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# Complex effects of Nitrogen Pollution and Grazing on Nectar resources of the Adult Bay Checkerspot Butterfly (*Euphydryas editha bayensis*)

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COMPLEX EFFECTS OF NITROGEN POLLUTION AND GRAZING ON NECTAR  
RESOURCES OF THE ADULT BAY CHECKERSPOT BUTTERFLY  
(*EUPHYDRYAS EDITHA BAYENSIS*)

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Nidhi Jain

December 2015

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## ABSTRACT

### COMPLEX EFFECTS OF NITROGEN POLLUTION AND GRAZING ON NECTAR RESOURCES OF THE ADULT BAY CHECKERSPOT BUTTERFLY (*EUPHYDRYAS EDITHA BAYENSIS*)

by Nidhi Jain

Recent anthropogenic increases in atmospheric nitrogen due to urbanization and combustion have had many adverse effects on natural systems, including loss of biodiversity, especially in sensitive habitats. One such region is the serpentine ecosystem of Coyote Ridge in San Jose, CA, the last refuge for recurring populations of the federally threatened Bay Checkerspot Butterfly (BCB) (*Euphydryas editha bayensis*). Increases in non-native grass cover and decreases in native forb cover (including cover of the BCB's native larval host plants) have been attributed to the fertilizing effects of increased atmospheric nitrogen deposition. To counteract this effect, grazing has been implemented as a grassland management strategy. However, the effects of nitrogen enhancement and grazing, and the combined effects on shoulder-season nectar resources, have not been previously studied. This research aimed to fill this gap by utilizing a split block experimental setting at Coyote Ridge with four treatments, comprising of fertilized, unfertilized, grazed and ungrazed plots. According to the study results, nitrogen enhancement tended to reduce the abundance of nectar resources in both grazed and ungrazed plots. It also tended to reduce native vegetation in the grazed plots, while potentially increasing its prevalence in the ungrazed plots. These findings suggest that the effects of grazing and nitrogen on serpentine ecosystems are complex, highlighting the need to reduce nitrogen deposition.

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## Introduction

Insects are an integral part of an ecological community. Due to habitat loss and limited attention to insect conservation, the rate of invertebrate extinction is higher than that of any other group of living organisms (Ehrlich & Wilson, 1991). The central coast of California is a biological diversity hotspot for several communities and is characterized by the largest coverage of serpentine soil habitat in North America (Rajakaruna et al., 2009). While serpentine bedrock underlays only 1% of California, this comparatively small area is home to 13% of California's endemic species (Rajakaruna et al., 2009), including the Bay Checkerspot Butterfly (*Euphydryas editha bayensis*). California has several univoltine species that have long flight periods because of mostly mild winters and cool summers. Nevertheless, inland insects, such as the endangered Bay Checkerspot Butterfly (BCB), that are found on higher elevations, have shorter flight times and therefore a shorter window for foraging, mating and laying eggs. In addition, the BCB is an umbrella species, whose conservation affects the protection of plant communities associated with this federally threatened insect. The Bay Checkerspot Butterfly is endemic to Northern California and used to be present at several sites, but is presently found in the region's largest serpentine outcrop, Coyote Ridge in San Jose.

Research at Coyote Ridge is unique because of the composition of the serpentine soils and specific climate, which allows certain plant and insect species to evolve. Investigations carried out in this area can thus address several serious management concerns, including effects of grazing and an increase in atmospheric

nitrogen. Studying and understanding the availability of nectar resources used in the BCB diet was the focus of this study.

## **Background**

Serpentine soils are derived from ultramafic rocks. The process by which this rock type transforms into soil depends on its chemical composition as well as biotic factors. As a result of these chemical responses, many different types of soils occur on serpentine areas. Serpentine vegetation is primarily characterized by the physiognomic differences that distinguish it from the vegetation of surrounding rocks and the types of species present, including rare species and combinations of species.

Serpentine soils typically have low levels of nitrogen, but high levels of magnesium, which most plants cannot tolerate. The native plants found in these soils are adapted to low nutrient content and low nitrogen levels (Schaefer et al., 2007), and are highly susceptible to even minor fluctuations in soil content. Several invasive species also thrive in these conditions and have outcompeted native vegetation over time. Coyote Ridge is a unique ecosystem, characterized by serpentine soils, plants and animals endemic to this region.

