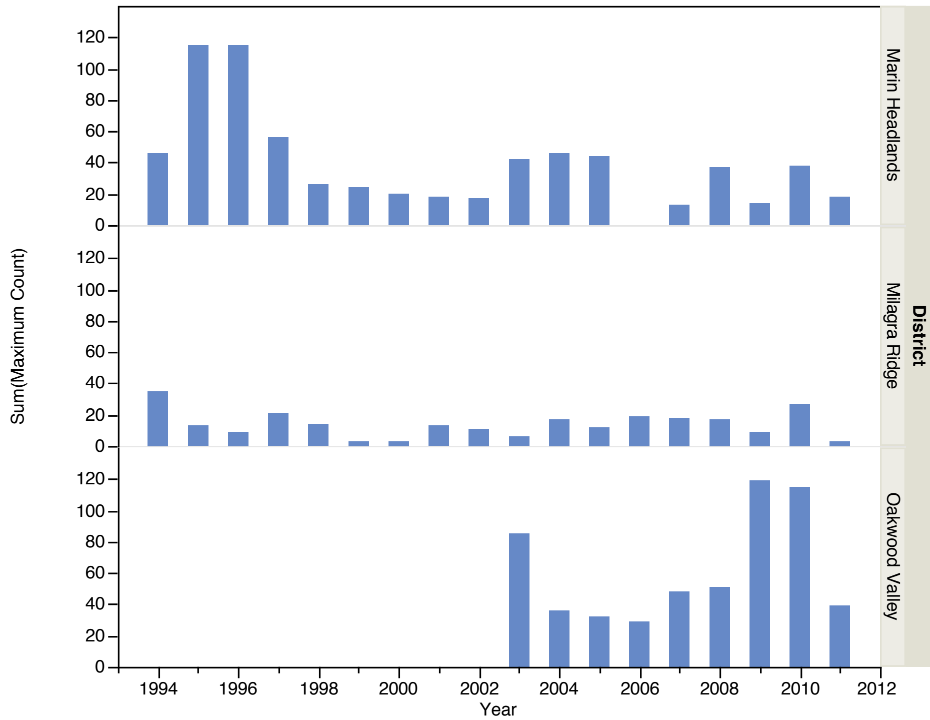

Figure 3. Sum of the peak count of mission blue butterfly on transects each year in each district. Survey data are not available for Marin Headlands in 2006 or Oakwood Valley before 2003.

Transect data indicate the Marin Headlands population has declined substantially since surveys began in the early 1990s. Abundance improved after 1998–2002 declines but has fluctuated at low levels in subsequent years. Peak counts at Marin Headlands are directly comparable year-to-year and with long-established Milagra Ridge transects.

The larger Marin Headlands district contains clusters of transects that, when viewed individually, provide additional insight into this area. Mission blue butterflies are no longer present at the Battery Duncan or Wolfback Ridge transect clusters, while peak numbers have declined in the Rifle Range and Slacker Ridge areas and are low and variable at Battery Cavallo (Figure 4).

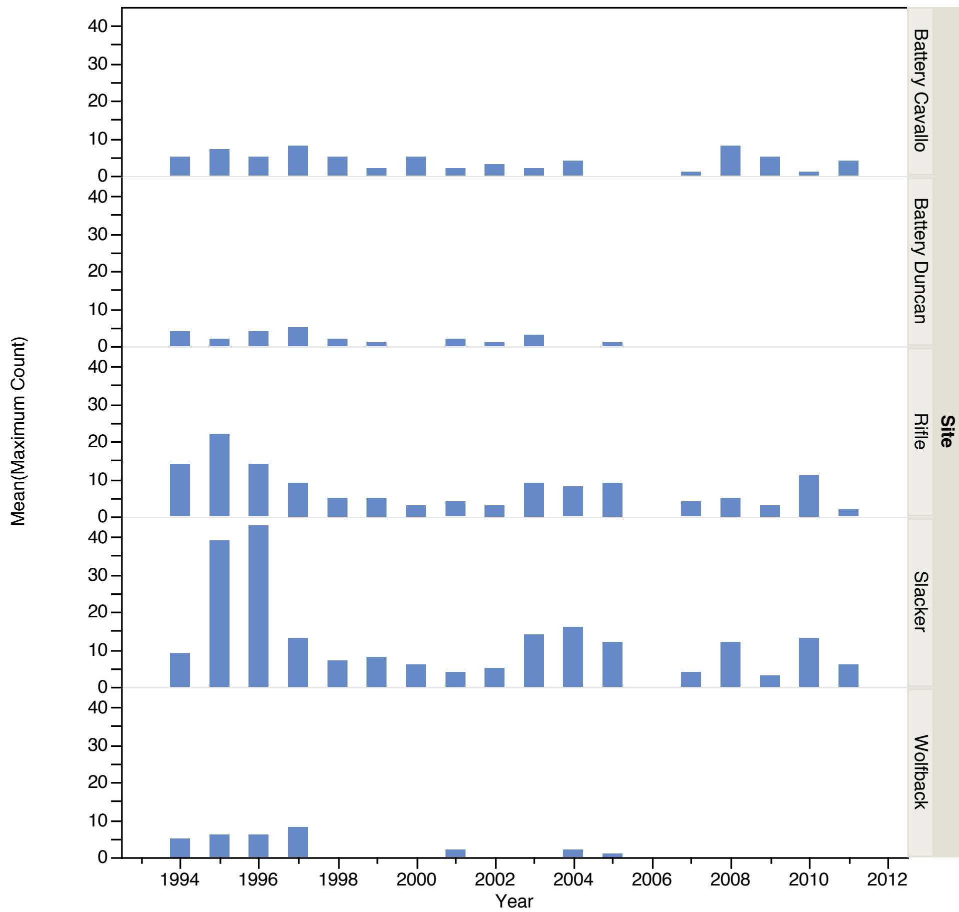

Figure 4. Sum of the peak count of mission blue butterfly on transects each year by clusters within the Marin Headlands district. Data were not collected in 2006.

Physical conditions vary between and within sets of transects at Marin Headlands, with most uniformity at closely-spaced Battery Duncan and Wolfback Ridge transects. Rifle Range transects share a southwest aspect but are more spread out in a near-contiguous lupine patch. Habitat diversity is high at Slacker Ridge (Rashbrook and Cushman 1999). Battery Cavallo is most protected. Compared with Milagra Ridge, Marin Headlands was described as lacking sheltered places, with a greater microclimate range (Wang 2006).

Milagra Ridge transects sample diverse habitat. All three foodplant species are present, with their distribution constrained by specific preferences. Topographic and climatic convergence has created protected habitat at the most-favored Quarry site (Transect 2). Another more-protected site is farthest inland at the Rock Garden. Less-protected sites are at the northwest end of Lupine Ridge, the eastern Gun and Bunker Zone, and on the Pacific View Slope. Peak counts here (i.e., Transects 13, 9, 6, 5; experimental B) were high. Other transects with acceptable habitat, although usually with *L. variicolor* dominant rather than *L. albifrons*, recorded consistently fewer butterflies — often none.

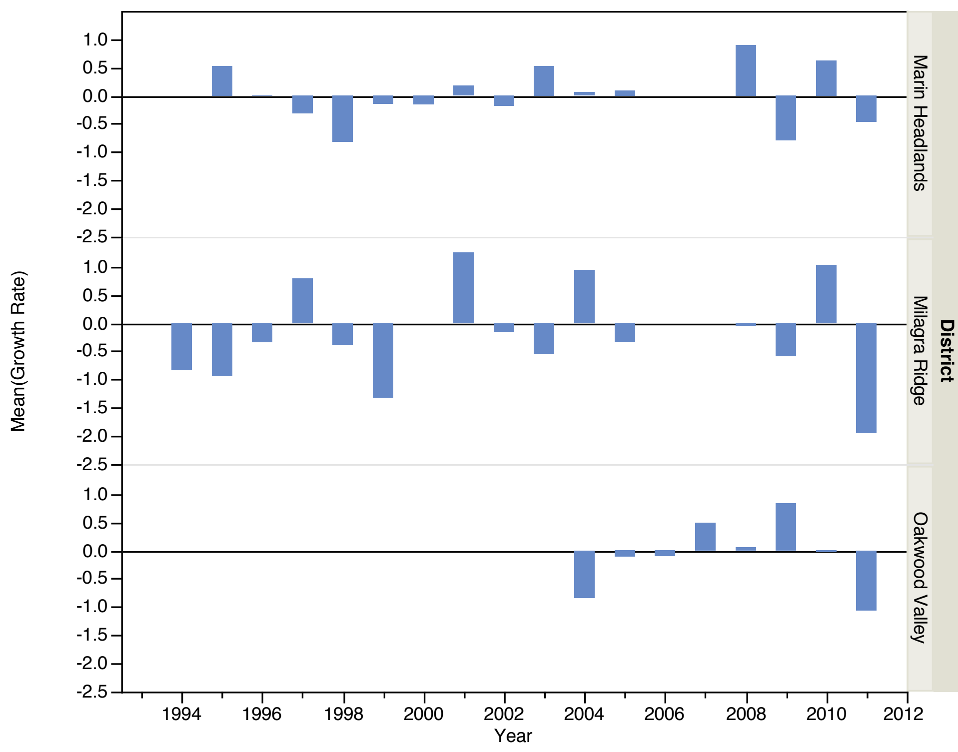

Figure 5. Mean growth rate in mission blue butterfly size (measured as peak transect count) at Marin Headlands, Milagra Ridge, and Oakwood Valley.

Measures of population growth (and decline) at the district scale show that estimated population indices (peak counts) are highly variable (Figure 5) and this pattern holds true for the clusters of transects within the Marin Headlands (Figure 6).