## **Literature Review**

Habitat degradation is widely recognized as the main cause of biodiversity loss. In regions with biodiversity hotspots, endangerment increases with habitat loss (Gordon et al., 2007). As home to over a hundred endemic plant, fish and wildlife species listed as threatened, endangered, or extinct, California is one of the key biodiversity hotspots in North America (Connor et al., 2002). Biodiversity degradation is expected to

endanger arthropods in particular, as about 40,000 insect species have already become extinct globally. Even though about one million insect species have been identified thus far, 5-10 million are believed to exist (Stork, 1988). However, the fact that hundreds are becoming extinct every day indicates their fragility and significant potential for erosion in diversity (Bonebrake et al., 2010). In order to effectively conserve insect populations, their ecologies and habitats have to be better understood.

When competition increases, non-native species in the ecosystem tend to outcompete the native plant species (Bennett et. al., 2012). As suggested by Teague et al. (2011), invasive plants are typically more adaptive relative to the native species, allowing them to proliferate in certain ecosystems.

#### **Native-exotic species competition in Serpentine ecosystems**

A field based experiment by Selmants et al. (2012), compared realistic and randomized plant species loss in the serpentine grassland in California. Blocks contained plots randomly assigned to realistic loss order and randomized loss both with the same number of plants. Results showed that the biomass of exotic plant species was inversely related to native species richness in the realistic loss order. In the random species loss order, invader species biomass was low across the species monitored. This study supported field based realistic species loss experiments that link biodiversity and ecosystem functionality in conservation of anthropogenic changes.

In a laboratory experiment, Vallano et al. (2012) studied the performance and competitive dynamics of five plant species native to California, found in Coyote Ridge (*Plantago erecta*, *Layia gallardiodes*, *Lasthenica californica*, *Vulpia microstachys* and

*Cryptantha flaccida*) and the non-native grass *Lolium multiflorum*. The studied species were subjected to different combinations of gaseous nitrogen and solid ammonium nitrate. In the treatment comprising of higher amounts of solid ammonium nitrate (fertilizer) and NO<sub>2</sub> deposition, shoot biomass of the non-native grass *Lolium multiflorum* increased as did that of *Layia* and *Cryptantha*. In addition, when competitive ability, measured by relative yield potential (RYP), was assessed, it revealed an increase in RYP of *Lolium multiflorum* in soils characterized by NO<sub>2</sub> and nitrogen content relative to all native plants. These results indicated that non-native species have a competitive ability to out-crowd the native species.

#### **The effects of nitrogen increase**

Weiss (1999) estimated amounts of anthropogenic nitrogen deposition from various sources on Coyote Ridge, CA. Results showed that the invasive grass species were able to utilize atmospheric nitrogen deposition to outcompete the native species, thus reducing diversity. In particular, invasive grasses such as *Lolium multiflorum* utilized this nitrogen and out-crowded native species, such as *Plantago erecta*, *Muilla maritima*, *Cryptantha flaccida* and *Allium serra*, among others.

Weiss also studied grazing as a tool for removing some nitrogen biomass, by comparing grazed and ungrazed sites for three consecutive years beginning in 1996. The results yielded by this initiative revealed differences in plant composition between grazed and ungrazed sites assessed in 1996. In addition, the author reported that grazing regimes in winter and summer resulted in higher densities of the native

*Plantago erecta* and lower densities of the introduced grass *Lolium multiflorum*.

Significant change in the atmospheric nitrogen content is causing shifts in plant species composition. It is decreasing species diversity through alteration of certain ecosystems. In some cases, native plants in ecosystems with low fertility exhibit lower growth rates and do not respond well to soil nutrient increases (Vitousek, 1986). In a study conducted by Brooks (2003) in the Mojave Desert, which can be classified as a low productive ecosystem, the author designed plots to assess different levels of nitrogen deposition. The purpose of the study was to evaluate how increased levels of soil nitrogen affect annual plant communities in the desert. Fertilization during 1996 and 1997 was used to simulate increased nitrogen levels. The results showed that the effects of fertilization on annual plants decreased native annual plant density, biomass and species richness. This outcome was attributed to the increased competition for soil, water and other nutrients with alien species.

Nitrogen deposition not only affects exotic cover above ground growth, it can affect below ground microbial communities as well. Esch et. al. (2012), studied potential N-mineralization to look at the combined effect of grazing (simulated through fenced blocks) and Nitrogen deposition (simulated by adding fertilizer). Data on underground cover showed that increased grazing and nitrogen were correlated with increased microbial activity. Exotic cover was also generally correlated with increased microbial activity. Seasonal effects on abiotic factors and plant phenology were also found. There was lower microbial activity occurring at peak plant biomass. Thus, the combination of grazing intensity and soil nitrogen availability might affect the

microbial community in serpentine grasslands through changing non-native cover.

Pasari et al. (2014), studied the interactions of resource availability and disturbance on plant species richness and the spread of non-native plants. The authors simulated nitrogen deposition with fertilizer and manipulated grazing with fencing. Grazing has been used as a management strategy in California grasslands. Nitrogen deposition has facilitated nutrient poor ecosystems by promoting nitrophilic invasive plants' spread. The results showed that native species diversity may increase slightly under low-level nitrogen deposition with moderate grazing. Also, grazing might be effective at limiting non-native cover as nitrogen continues to accumulate.

### **Managing disturbed ecosystems: Grazing**

Grazing has been implemented as an extensive management regiment at Coyote Ridge for several decades. This measure was based on the hypothesis that top-down factors, such as grazing, may have the ability to regulate the structure of grassland plant communities. Grazing can lead to preferential consumption of certain species, eventually resulting in a modification of the composition and diversity of grassland communities (Collins et al., 1998). Grazing, in general, may have a positive effect on diversity, if resource availability increases. However, it may also interact with nutrient enrichment. The native plants found in these serpentinitic soils are adapted to low nutrient content and low nitrogen levels.

Weiss (1999) set up vegetation plots in 1996 and monitored their progress over time, in order to assess the differences in plant composition between grazed and ungrazed serpentine grasslands on multiple locations. Grazing was removed in 1985

and again in 1990. This regimen allowed the cover of the invasive species *Lolium multiflorum* to be compared to the native *Plantago erecta*, between grazed and ungrazed sites. The results showed that sites on which grazing was permitted were characterized by higher densities of *P. erecta* and lower densities of invasive grasses. In addition, the amount of grass cover increased and *Plantago* cover decreased when grazing ceased in 1985 and 1990.

In a study by Hayes & Holl (2003), the impact of cattle grazing on plant communities in the coastal prairie of California were studied. They surveyed the vegetation community composition, focusing on native annual forbs utilizing structures at 25 paired grazed/ungrazed sites. They found that native annual forb species richness and cover was higher in grazed sites. Non native annual grass and forb cover was higher in grazed sites, native grass cover and species richness did not differ in grazed or ungrazed sites. These results suggested that grazing might be a valuable management tool of vegetation communities that are prone to disturbances.

More recently, Marty (2005) conducted a study in the Central Valley in California, examining the effects of grazing treatments across 72 vernal pools, comprising of ungrazed, continuously grazed, wet-season and dry season grazed. These different grazing patterns were allowed to continue for three years and data pertaining to abundance was collected. The study findings revealed that the ungrazed pools had 88% higher cover of non-native grasses and 47% lower cover of native species at continuously grazed sites. Moreover, native plant richness declined by 25% in ungrazed



pools and adversely affected native species richness. The results of this investigation confirmed that grazing can be a useful grassland management tool.

Esch et al. (2012) monitored grazing intensity to assess grazing and nutrient enrichment effects on microbial extracellular enzyme activity. Increased grazing and nitrogen were correlated with increased microbial activity and grazing directly impacts soil community function. Similarly, Pasari et al. (2014) manipulated grazing with fencing and monitored grazing intensity using camera traps in a 4 year factorial experiment to assess the effects of grazing and N deposition on native and exotic species dynamics. Grazing intensity varied within different functional groups. Also, native species diversity may increase under low level N deposition with moderate grazing although it may not be effective at limiting exotic cover.