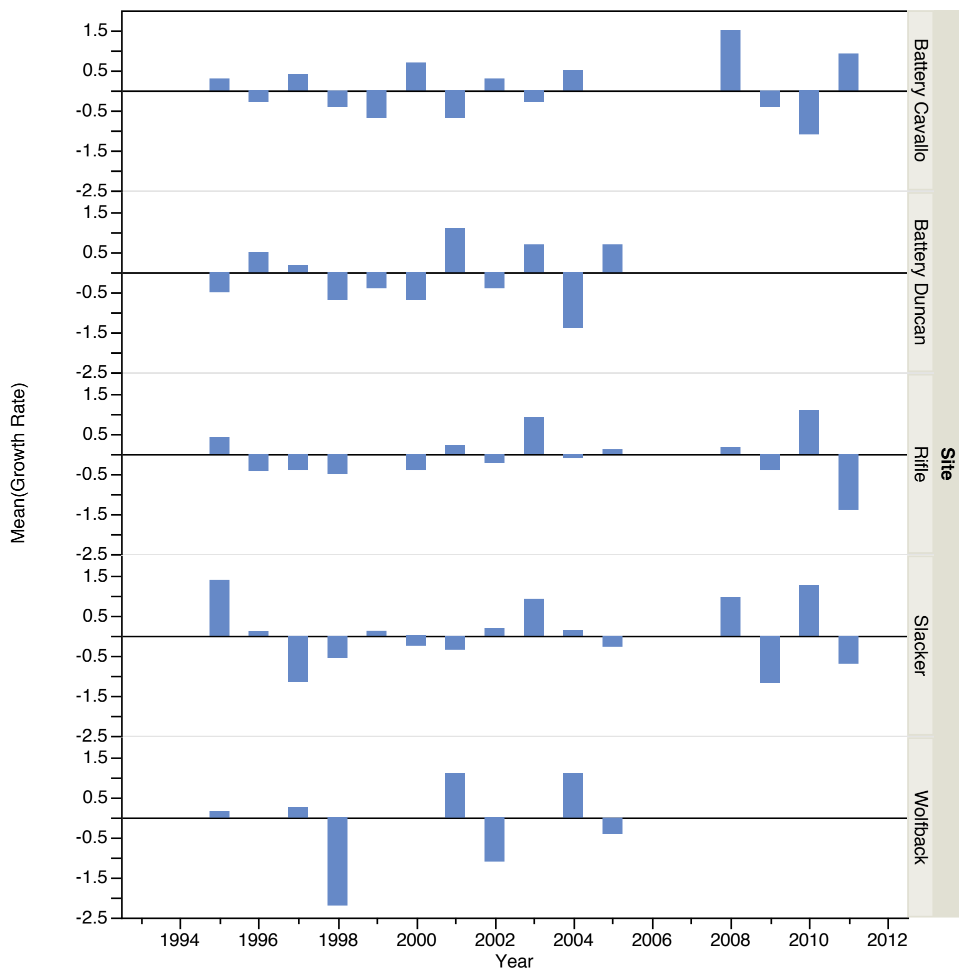

Figure 6. Mean growth rate in mission blue butterfly size (measured as peak transect count) by transect area at Marin Headlands. Data were not collected in 2006.

Comparison of annual growth estimates also shows that "good" and "bad" years are not consistent for all sites. For example, in 2004 the peak abundance of butterflies increased substantially at Milagra Ridge, declined at Oakwood Valley, and was nearly unchanged at Marin Headlands. At the district level, some years were "bad" in all districts surveyed, including 2011, 1999, and 1998; others were "good" for all districts surveyed: 2010 and 2001. Unusual environmental conditions and lupine dieback followed by regrowth may explain 1998, 1999, and 2001. For 2010–2011, experimental transects at Milagra Ridge and Oakwood Valley affected growth rates. At the site scale within the Marin Headlands district, fluctuations of peak numbers were not synchronous (Figure 6). "Bad" years for all transect groups were 1998 and 1999 while the only year with increases for all occupied areas was 2008, when only two transect groups were occupied.

Transformation of the transect data to grid cells allows for quick visual and quantitative comparisons between sites and over time. Butterfly presence/absence data were first grouped by year and location. Alignment of 250-m grid cells with the UTM projection created "fishnet" overlays that were not random but not biased. Grids extended beyond observations and captured the distribution of foodplants as surveyed. All transect data were associated with 5-m buffers, overlaid by the grid, and spatially joined. A similar process was used to incorporate the transect data with off-transect data associated with buffered points or polygon buffers. Additional off-transect observations based on descriptions were located within appropriate grid cells. For each grid cell, number of years present, last year present, number of years surveyed, and last year surveyed were calculated for both the transect data and the combined transect and off-transect data. For each region, the number of years present and the last year present were mapped. These data are presented with available foodplant surveys to aid in interpretation.

For the Marin Headlands, the decline in lupine abundance between surveys in 1991 and 2006 is readily apparent (Figure 7). During this period, lupine in the eastern part of the district declined substantially. The gridded results of the transect surveys confirm the adverse outcome of this change. The number of years of presence within grid cells in the eastern regions is lower than to the west. Transect clusters within these cells had major declines based on butterfly peak counts, with zero presence in recent years both farthest north at Wolfback Ridge and slightly southeast at Battery Duncan; the easternmost Battery Cavallo transects maintained butterfly presence. The further inclusion of off-transect observations made incidental to transect surveys further illustrates this picture, with a clear reduction in the distribution of the butterfly over time (Figure 7). Addition of the off-transect data does not substantially alter the conclusion from the transect peak counts or gridded transect data alone that a substantial decline has occurred, but it does provide additional detail into the dynamic nature of the distribution over time.

At Oakwood Valley, the shorter record of survey results shows a more stable lupine distribution (Figure 8). This, not surprisingly, is associated with a more stable distribution of the butterfly, with no evidence of range reduction or shifts in distribution over the 2003–2011 timeframe. Mission blue butterflies were recently discovered and lupine patches were surveyed in adjacent Tennessee Valley to the west (Bennett 2008a).

Milagra Ridge surveys show a distinct decline in distribution of two lupine host plants leading up to the most recent surveys in 2009 (Figure 9). The gridded distribution from the transect surveys indicates that the butterflies are less persistent in the northeastern portion of the survey area. The continually occupied northwest-of- center grid cell contains the most-desirable Quarry region with Transect 2, plus adjacent Transects 1, 4, and 5. The range contraction apparent in the southwestern portion of the survey area is somewhat less striking when off-transect data are added to grids.

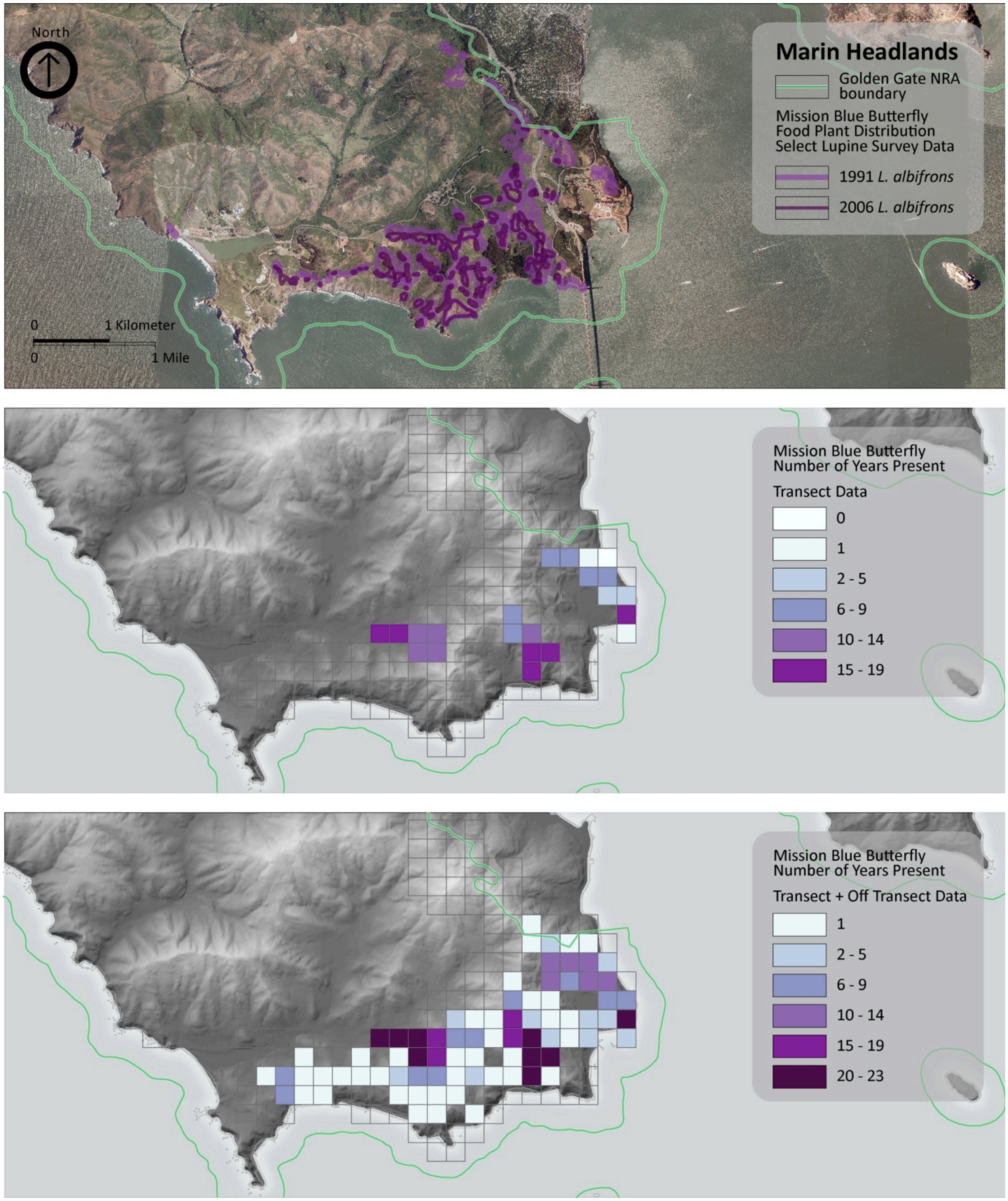

Figure 7. Status of lupine host plant and mission blue butterfly at Marin Headlands. Top: Distribution of lupine foodplants in 1991 and 2006. Middle: Number of years present on transects within 250-m grid cells, 1994–2011. Bottom: Number of years present on and off transects within 250-m grid cells, 1987–2011.