### **Animals as umbrella species**

Umbrella species are useful to study when making conservation-related decisions, as their conservation implicitly contributes to the protection of other species in the ecosystems (Roberge & Angelstam, 2004).

Umbrella species have been used as a tool for determining the minimum size of conservation. Generally when species are selected as the umbrella or the focal conservation species, large mammals, birds and invertebrates have been chosen. The umbrella species generally has a target species that benefits directly from the umbrella conservation. For example, the Capercaillie leks in alpine forests in Switzerland have been chosen to target birds; the white-backed woodpecker in Spruce forests for benefitting beetles and the California gnatcatcher in Southwestern sage

scrubs for plants (Roberge and Angelstam, 2004).

Launer and Murphy (1994) showed that, if all sites occupied by the Bay Checkerspot Butterfly were preserved, about 98% of the native spring flowering plant species would also benefit. Some of the rare and endemic species would also recover in populations.

**Bay Checkerspot Butterfly.** The Bay Checkerspot Butterfly (BCB) *Euphydryas editha bayensis*, a subspecies of the Checkerspot Butterfly, is univoltine, producing one brood of offspring per year. Females lay up to 200 egg masses, generally on the most exposed parts of their host plants, thus allowing for efficient feeding (Murphy et al., 1983).

In each reproductive cycle, eggs hatch in about two weeks and the larvae feed for about 15 days until they reach diapause stage. They remain in the diapause state until winter precipitation allows the plants that serve as their annual food to bloom. After five to six months in the diapause phase, they will continue feeding on *P. erecta* until pupation. Females generally emerge three days after the males and mate almost immediately. After a few weeks, the females emerge as adults and feed on a variety of nectar sources (Weiss et al., 1988).

The Bay Checkerspot Butterfly has been considered an umbrella species for the serpentine ecosystem. To understand the conservation needs of the bay checkerspot butterfly, then, it is critical to understand its life cycle and diet needs.



*Figure 1.* Bay Checkerspot Butterfly feeding on *Amsinckia intermedia*. (N. Jain, personal photograph, April 2014).

***Feeding strategies: specialist versus generalist.*** A combination of physiology and preference makes an organism a specialist or a generalist feeder. Specialists only consume a small range of food sources, usually within a narrow taxon. Certain species may be categorized as non-opportunistic specialists; others are non-opportunistic generalists (Amundsen, 1995).

***Larval diet.*** The threatened Bay Checkerspot Butterfly is well established to be a specialist feeder on the native herb, *Plantago erecta* (Weiss, 1999). As a result, management strategies that affect the host plant directly affect the larval success. Weiss (1999) studied the effects of nitrogen deposition and grazing on the Bay Checkerspot larvae. During the 1996-1998 period, data on the post-diapause larvae density was collected from six serpentine outcrop locations in the bay area, CA. The population estimates at the Silver Creek site revealed a pattern of initial growth followed by a steady decline, and finally extinction. Overall, all sites were characterized by a decline in larval counts as a result of removal of grazing, which enabled invasion of non-native

grasses.

Allocation of larval food resources affects adult morphology and fitness in many insect families. Boggs (1986) showed the effects of adult morphology and female fitness on the larval butterfly *Speyeria mormonia*. Using a split-brood design, food intake was reduced by half during the last larval instar. Subsequent analyses revealed that the resulting adults had smaller body mass and forewing length compared to those of control animals whose diet was not restricted. In addition, the author reported that realized fecundity reduced with the decreasing adult survival, and was not affected by body mass or larval feeding treatment. Adult survival was lower in the group subjected to larval starvation. Thus, Boggs concluded larval dietary restriction had a direct effect on survival, whereas fecundity was affected by adult dietary restriction.

The Kingsolver & Huey (2008) model suggests that several factors affect lepidopteran fitness, including fecundity. In particular, adult size is determined by larval food intake, while realized fecundity depends on the actual number of eggs produced.