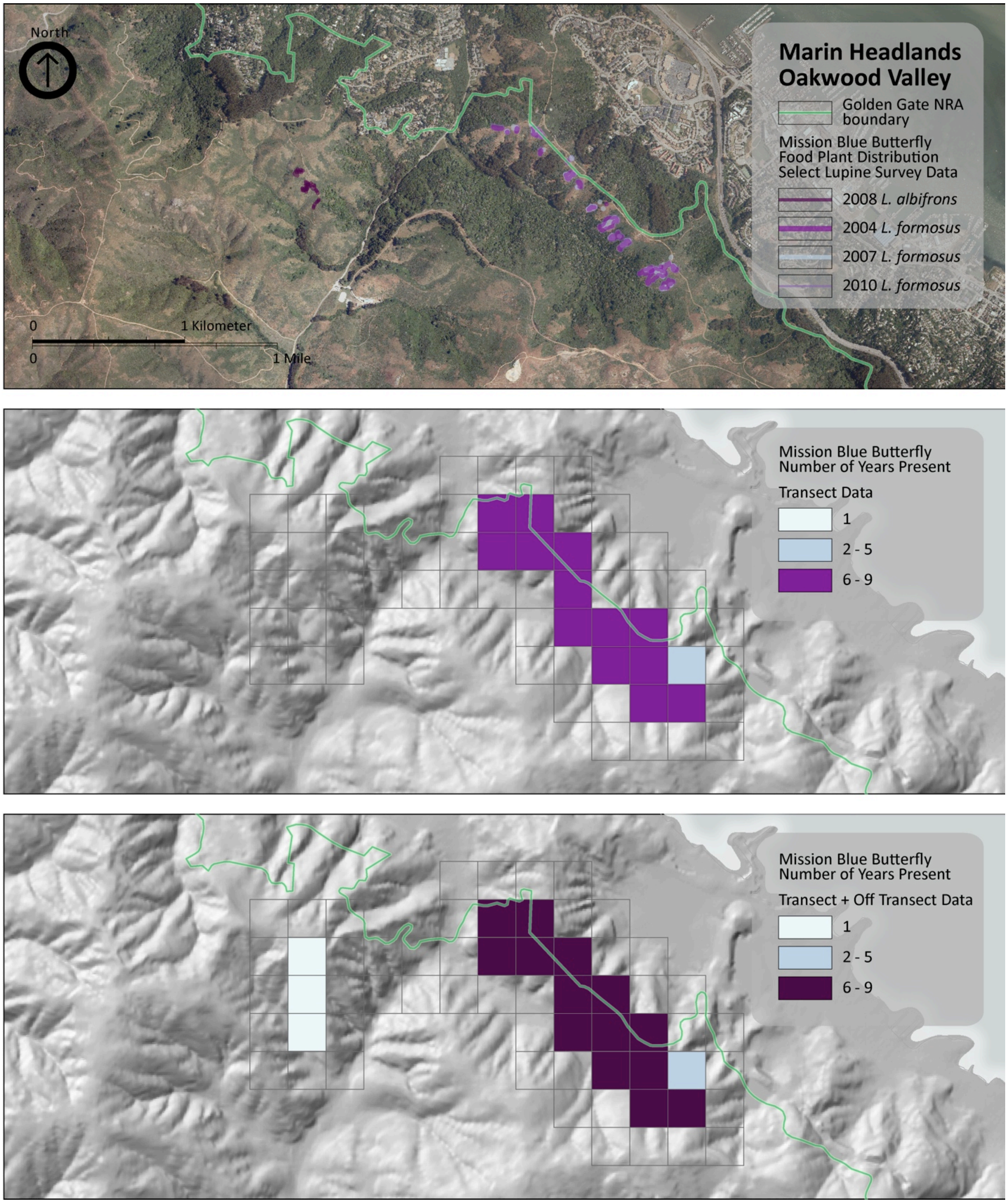

Figure 8. Status of mission blue butterfly at Oakwood Valley. Top: Distribution of lupine foodplants in 2004, 2007, 2008, and 2010. Middle: Number of years present on transects within 250-m grid cells, 2003–2011. Bottom: Number of years present on and off transects within 250-m grid cells, 2003–2011.

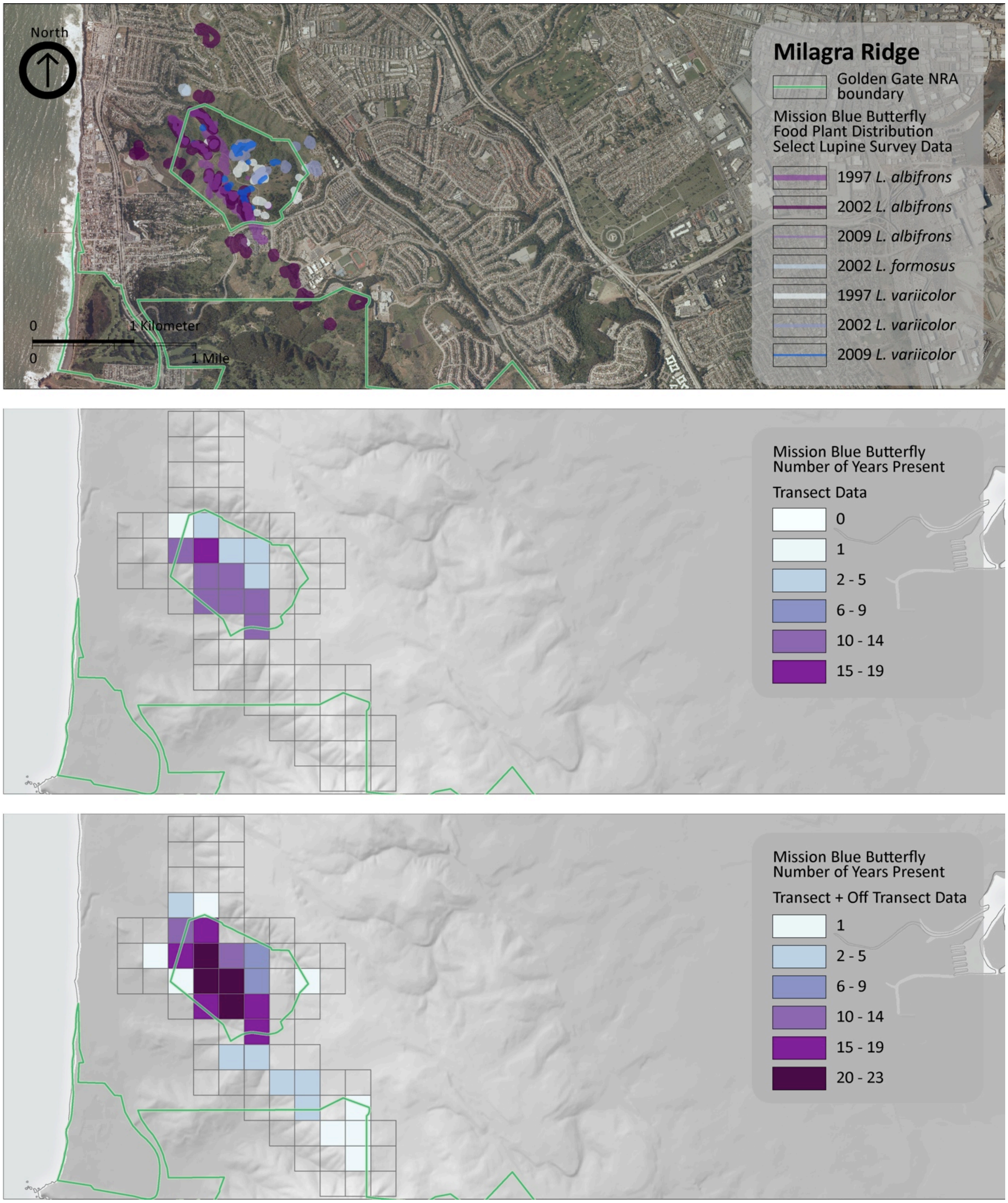

Figure 9. Status of mission blue butterfly at Milagra Ridge. Top: Distribution of lupine foodplants in 1997, 2002 and 2009. Middle: Number of years present on transects within 250-m grid cells, 1994–2011. Bottom: Number of years present on and off transects within 250-m grid cells, 1985–2011.

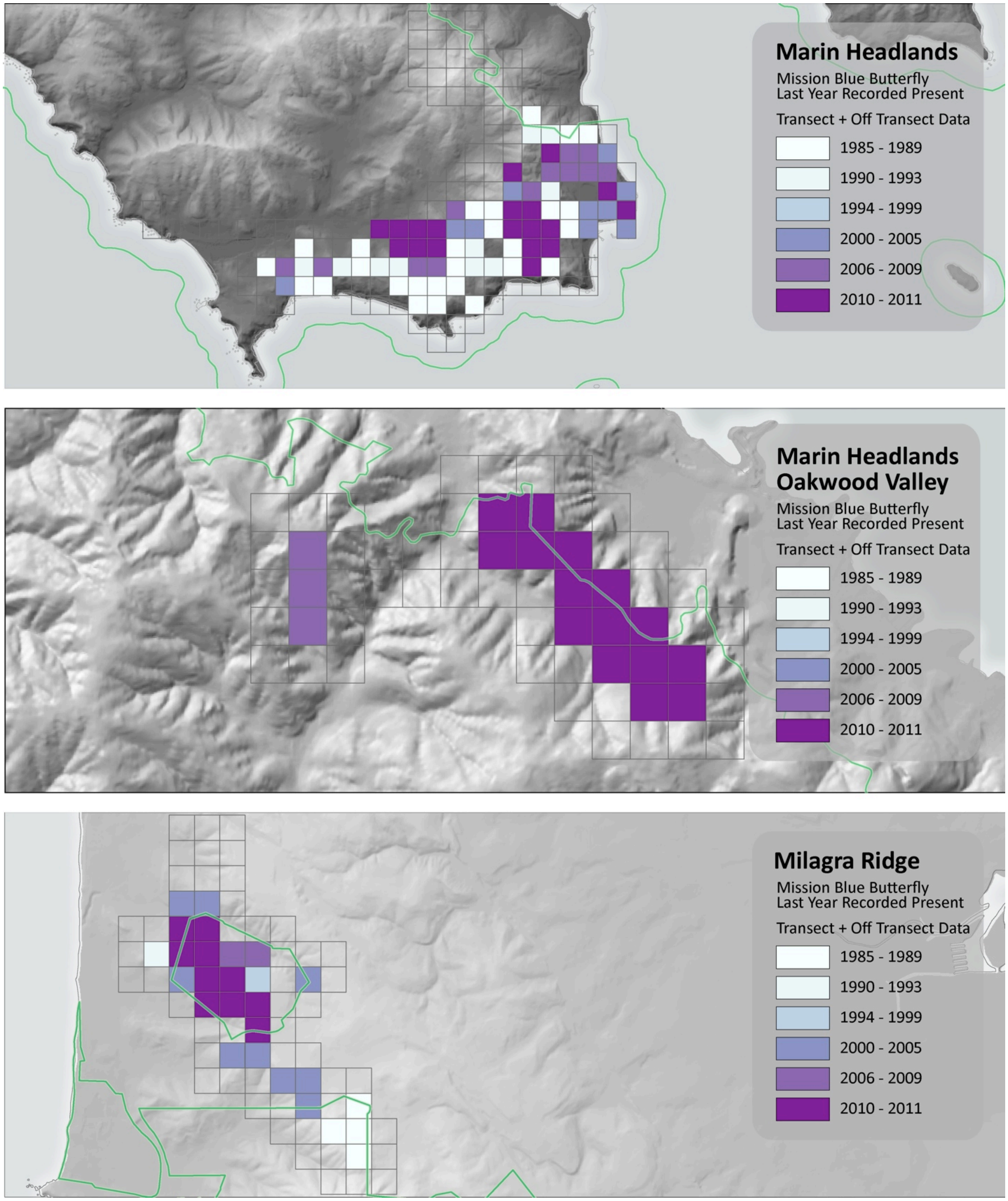

Figure 10. Last year mission blue butterfly was recorded in transect or off-transect observations at Oakwood Valley, Marin Headlands, and Milagra Ridge.

A map showing the most recent year that butterflies were observed on both transect and off-transect surveys by 250-m grid cell illustrates a pattern of range contraction at each of the areas studied, especially on the decadal scale (Figure 10). Although recent non-detections do not necessarily mean that the species is absent, the congruence between these patterns and the available foodplant surveys suggests that mission blue butterflies have declined, both in range and number, at Marin Headlands and Milagra Ridge.

Discussion

The data available for this long-term assessment were of variable quality and inconsistent methodologies. Despite surveying different sites within the same NPS administrative area, the survey techniques and approaches were not standardized. Data collected to conform to the same protocol revealed multiple forms of bias. Although a standardized database was developed and was extremely useful, it required extensive quality control and suffered from wide variation in its use by different surveyors.

Despite the limitations in the survey data, a coherent picture of the status of mission blue butterfly at these locations can be ascertained. This picture is aided by the inclusion of foodplant surveys and geographic processing of transect and off-transect observations made over the years. As would be expected, the butterfly does well where the foodplants are present within the occupied districts.

An alternative scheme to monitor mission blue butterfly across these sites may be appropriate. Several options are available. Some authors have used distance sampling to improve estimates of detectability, but the populations are generally too small for this (60 observations needed)

(Buckland et al. 1993). Raw transect counts and peak counts have been shown to provide reliable information (Collier et al. 2008, Haddad et al. 2008, Isaac et al. 2011), but their continued use here under highly variable conditions is problematic (Harker and Shreeve 2008). Occupancy modeling might be appropriate here, since the population is small and not all lupine patches are occupied (Bried and Pellet 2011). Occupancy alone could be used to track population status. This is an important approach where distribution is patchy and dynamic (Wahlberg et al. 2002, WallisDeVries 2004) and is essentially what we have done with the grid-cell analysis.

We recommend the use of a grid-format matrix to delineate survey regions and to record the distribution of mission blue butterfly within the GGNRA areas where it is now monitored, and in any other appropriate habitat within NPS' GGNRA boundaries, using presence/absence data collected by whatever means are necessary to establish occupancy within a set area, with an emphasis on surveys focused on feeding evidence and immature life stages rather than adult butterflies. An adult monitoring component would continue at a different spatial and temporal scale than at present. A detectability estimate could be calculated, and consistent relative abundance metrics derived from occupancy data. All existing and future data would integrate within this format.

We recommend an enhanced plan, to include regular surveys to map lupine foodplants, measures to strategically augment lupine biodiversity for a more pathogen-resistant and resilient ecosystem, and targeted disturbance as a management tool to regenerate early-successional habitat. Improved connectivity within and between habitat patches on NPS property and between the GGNRA areas and adjacent sites with butterfly populations or with appropriate habitat and historic occupancy is likely to support species' persistence within GGNRA. Active ecological management and habitat monitoring are crucial (Bried 2008) and we strongly recommend a cooperative and collaborative approach towards the regional conservation challenge of mission blue butterfly recovery.

A full description of an improved monitoring plan is beyond the scope of this document, and will require pilot field studies. Within an individual survey unit, occupancy can be determined by evidence of feeding or any butterfly life stage. Details such as establishing the phenology of each life stage, and various survey protocols such as the amount of time spent searching for adult butterflies will have to be worked out in the field.

Determining true absence in a patch of lupines is difficult; one can only estimate a decreasing probability of presence with multiple surveys. But the key elements to establish occupancy and relative abundance are as follows:

1) Establishing an appropriate grid-cell matrix, size to be determined, to record presence/absence of mission blue butterfly;
2) Searching lupines of each species (where present) within a set area for evidence of feeding or post-diapause larvae;
3) If no feeding evidence or post-diapause larvae are found, then return for visits to spot adults during the flight season;
4) If no adults are found, search for eggs within a set area on lupines of each species where present.

Key habitat management elements to integrate with monitoring are as follows:

1) Updating maps of lupine distribution on a regular basis, time interval to be determined, to include an assessment of health and other characteristics;
2) Increasing lupine biodiversity to build a more resilient and pathogen-resistant ecosystem that meets specific requirements and butterfly preferences;
3) Using various forms of targeted disturbance as a management tool to regenerate early-successional habitat adapted to natural disturbance;
4) Improving connectivity within and between habitat patches at GGNRA areas with mission blue butterfly monitoring and between GGNRA and adjacent sites;
5) Providing support for cooperation between GGNRA areas, and collaboration between NPS, USFWS, and other agencies, organizations, and individuals working throughout the region to achieve mission blue butterfly recovery.

Excellent recommendations have been suggested by GGNRA wildlife biologists or other butterfly monitors. We have tried to credit them appropriately. We reviewed data made available for 1985–2011. Abundant data exist for 2010 for all GGNRA sites. For many reasons, the 2010 data strongly support alternative rather than established monitoring methods, and several examples illustrate important points and recommendations. The discussion examines several issues: butterfly and lupine habitat; current monitoring strategies that estimate relative abundance of adult butterflies on fixed linear transects; off-transect data; wandering transects; and options to incorporate immature life stage monitoring to more accurately determine butterfly presence/absence and distribution.

Butterfly and Lupine Habitat

The major problem encountered by monitors seems to be that fixed transect schemes do not keep up with the distribution of foodplants. Great effort has been expended to preserve fixed transects and maintain near-continuous datasets at Milagra Ridge and the Marin Headlands. At Milagra Ridge, transects established in 1994 were shortened, eliminated, realigned, and relocated in response to changing foodplant distribution (Breheny 2011). Transects established at Marin Headlands in 1993–1994 experienced a dramatic habitat quality decline — assessed by lupine foodplant presence — documented by comparing data from 4 to 6 vegetation surveys made on each transect between 1995 and 2008 (Bennett 2008b). Surveys measured the percentage of absolute cover for host plants, native and non-native grasses, forbs, shrubs and other vegetation. To improve Marin Headlands sampling, Rashbrook (2005) recommended that 5 of 17 fixed transects be eliminated (and removed from the database) because 4 Wolfback Ridge transects and inaccessible Slacker Ridge T115 together accounted for ~2% of data. On 3 of 4 Wolfback transects, butterflies were last seen in 1997; no lupines were on Bennett's 2008 survey.

At Milagra Ridge, Lambert (2001) recommended annual surveys to assess host plant presence/absence, percent cover, and health to investigate correlations between host plant availability on monitoring transects and fluctuations in butterfly abundance. For the "larger Milagra Ridge vicinity," defined as areas with known butterfly populations within 1 km of the GGNRA boundaries, additional mapping every 3 years using percent cover of foodplant species was also recommended (Lambert 2001). At the time, these locations were surveyed at least once during the year and observations were included with off-transect data. Crooker (2009) recommended mapping foodplants at 5-year intervals to realign survey transects within a shifting lupine distribution (as done in 2010, Crooker and Whitty 2011b). At San Bruno Mountain, Habitat Conservation Plan managers have noted that an area of mission blue butterfly habitat can significantly decline in quality or size over the course of a year (TRA Environmental Sciences 2008).

Continual changes in lupine distribution are expected, given they are early-successional species. Less-predictable variables in this already variable landscape are recurring fungal pathogens, erratic weather patterns, and other potential effects of climate change. We recommend fine-scale surveys annually or at least every two years to map foodplants, assess their health, record their size using size classes or stem counts as an age-class proxy, and capture other relevant attribute data. Survey details will need to be carefully thought out. Information about nectar sources, particularly near high-density lupine patches, invasive species within and near habitat patches, and soil characteristics would help evaluate habitat quality. Vegetation surveys as a separate endeavor prior to annual monitoring of the various butterfly life stages would closely track lupine health and monitor the progress of habitat enhancement or restoration projects.

Based on our examination of reports, maps, and GIS files, lupine distribution at GGNRA has been carefully surveyed, overall, although data are inconsistent and were collected for different purposes by different investigators. We have reasonable confidence in the data. Recent Milagra Ridge and Oakwood Valley GIS datasets are good, and additional surveys at Marin Headlands would complement existing data for a beneficial time-series baseline. Integration of other vegetation data from various sources would be appropriate if the original spatial scale and attributes were maintained. Off-transect data sheets have often provided anecdotal data about host plant dieback and regrowth.

Lupine Habitat Preferences and Restoration Issues

The three perennial lupine species used by mission blue butterfly have environmental preferences that affect their distribution. Flowering and senescent periods are staggered over several months. *Lupinus albifrons* — silver lupine — is most widespread and the favored foodplant. It prefers dry habitats, south and east-facing slopes, rocky outcrops at ridgelines, and disturbed soils like firebreaks. *L. variicolor* — manycolored or varied lupine — is more of a generalist; it tolerates dry, rocky, or thin soils but also grows in deeper soils. *L. formosus* — summer lupine — likes disturbed soil within landslides or roadcuts, but prefers a mesic habitat, a northerly exposure, and sandy or deeper soils.

In the largest section of mission blue butterfly habitat, in the northern part of the range at Marin Headlands, early surveyors concluded neither *L. formosus* nor *L. variicolor* habitat existed (Thomas Reid Associates 1987a), but *L. albifrons* was well-distributed across the southeastern ridges (Figure 7); this distribution has shifted and contracted somewhat but is comparatively stable. Farther north, in the Oakwood Valley (Figure 8), all the lupine habitat patches are *L. formosus*. Less than 1 km west, a disjunct group of *L. albifrons* patches supports butterflies in the northern Tennessee Valley.

All three lupines occur naturally within the central and southern part of the butterfly's range. At Milagra Ridge, *L. albifrons* is most prevalent; it and *L. variicolor* are both more widely distributed than *L. formosus* (Figure 9). Butterflies reportedly feed on all three species (Thomas Reid Associates 1993, Lambert 2001). Observers at San Bruno Mountain indicated *L. albifrons* and *L. formosus* were preferred equally as foodplants over *L. variicolor* (Thomas Reid Associates 1987a, 1999), and that *L. variicolor* tended to be most used when plants were either large, in large patches, or in close proximity to either *L. albifrons* or *L. formosus* patches (TRA Environmental Sciences 2008).

L. albifrons is the major butterfly food source at Milagra Ridge because it is most widely distributed, and it is the only food source at Marin Headlands. It is also the only one severely impacted by fungal pathogens like anthracnose-causing *Colletotrichum lupini*. California native plants are adapted to a warm dry summer and cool wet winter climate. Plants like *L. albifrons*, adapted to comparatively xeric conditions, are more susceptible to fungal diseases activated by waterlogged soils. Disastrous consequences can result from occasional El Niño (ENSO) winters, which are often warm and extraordinarily wet.

Following the El Niño winter of 1997–98, widespread *L. albifrons* dieback was reported during 1998–2000 at Marin Headlands (Rashbrook and Cushman 1999, 2000) and at Milagra Ridge (Lucas 1998, Newby 1999, 2000). Very low mission blue butterfly counts recorded during 1998–2000 correspond with the atypical conditions (Rashbrook and Cushman 2000). The impact was most severe at Milagra Ridge, with a small population. At San Bruno Mountain, between GGNRA sites, fungal dieback decimated *L. albifrons*, but *L. formosus* was not negatively affected by the pathogen; butterfly numbers were "consistently high" in *L. formosus* patches (Thomas Reid Associates 2001).

In 2010, at Milagra Ridge, a new *L.albifrons* dieback episode was reported that affected >90% of plants within the area's most productive and protected habitat patch (the Quarry; Transect 2); the potential for "dire consequences" (Whitty and Crooker 2011) is not overstated. Whitty and Crooker (2011) argue that the major threat to the mission blue butterfly population at Milagra

Ridge and potentially at Marin Headlands as well is the effect of fungal pathogens on *L. albifrons*, the dominant foodplant at both sites. They suggest mitigation by increasing lupine diversity, planting the more pathogen-resistant *L. formosus* and *L. variicolor* throughout mission blue butterfly habitat.

Measures to increase lupine biodiversity are essential to provide a resilient habitat and support mission blue butterfly recovery. Likely objectives would be to enhance, expand, and connect existing habitat patches rather than attempt to establish new habitat. We recommend first mapping existing lupines, with spatial analysis integrated to identify topographic features that form wind-protected sites and niche microclimates. This site-specific approach would influence seed collection and plant propagation activities, and ideally have support from GGNRA's native plant experts. An analysis of the existing landscape matrix and the desired initial configuration of habitat patches with increased lupine biodiversity, along with actual foodplant use observations, would help determine an optimal mix of lupines and associated nectar species for a particular location.

Patches of *L. variicolor* in the northeast section of Milagra Ridge were unaffected by the fungus; however, comparatively little butterfly activity has ever been recorded here. It is likely these patches are not too distant from others to be viable (USFWS 1996, 2010, TRA Environmental Sciences 2008). An increase in *L. variicolor* density with integrated *L. formosus* patches could produce attractive habitat. Since *L. formosus* appears to be pathogen-resistant and more desirable to the butterfly than *L. variicolor*, propagating and planting substantially more *L. formosus* than *L. variicolor* may be advisable in most situations. At Twin Peaks, where *L. albifrons* is predominant, and dieback occurred in 1998–2000, a sitewide revegetation augmented the small

L. variicolor population and incorporated new *L. formosus* patches (Wayne et al. 2009, Weiss et al. 2011). As an indicator of success, post-diapause butterfly larvae were found on new *L. formosus* plants two years after reintroduction of mission blue butterfly to Twin Peaks from San Bruno Mountain. The robust Oakwood Valley population has only *L. formosus*.

Whitty and Crooker (2011) note "difficult and mixed results" were obtained growing and planting out lupines, referring to a 2004 Milagra Ridge revegetation project. We do not have details about this effort, but many variables can negatively affect results. Successful and unsuccessful endeavors alike are valuable guidance. Lupine management at other occupied sites within the region, such as at Twin Peaks (Wayne et al. 2009), San Bruno Mountain (TRA Environmental Sciences 2008), and the San Francisco Peninsular Watershed (USFWS 2010) could provide strategies to incorporate (or avoid) at GGNRA.

We strongly recommend the use of intentional disturbance as a management tool for habitat enhancement and restoration at Milagra Ridge and Marin Headlands. Targeted disturbance can be used to stimulate development of early successional habitat near existing habitat. Within GGNRA, methods presumably could include controlled burning — not always an alternative — or other approaches. An ongoing GGNRA investigation by Merkle of habitat enhancement alternatives (Crooker 2009), and updates posted on the GGNRA website (2012) are encouraging. Disturbance effectively ensures regeneration of suitable foodplant patches (Wayne et al. 2009, Longcore and Osborne 2011, Figure 7). Availability of recently burned high-quality early successional habitat was shown to be very important for Karner blue butterfly. Although foraging rates were similar in treated or untreated habitat, female butterfly ovipositions within managed (burned or mowed) grassland were significantly higher (122 of 127 events) (Pickens and Root 2009). At San Bruno Mountain, higher densities of lupines and butterflies have been reported on cut slopes and roadcuts; while these provide early-successional habitat, they frequently are in more sheltered and wind-protected locations also (Thomas Reid Associates 1999).

Habitat Characteristics for Butterfly Persistence

Habitat connectivity, quality, and size largely determine butterfly persistence (Bried 2008). Re-establishing or maintaining connectivity by enhancing corridors or stepping-stones between habitat patches has frequently been recommended (e.g., Lambert 2001, Lindzey 2004, Crooker 2009); this applies within and between sites or areas. Within individual areas, Marin Headlands would likely benefit from links between productive habitat patches and formerly occupied locations where habitat exists. This type of effort is critical at Milagra Ridge, with its increasingly "polarized" distribution of butterflies at the extreme ends of the NPS property (Crooker 2009), locations where butterflies may concentrate because habitat patches at the Quarry and Rock Garden are sheltered.

Given Milagra Ridge's position as the northern occupied patch in a series of occupied habitat patches that extends south to Skyline College, through GGNRA's Sweeney Ridge, and into the San Francisco Peninsular Watershed, it seems very likely that a potential mission blue butterfly metapopulation structure includes Milagra Ridge (USFWS 2010). The small population at Milagra Ridge would likely play a critical role helping to sustain a metapopulation (Lindzey and Connor 2010), and benefit from genetic interchange. The data we have received, however, do not allow us to make further inferences.

Maintaining an enhanced habitat corridor from south of Milagra Ridge to north of Sweeney Ridge was recommended a decade ago (Lambert 2001). Most intervening habitat has been lost and the remainder fragmented by roads, trails, and development, but any remnants could be extraordinarily valuable for butterfly dispersal to and from Milagra Ridge and occupied territory to the south. Mission blue butterflies are described as weak fliers, but there is strong evidence they are capable of 400–600 m flights or farther between habitat patches (Thomas Reid Associates 1981, USFWS 1996, 2010).

Populations in the San Francisco Peninsular Watershed are monitored (USFWS 2010). We have anecdotal evidence about Skyline College and Sweeney Ridge populations (Whitty and Crooker 2011) but have no indication that surveys are conducted at either location or adjacent to Milagra Ridge. It is likely in the best interests of mission blue butterfly populations as a whole and for those within GGNRA for NPS to be actively involved with USFWS in a regional conservation strategy.

Translocation of butterflies from another site, potentially San Bruno Mountain, was recommended to increase butterfly numbers and genetic diversity at Milagra Ridge by "managing butterflies themselves, not just their habitat" (Whitty and Crooker 2011). Efforts to stabilize and increase the population by removing invasive plants and planting nursery-grown lupines — "manipulating habitat" — has likely led to extreme frustration as butterfly numbers apparently continue to plummet and food plants die back yet again (Breheny 2011, Whitty and Crooker 2011). A prerequisite to butterfly introduction from another site to Milagra Ridge, however, would be habitat manipulation, at a minimum to increase lupine biodiversity. An example of the process would be the recent successful reintroduction at Twin Peaks (Wayne et al. 2009, Weiss et al. 2011).

Habitat quality is inextricably linked to climate and to other environmental factors over which there is no control. Weather conditions within GGNRA are extremely variable, and the climate is changing; sites nearest the ocean may become even more diverse (Ackerly et al. 2010). In addition to even more variable weather, autumn and winter minimum temperatures are higher (Western Regional Climate Center 2012). Different butterfly populations or different life stages in the same population may be affected in potentially unexpected ways. Given there are adequate resources, environmental stochasticity most affects population persistence (Roy et al. 2001). Density-dependent factors may apply when immature life stages are considered, but population studies rarely consider larval survival (Nowicki et al. 2009). Dormant butterflies in Oregon and British Columbia were negatively affected by temperatures that were warmer in autumn and more variable in winter because these phenological shifts led to increased consumption of stored energy reserves and decreased fitness (Williams et al. 2012).

Monitoring Strategies on Transects

Counts of adult butterflies observed on fixed survey transects are used to attempt to derive standardized assessments of population status for an animal recognized for its typically wide fluctuations in annual numbers (Pollard 1988, Roy et al. 2001) and its susceptibility to unfavorable weather — either too hot, cold, wet, dry, foggy or windy (Nowicki et al. 2008). This butterfly is adapted to specific early-successional foodplant resources in a dynamic landscape but constrained to habitat fragments in an urbanized matrix — in a region with a range of local microclimates and changing climate patterns, already known for unpredictable weather — which along with various seasonal factors affects both detectability and variability of adult butterflies (Pellet 2008). Even without considering observer/sampling variability, such uncertainty is difficult to standardize.

Fixed-Route Transects

Fixed-route transects (Pollard 1977, Pollard and Yates 1993) are a long-established method for butterfly monitoring. Survey protocols specify a precise window to minimize variability of environmental conditions. Crooker and Whitty (2011b) note that narrow time and weather parameters often compete with other natural resource management commitments at GGNRA. Additional limitations contribute to overall uncertainty and make them less desirable to assess distribution and abundance of mission blue butterfly at GGNRA. Nowicki et al. (2009) argue that most transect-based population studies have design deficiencies because they focus on adults and neglect other life stages. Raw counts on transects give indices of relative abundance that should correlate with daily trends, but they do not necessarily reflect annual abundance, because this species' highly variable emergence pattern temporally fragments the population (Nowicki et al. 2008). Another problem is that the impact of environmental stochasticity on adult numbers can be confounded with its simultaneous impact on adult longevity, affect the transect counts, and lead to poor estimates of relative abundance (Nowicki et al. 2009).

Butterfly detectability is imperfect, with individual detection probability unknown. An apparent change in abundance could, instead, be a change in detection probability. True abundance measures should incorporate a detection probability component (Haddad et al. 2008, Nowicki et al. 2008). Probability of detection increases with the number of surveys per season and with seasonal abundance, and will vary according to sampling intensity and potentially with the observer (Pellet 2008). A detection index has to be developed without mark-recapture-release or distance sampling for most endangered species, but an estimate also could be calculated using a second simultaneous observer. Finally, a cryptic, rare, sparsely distributed species is likely to always be more difficult to detect (Pellet 2008).

Sampling effort adds another wrinkle. Abundance indices based on monitoring adult butterflies along established linear transects at GGNRA remain flawed despite efforts to adjust data values to attempt sampling-effort corrections (Lambert 2002, Lindzey 2004, Crooker 2009) and randomize transect-sampling schemes (Crooker 2009). Reviews of datasheets indicate flight-season surveys were not always repeated within recommended time intervals; whether due to inclement weather or scheduling constraints, this would affect seasonal abundance measures based on summed weekly counts. Shortened flight seasons would result in compressed peak counts. Individual peak counts, however, would not be affected. We reviewed figures and all supplemental spreadsheets included with reports to better understand the methods used for comparisons between years, between transects, and between observers. Monitors noted transect data are inherently variable (Rashbrook 2005); and although “adequate for detecting gross changes” they are likely to be “highly variable and inconclusive” for smaller populations (Crooker and Whitty 2011a). We agree strongly; with very small sample sizes and frequently with zero values, these data do not lend themselves well to typical statistical procedures.

In 2010, monitors on fixed linear transects at Milagra Ridge recorded 5 butterflies, the lowest number since 2000, with only 3 more recorded off-transect; it was the narrowest distribution (Transects 2 and 9), shortest flight season (1 day) and latest initiation date (May 4^{th}) ever recorded (Whitty and Crooker 2011). During the same year, experimental transects were created at Milagra Ridge and Oakwood Valley as components of a study to compare monitoring methods (Crooker and Whitty 2011b). The method-comparison report (Crooker and Whitty 2011b) indicated 11 butterflies were recorded on 4 transects (2, 3, 5, and13) during 9 weeks on "new" linear transects reconfigured to align with the current lupine distribution within Milagra Ridge habitat patches. Monitors recorded 34 butterflies on wandering transect routes through the same patches plus three adjacent areas (Crooker and Whitty 2011b). Differences in counts acquired by the three methods were not too surprising. When higher counts are considered with the expanded spatial extent and temporal range, however, the combined results could alter the perception that 2010 was an extraordinarily bad year.

We compared raw data and spreadsheets with the reports (Crooker and Whitty 2011a, Crooker and Whitty 2011b). On wandering transects, 57 butterflies were recorded, but we do not know the reasons for an adjustment. On established linear transects, with both GGNRA and long-term volunteer data (from Darling, as in 2004–2009) included, 9 adults were observed on 4 transects (2, 9, 10, 13) over 4 weeks with 1 off-transect observation the following week. This differed from the other dataset but volunteer data filled 10-day and 14-day data gaps within the flight season. On the new linear transects, one additional survey added 7 butterflies. With all transects and all data included, the 2010 flight season at Milagra Ridge extended from April 14th through June 17th.

As with many datasets, various conclusions could be drawn. Rashbrook and Cushman (2000) recognized that an extraordinarily late, very short season at Marin Headlands was "artificial" when based solely on data from established transects; with the inclusion of incidental off-transect sightings, the flight season nearly tripled (from 21 days to 57) and the start date was consistent with other years. A decade later, Bennett (2010) noted an important change in the spatial distribution of incidental off-transect observations at the Marin Headlands: as lupine habitat moves farther away from established transects, current monitoring protocols may no longer capture off-transect observations at all.

A redesign of the fixed-transect monitoring program to fully integrate off-transect, incidental sightings was suggested as a way to maximize data without additional surveys (Rashbrook and Cushman 2000, Rashbrook 2005); this was prior to GPS data at Marin Headlands. Other monitors at Milagra Ridge and Marin Headlands have regularly recommended that a standardized effort be implemented to capture off-transect data (e.g., Lambert 2001, Lindzey 2004, Bennett 2009).

If fixed transect surveys must continue, we very strongly recommend an integrated and standardized program to appropriately capture all off-transect butterfly locations and associated attributes with a GPS unit while in the field. Many additional details would need to be specified. Collaboration to standardize collection methods and metadata for such records would be beneficial. At Milagra Ridge, a specific program to collect off-transect data (pre-GPS) was in place during 1999-2001; printed maps with subsites and landmarks were included with off-transect datasheets. We found maps useful to identify locations within and near Milagra Ridge that later received just a description, which after a decade became unused names and unknown locations. Without associated maps or coordinates, the off-transect data are of far less value than they otherwise might be.

Wandering Surveys

Wandering transects through habitat patches were very successful at Oakwood Valley during 2003–2010. Techniques were continually revised to develop an efficient process; in 2009, lupines were flagged in advance to avoid trampling and to help monitors direct the survey (Crooker 2011b). Monitors meandered through patches, covered ~ 80% of the lupines, zigzagging to minimize double-counting adults (Crooker 2011b), and captured data comparable to on-transect plus off-transect observations. Disadvantages of traditional wandering surveys are that they are time-consuming and non-standardized.

We recommend that timed wandering surveys through habitat patches be implemented for adult butterflies for a multiple life stage monitoring approach. Timed wandering surveys are comprehensive, have high detectability, and are appropriate for limited park resources (Kadlec et al. 2012). Timed surveys through defined areas within grid cells would overcome disadvantages of traditional wandering surveys yet retain the benefits.

Fixed-transect surveys for adult butterflies are unlikely to capture actual distribution and do not provide dependable relative abundance metrics. We recommend a shift to other standardized methods to more reliably and accurately assess population trends. We would suggest that, given the necessary relationship between foodplants and larval development, it is not productive to continue to survey fixed transects in areas where foodplants are absent.

Multiple Life Stage Monitoring

We suggest mapping foodplant distribution each year (or as often as feasible) and then switching to a scheme to track occupancy within a set area using multiple life stages. This would include initial searches for feeding evidence and/or post-diapause larvae (Lindzey and Connor 2010), then timed wandering surveys for adults (Crooker 2011b) and egg surveys (Wang 2006) if required. Adult stages are more exciting to see, but documenting reproduction is more important for tracking long-term population trends. An immature life-stage survey based on foodplant distribution would probably provide better long-term information about the species' status and the raw material to produce population viability estimates in a sophisticated manner. Furthermore, it would keep the focus of conservation efforts on the foodplants, rather than tracking adult flight. Adult observations would be a component, but would primarily be important in focused studies to investigate resource use (both space and nectar sources, perches, etc.).

For the purpose of tracking occupancy (as defined by reproduction), following our earlier efforts and our recommendations to track occupancy rather than abundance (Longcore et al. 2010), we would suggest first establishing an appropriate grid-cell matrix to record presence/absence of mission blue butterfly. GPS waypoints would be used to locate grids in the field rather than permanent stakes or flags. Adoption of a 250-m grid would allow for a 5–10 m margin of error well within GPS accuracy and precision. A 100-m grid matrix could certainly be used instead but would substantially decrease the acceptable amount of error and increase the number of survey cells.

With multiple search protocols for several life stages, a grid-based overlay provides several advantages. Within each defined region — or grid cell — once occupancy is confirmed, by whatever means are necessary to determine true presence or absence during a given year, the location is "checked off" and a surveyor need not return to that area until the following year.

Detection of non-adult life stages is a valuable occupancy indicator and evidence of breeding at that location. The ability to spatially associate butterfly presence, evidence of reproduction, and species' absence with habitat location, habitat quality, and management actions will enhance decades-long conservation efforts intended to ensure the butterfly's persistence at GGNRA.

Our recommendation to improve the current mix of adult survey efforts is to train surveyors on a protocol to first map foodplants and then begin sequential observations within defined areas to survey plants for feeding evidence and/or presence of post-diapause larvae; and then, if necessary, to conduct timed wandering surveys for adults; and finally, if no other evidence of occupancy has been found, to survey plants for presence of butterfly eggs.

This multiple life-stage approach is a hybrid scheme based on earlier monitoring efforts. We briefly acknowledge those efforts as they have been used for mission blue butterfly and provide a rough description of recommended actions. All survey protocols will require pilot field studies. Surveys are conducted within specific areas. Lupine mapping is conducted first. It is possible to integrate foodplant mapping with the search for larval feeding evidence and/or post-diapause larvae, as is done at San Bruno Mountain (TRA Environmental Sciences 2008). Combining tasks may not be an appropriate method to use at GGNRA. Timing of surveys will vary with the phenology of life stages but will occur in the same order at any given location, with searches for evidence of feeding and post-diapause larvae, adults, and eggs conducted in that order.

Post-diapause larval feeding evidence ("feeding damage") determines occupancy and is evidence of reproduction. Lupines of each species (where present) within a set area are searched for evidence of feeding. We strongly recommend searching for more noticeable post-diapause feeding evidence rather than less-pronounced pre-diapause feeding evidence (TRA Environmental Sciences 2008, Weiss et al. 2011). Another advantage to an early-season search (typically in February) would be higher confidence in results, because of less damage done by other organisms, although mission blue butterfly feeding is distinctive (Lindzey and Connor 2010). Conducting later searches to ascertain evidence of pre-diapause larval feeding also might coincide closely with the peak adult flight season (typically in May) and could interfere with the ability to appropriately monitor adults, if that were necessary.

Crooker and Whitty (2011b) compared five types of monitoring at Milagra Ridge and Oakwood Valley in 2010: three transect variants, egg monitoring, and feeding evidence. They concluded that identifying evidence of feeding took the most time, had the most impact on habitat, and required the greatest level of technical expertise, particularly when searching *L. albifrons*; *L. formosus* was easier because it has larger leaves. They recommend against future feeding damage monitoring (Crooker and Whitty 2011b). A "Guide to Life (with)in the Lupines" was created by an intern (Abercrombie) to clarify feeding damage and aid in identifying larvae (Crooker and Whitty 2011b); we presume it could be quite useful. We reviewed the April and May 2010 feeding damage monitoring datasheets, which were very detailed. Plants were numbered within patches, with size classes, percentage of dieback (at Milagra Ridge), number of plant leaflets with evidence of feeding (almost all in May), presence of larvae or eggs, and other comments noted.

Compared with other methods, the larval feeding evidence indicated butterflies were distributed far more widely at Milagra Ridge in 2010. Feeding was detected in 10 of 12 habitat patches and eggs were detected in 7 of 12; adults were detected in 5 of 13 patches on wandering transects, in 4 of 12 on reconfigured fixed transects, and in 2 of 12 on established transects (Crooker and

Whitty 2011b). Experienced monitors conducted plant surveys, but apparently damage caused by other larvae and fungal dieback made identification difficult. As with other 2010 data, various conclusions could be drawn.

Late-instar larval surveys could be in lieu of or in addition to feeding evidence surveys. Timing would be the same, in February or March (Lindzey and Connor 2010). Larval survey s have been conducted at GGNRA for various purposes with varying protocols, with more-detailed foodplant surveys or as a trial monitoring scheme, at Milagra Ridge (Lindzey 2005b, Crooker 2009), Marin Headlands (Wang 2006, Bennett 2007), and Oakwood Valley (Lindzey 2005a, 2006b, Crooker 2009). Larval surveys have also been conducted at San Bruno Mountain (TRA Environmental Sciences 2008) and at Twin Peaks (Weiss et al. 2011). We recommend the survey protocol of Lindzey and Connor (2010). Their sampling strategy specified one visit to a particular location during the peak of larval activity; this was usually 4 to 6 weeks after the first larvae were detected at a site (Lindzey and Connor 2010). Late-instar larvae were described as easy to detect. We recommend, however, that GGNRA pilot studies also incorporate a similar protocol with a second round of sampling to estimate the detectability and repeatability of the larval surveys (Lindzey and Connor 2010).

Additional benefits of larval surveys have been noted. Weather conditions throughout the range during the flight season are unpredictable: wind, fog, and low temperatures frequently preclude adult butterfly surveys, whereas larval surveys can be completed as scheduled despite inclement weather (Lindzey 2006b). Variability between surveyors affected differently by weather conditions would be reduced with a larval surveys or a larval component. These observations would hold true for all monitoring of immature life stages.

If no feeding evidence or post-diapause larvae are found, monitors return to locations where occupancy has not been verified for visits to spot adults during the flight season, using a timed protocol on wandering transects through habitat patches to search for adult butterflies. It may be determined, based on pilot studies, that this component is not worth the time and effort expended for the additional amount of data collected, in comparison to other monitoring of immature life stages or evidence of larval feeding.

If no feeding evidence or post-diapause larvae or adults are found, monitors return to search for eggs within a set area on lupines of each species (where present). Egg surveys are straightforward — eggs are deposited on upper plant surfaces and easily detected. Crooker and Whitty (2011b) compared this method at Oakwood Valley and Milagra Ridge, classifying eggs by age by their appearance; they noted egg surveys required no technical expertise and were easier than finding feeding damage or adults. Wang (2006) described an egg as "white and echnoid-shaped — like a sea urchin without spines. Macroscopically, it is ornamented with tiny polygons." There may be difficulty, however, discerning mission blue eggs from Acmon blue eggs (USFWS 2010, Crooker and Whitty 2011b). GGNRA egg surveys have included observations at Marin Headlands (Wang 2006, Bennett 2007), Oakwood Valley (Crooker 2011b), and Milagra Ridge (Lambert 2002, Wang 2003, Crooker 2011b); egg surveys also been done at Twin Peaks (Weiss et al. 2011) and San Bruno Mountain (TRA Environmental Sciences 2008).

Improved, reliable data to manage mission blue butterfly populations and their habitat to ensure their persistence at GGNRA are the primary incentive for a new monitoring protocol. We have discussed others, and there may be unforeseen benefits. Combined with regular lupine mapping, it might enable surveyors at Marin Headlands to examine formerly occupied habitat not near transects, or continue to find new occupied locations (Bennett 2007b, 2008a). Scheduled surveys of immature life stages could help alleviate weather and time constraints of monitors who survey both Milagra Ridge and Oakwood Valley. To facilitate transect monitoring at Milagra Ridge, with a declining population, a minimalist approach has been in place at Oakwood Valley (Crooker 2008); with some modification, we support that presence/absence approach. With a field-tested habitat and multiple life stage monitoring protocol, Milagra Ridge might also expand surveys into adjacent areas where butterflies were last recorded in 2000–2004 or earlier.

Intra- and Inter-Agency Coordination

The methods of monitoring mission blue butterfly and reporting those results vary both within the properties managed by the National Park Service and between these lands and other occupied habitats. It would be possible to coordinate and standardize these efforts to a large degree with the participation of each of the landowners and associated land managers. Annual meetings are already being convened for all mission blue butterfly researchers, which represents a significant opportunity. Guidance from the U.S. Fish and Wildlife Service on a repeatable standard for monitoring and reporting mission blue butterfly distribution and abundance across its range would be extremely useful going forward. The effort represented by this report and by Longcore et al. (2010) to consolidate and standardize data from mission blue butterfly survey efforts is quite substantial. Future monitoring efforts should be designed to avoid the need for such extensive post-processing so that patterns and trends can be more rapidly distinguished and inform management actions. Many options are available in this regard, including standardized online reporting of annual surveys that would be linked to a pre-determined geographic framework, establishment of standards for foodplant mapping and return interval across the species range, and other innovations that would allow managers to see and understand the results faster and integrated over a larger area.

Literature Cited

Ackerly, D.D., S.R. Loarie, W.K. Cornwell, S.B. Weiss, H. Hamilton, R. Branciforte, and N.J.B. Kraft. 2010. The geography of climate change: implications for conservation biogeography. Diversity and Distributions 16: 476–487.

Arnold, R. A. 1983. Ecological studies of six endangered butterflies (Lepidoptera, Lycaenidae): island biogeography, patch dynamics, and the design of habitat preserves. University of California Publications in Entomology 99: 1–161.

Bennett, S. 2007a. 2007 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–17. Golden Gate National Parks Conservancy, San Francisco.

Bennett, S. 2007b. Survey of the endangered Mission blue butterfly in the Marin Headlands: Spring 2007, pp. 1–14. Golden Gate National Parks Conservancy, San Francisco.

Bennett, S. 2008a. Survey of the endangered Mission blue butterfly in the Marin Headlands: Spring 2008, pp. 1–14. Golden Gate National Parks Conservancy, San Francisco.

Bennett, S. 2008b. Vegetation analysis of the Marin Headlands Mission blue butterfly monitoring transects and impacts on butterfly monitoring techniques, pp. 1–9 + figures and tables. Golden Gate National Parks Conservancy, San Francisco.

Bennett, S. 2009. Survey of the endangered Mission blue butterfly in the Marin Headlands: Spring 2009, pp. 1–12. Golden Gate National Parks Conservancy, San Francisco.

Bennett, S. 2010. Survey of the endangered Mission blue butterfly in the Marin Headlands: Spring 2010, pp. 1–13. Golden Gate National Recreation Area, San Francisco.

Breheny, K. 2011. Draft report: 2011 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–40. Golden Gate National Parks Conservancy, San Francisco.

Bried, J.T. 2009. Information costs of reduced-effort habitat monitoring in a butterfly monitoring program. Journal of Insect Conservation 13: 615–626.

Bried, J. T., and J. Pellet. 2011. Optimal design of butterfly occupancy surveys and testing if occupancy converts to abundance for sparse populations. Journal of Insect Conservation online early.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman & Hall, London.

Butsic, V., G. Radke, N. Keller, and C. Crooker. 2005. The Mission blue butterfly at Fort Baker: abundance and presence 2001–2005, pp. 1–11. Golden Gate National Parks Conservancy, San Francisco.

Collier, N., D. A. Mackay, and K. Benkendorff. 2008. Is relative abundance a good indicator of population size? Evidence from fragmented populations of a specialist butterfly (Lepidoptera: Lycaenidae). Population Ecology 50: 17–23.

Crooker, C. 2008. 2008 Mission blue butterfly survey, Oakwood Valley, Golden Gate National Recreation Area, pp. 1–13. Golden Gate National Parks Conservancy, San Francisco.

Crooker, C. 2011a. Final report: 2009 Mission Blue Butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–50. Golden Gate National Parks Conservancy, San Francisco.

Crooker, C. 2011b. Final report: 2009 Mission blue butterfly survey, Oakwood Valley, Golden Gate National Recreation Area, pp. 1–49. Golden Gate National Parks Conservancy, San Francisco.

Crooker, C., and E. Whitty. 2011a. Draft Report: Comparison of different data sources for monitoring Mission blue butterflies, Milagra Ridge, 2004–2010, pp. 1–39. Golden Gate National Parks Conservancy, San Francisco.

Crooker, C., and E. Whitty. 2011b. Draft Report: Comparison of five methods for monitoring Mission blue butterflies, Golden Gate National Recreation Area, pp. 1–65. Golden Gate National Parks Conservancy, San Francisco.

Crooker, C., and E. Whitty. 2011c. Final report: 2010 Mission blue butterfly survey, Oakwood Valley, Golden Gate National Recreation Area, pp. 1–39. Golden Gate National Parks Conservancy, San Francisco.

DiGirolamo, L. 1996. 1996 survey on the status of the endangered Mission blue butterfly on Milagra Ridge in the Golden Gate National Recreation Area, pp. 1–9. Golden Gate National Parks Association, San Francisco.

Downey, J. C. 1957. Infraspecific variation and evolution in populations of *Plebejus icarioides* (Bdv.). Dissertation, University of California, Davis, California.

Downey, J. C. 1962. Host–plant relations as data for butterfly classification. Systematic Zoology 11: 150–159.

Guppy, C. S., and J. H. Shepard. 2001. Butterflies of British Columbia including western Alberta, southern Yukon, the Alaska panhandle, Washington, northern Oregon, northern Idaho, northwestern Montana. University of British Columbia Press, Vancouver, British Columbia, Canada.

Haddad, N. M., B. Hudgens, C. Damiani, K. Gross, D. Kuefler, and K. Pollock. 2008. Determining optimal population monitoring for rare butterflies. Conservation Biology 22: 929–940.

Harker, R.J., and T.G. Shreeve. 2008. How accurate are single site transect data for monitoring butterfly trends? Spatial and temporal issues identified in monitoring *Lasiommata megera*. Journal of Insect Conservation 12: 125–133.

Hereth, C. 1997. 1997 Mission blue butterfly monitoring report, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–15. Golden Gate National Parks Association, San Francisco.

Isaac, N. J. B., K. L. Cruickshanks, A. M. Weddle, J. M. Rowcliffe, T. M. Brereton, R. L. H. Dennis, D. M. Shuker, and C. D. Thomas. 2011. Distance sampling and the challenge of monitoring butterflies. Methods in Ecology and Evolution online early.

Kadlec, T., R. Tropek, and M. Konvicka. 2012. Timed surveys and transect walks as comparable methods for monitoring butterflies in small plots. Journal of Insect Conservation 16: 275–280.

Lambert, A. 2001. 2001 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–26. Golden Gate National Parks Association, San Francisco.

Lambert, A. 2002. 2002 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–26. Golden Gate National Parks Association, San Francisco.

Lindzey, S. 2004. 2004 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–18. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S. 2005a. Distribution of Mission blue butterfly at Oakwood Valley: results from three years of presence/absence surveys (2003–2005), pp. 1–3. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S. 2005b. 2005 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–17. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S. 2006a. 2006 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–14. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S. 2006b. 2006 Mission blue butterfly survey, Oakwood Valley, Golden Gate National Recreation Area, pp. 1–6. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S. 2007. 2007 Mission blue butterfly survey, Oakwood Valley, Golden Gate National Recreation Area, pp. 1–5. Golden Gate National Parks Conservancy, San Francisco.

Lindzey, S., and E. F. Connor. 2010. Monitoring the mission blue butterfly using immature stages. Journal of Insect Conservation online early.

Longcore, T., and K. H. Osborne. 2011. Final report for 2011 Palos Verdes blue butterfly adult surveys on Defense Fuel Support Point, San Pedro, California. (NAVFAC SW Agreement # N62473-11-2-2304), pp. 1–18. The Urban Wildlands Group, Los Angeles.

Longcore, T., C. S. Lam, P. Kobernus, E. Polk, and J. P. Wilson. 2010. Extracting useful data from imperfect monitoring schemes: endangered butterflies at San Bruno Mountain, San Mateo County, California (1982–2000) and implications for habitat management. Journal of Insect Conservation 14: 335–346.

Lucas, S. 1998. 1998 Mission blue butterfly monitoring report, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–9. Golden Gate National Parks Association, San Francisco.

Newby, E. 1999. 1999 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–30. Golden Gate National Parks Association, San Francisco.

Newby, E. 2000. 2000 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–39. Golden Gate National Parks Association, San Francisco.

Nowicki, P., J. Settele, P.-Y. Henry, and M. Woyciechowski. 2008. Butterfly monitoring methods: the ideal and the real world. Israel Journal of Ecology & Evolution 54: 69–88.

Nowicki, P., S. Bonelli, F. Barbero, and E. Balleto. 2009. Relative importance of density-dependent regulation and environmental stochasticity for butterfly population dynamics. Oecologia 161: 227–239.

O'Connor, M. 2008. Final report: 2008 Mission blue butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–35. Golden Gate National Parks Conservancy, San Francisco.

Pellet, J. 2008. Seasonal variation in detectability of butterflies surveyed with Pollard walks. Journal of Insect Conservation 12: 155–162.

Pickens, B. A. 2007. Understanding the population dynamics of a rare, polyvoltine butterfly. Journal of Zoology 273: 229–236.

Pickens, B.A., and K.V. Root. 2009. Behavior as a tool for assessing a managed landscape: a case study of the Karner blue butterfly. Landscape Ecology 24: 243–251.

Pollard, E. 1977. A method for assessing change in the abundance of butterflies. Biological Conservation 12: 115–132.

Pollard, E. 1988. Temperature, rainfall and butterfly numbers. Journal of Applied Ecology 25: 819–828.

Pollard, E., and T. J. Yates. 1983. Monitoring butterflies for ecology and conservation. Chapman & Hall, London.

Rashbrook, V. K. 2001. Survey of the endangered Mission blue butterfly on the Marin Headlands: Spring 2001, pp. 1–31. Golden Gate National Parks Association, San Francisco.

Rashbrook, V. K. 2004. Survey of the endangered Mission blue butterfly on the Marin Headlands: Spring 2004, pp. 1–10. Golden Gate National Parks Conservancy, San Francisco.

Rashbrook, V. K. 2005. Survey of the endangered Mission blue butterfly on the Marin Headlands: Spring 2005, pp. 1–12. Golden Gate National Parks Conservancy, San Francisco.

Rashbrook, V. K., and J. H. Cushman. 1994. 1994 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–20. National Park Service/Golden Gate National Recreation Area.

Rashbrook, V. K., and J. H. Cushman. 1995. 1995 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–26. Golden Gate National Park Association, San Francisco.

Rashbrook, V. K., and J. H. Cushman. 1996. 1996 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–32. Golden Gate National Recreation Area.

Rashbrook, V. K., and J. H. Cushman. 1997. 1997 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–25. Golden Gate National Recreation Area.

Rashbrook, V. K., and J. H. Cushman. 1998. 1998 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–32. Golden Gate National Recreation Area.

Rashbrook, V. K., and J. H. Cushman. 1999. 1999 survey of the endangered Mission blue butterfly on the Marin Headlands, pp. 1–28. Golden Gate National Parks Association, San Francisco.

Rashbrook, V. K., and J. H. Cushman. 2000. Survey of the endangered Mission blue butterfly on the Marin Headlands: Spring 2000, pp. 1–26. Golden Gate National Parks Association, San Francisco.

Roy, D.B., P. Rothery, D. Moss, E. Pollard, and J.A. Thomas. 2001. Butterfly numbers and weather: predicting historical trends in abundance and the future effects of climate change. Journal of Animal Ecology 70: 201–217.

Shoulders, C. 1995. The 1995 Mission blue butterfly census at Milagra Ridge, Pacifica, California, pp. 1–5 + appendices. Golden Gate National Park Association, San Francisco.

Thomas Reid Associates. 1982. Final Report to San Mateo County Steering Committee for San Bruno Mountain: endangered species survey (San Bruno Mountain), biological study — 1980–1981. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1985. San Mateo 1985 Observations TRA. 1985 IPO butterfly observation transect log, observers V. Harris and R. Langston, pp. 1–6. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1987a. Marin 1987 Observations TRA. 1987 IPO butterfly observation transect log, observer R. Langston, pp. 1–8. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1987b. TRA maps 1987. Maps, pp. 1–5. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1987c. FOBA Observations 1987. Map, pp.1. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1988. Figure 4: Mission Blue Observations at Marin Headlands – 1988. Map, pp. 1. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1991a. Marin Headlands Mission blue butterfly survey, pp. 1–5. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1991b. Milagra Ridge Mission blue butterfly survey. Report No. PX-8140-1-0349, pp. 1–5. Golden Gate National Recreation Area.

Thomas Reid Associates. 1992. Results of Milagra Ridge Mission blue butterfly survey, pp. 1–2. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1993. GGNRA: Milagra Ridge, Pacifica, San Mateo Co., CA, April, May & June 1993 butterfly observations, pp. 1. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1994a. GGNRA: Milagra Ridge, San Mateo County, CA, 1994 butterfly observations, pp. 1–2. Permit WRO-GOGA-1994-004. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1994b. Results of Milagra Ridge Mission blue butterfly survey, pp. 1–2. Thomas Reid Associates, Palo Alto.

Thomas Reid Associates. 1999. San Bruno Mountain Habitat Conservation Plan 1998 Activities Report for Endangered Species Permit PRT 2-9818, pp. 1–16 + appendices. County of San Mateo, Palo Alto, California.

Thomas Reid Associates. 2001. San Bruno Mountain Habitat Conservation Plan 2000 Activities Report for Endangered Species Permit PRT 2-9818, pp. 1–17 + appendices. County of San Mateo, Palo Alto, California.

TRA Environmental Sciences. 2008. San Bruno Mountain Habitat Management Plan 2007. Revised March 2008, pp. 1–178 + appendices. San Mateo County Parks Department, Redwood City.

U. S. Department of Defense. 2008. Global positioning system standard positioning service performance standard, 4th edition. Accessed 10/11/2011. http://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf.

U.S. Fish and Wildlife Service. 1996. Draft Mission blue butterfly (*Icaricia icarioides missionensis*) 5-year review, pp. 27. Sacramento Fish and Wildlife Office, U.S. Fish and Wildlife Service, Sacramento, California.

U.S. Fish and Wildlife Service. 2010. San Bruno elfin butterfly (*Callophrys mossii bayensis*) and Mission blue butterfly (*Icaricia icarioides missionensis*) 5-year review: summary and evalution, pp. 39. Sacramento Fish and Wildlife Field Office, U.S. Fish and Wildlife Service, Sacramento, California.

U.S. National Park Service. 2002. Field data collection with global positioning systems standard operating procedures and guidelines 06/05/02. Accessed 10/11/2011. http://www.nps.gov/gis/data_standards/field_data_collection_GPS.html.

Wahlberg, N., T. Klemetti, and I. Hanksi. 2002. Dynamic populations in a dynamic landscape: the metapopulation structure of the marsh fritillary butterfly. Ecography 25: 224–232.

WallisDeVries, M. F. 2004. A quantitative conservation approach for the endangered butterfly *Maculinea alcon*. Conservation Biology 18: 489–499.

Wang, T. Y. 2003. Mission blue butterfly survey: Milagra Ridge, Golden Gate National Recreation Area. Golden Gate National Parks Association, San Francisco.

Wang, T. Y. 2006. 2006 Mission blue butterfly monitoring report, Marin Headlands, Golden Gate National Recreation Area, pp. 1–7. Golden Gate National Parks Conservancy, San Francisco.

Wayne, L., S.B. Weiss, and C. Niederer. 2009. Recovery action plan for the Mission blue butterfly (*Icaricia icarioides missionensis*) at Twin Peaks Natural Area, pp. 1–44. San Francisco Parks and Recreation Department and Creekside Center for Earth Observation, San Francisco.

Weiss, S.B., C. Niederer, L. Wayne, and K. Swenerton. 2011. Progress report for the Mission blue butterfly (*Icaricia icarioides missionensis*) at Twin Peaks Natural Area, pp. 1–6. Creekside Center for Earth Observation and San Francisco Parks and Recreation Department, San Francisco.

Western Regional Climate Center. 2012. California Climate Tracker. Accessed 4/1/2012. http://www.wrcc.dri.edu/monitor/cal-mon/index.html.

Whitty, E., and C. Crooker. 2011. Final report: 2010 Mission Blue Butterfly survey, Milagra Ridge, Golden Gate National Recreation Area, pp. 1–45. Golden Gate National Parks Conservancy, San Francisco.

Williams, C.M., K.E. Marshall, H.A. MacMillan, J.D.K. Dzurisin, J.J. Hellman, and B.J. Sinclair. 2012. Thermal variability increases the impact of autumnal warming and drives metabolic depression in an overwintering butterfly. PLoS ONE 7: e34470.