***Adult diet.*** Although little research has attempted to quantify the diet breadth of the adult Bay Checkerspot, nectar utilization observed in various related checkerspot species suggests that the members of this genus may function as nectar generalists (see Table 1).

Table 1

<i>Diet Breadth of Checkerspot Adults</i>		
Species observed	Nectar utilization	Study
Quino Checkerspot Butterfly ( <i>Euphydryas editha quino</i> )	<i>Lasthenia californica</i> , <i>Phacelia minor</i> , <i>Amsinckia intermedia</i>	Pratt & Emmel (2010)
Bay Checkerspot Butterfly ( <i>Euphydryas editha bayensis</i> )	<i>Lasthenia californica</i> , <i>Layia platyglossa</i> , <i>Allium serratum</i> , <i>Muilla maritima</i>	Weiss (1999)
Variable Checkerspot Butterfly ( <i>Euphydryas chalcedona</i> )	<i>Eriodictyon californicum</i> , <i>Diplacus aurantiacus</i>	Murphy et al. (1984)

Opportunistic generalists, i.e., those that respond to food sources that are available (Smith & Remington 1996), will benefit from any kind of energy resource available. They will have the advantage of consuming all available nectar resources. Available evidence shows that both actual fecundity (number of eggs produced) and realized fecundity (number of eggs that survive) may be affected by adult nutrition. Murphy et al. (1988) studied the effect of adult Bay Checkerspot Butterfly feeding on egg mass production. As a part of this investigation, post-diapause larvae were collected from two sites—Woodside and Edgewood, CA. All newly emerged adults were kept in identical conditions, but were fed different diets. As females fed with nectar produced more eggs than those that were fed diet that provided no nectar, the authors concluded that nectar plays an important role in increasing egg mass production, which could be crucial for population continuance.

A positive correlation between fecundity and adult butterfly nutrition has been reported in other studies. For example, a laboratory experiment conducted by Hill (1989) revealed that larger lepidopterans with nectar resources of higher quality generally lay more eggs than smaller females. In this work, two groups of the same adult butterfly species (*Euploea core corinna*) were fed with different concentrations of sucrose solution (1% and 25%, respectively). The experimental findings revealed that individuals fed with 25% sucrose lived longer and achieved higher fecundity rates than the group fed with 1% sucrose solution.

**Seasonality.** The BCB populations vary annually and are generally small in number. The ecosystem they inhabit also experiences high inter-annual variability (Hanson, 2015). In such small populations, the species' continued existence depends on reproductive success of every individual. The earliest or the last individuals in the season, or the few stragglers, could be the ones dictating the population fate in such variable conditions.

A study conducted by Hainsworth et al. (1991) investigated the availability of early nectar resources on painted lady (*Vanessa cardui*). As a part of this investigation, adult butterflies were fed with sucrose solutions from the same flower source (*Lantana camara*). The study sample was divided into three groups, whereby the first was fed at Day 2 following emergence, the second on Day 8, while the third received no feeding.

Subsequent analyses of the gathered data revealed that females from both groups that were fed upon emergence had increased fecundity rates relative to the group that had no nectar feeding upon adult emergence. Nevertheless, the egg count in

the group that ingested nectar on Day 2 was 22% higher than those that were fed later in their life cycles.

### **Research Objectives**

The objective of this study was to elucidate the changes in nectar resources of the adult threatened Bay Checkerspot Butterfly (BCB) due to anthropogenic air pollution. This was achieved by assessing the effects of the increased atmospheric NO<sub>x</sub> on the adult butterfly nectar resources by also understanding if grazing might change the impacts of nitrogen deposition on nectar resources and native vegetation growth.

### **Research Questions:**

Q<sub>1</sub>: Does the adult Bay Checkerspot Butterfly utilize a wide range of nectar resources available on Coyote Ridge?

Q<sub>2</sub>: How does nitrogen enhancement affect the presence of early and late (shoulder-season) nectar resources for the Bay Checkerspot Butterfly?

- H<sub>0</sub>: The relative number of nitrogen-enhanced plots that contain shoulder-season nectar resources of the Bay Checkerspot Butterfly will not differ from the relative number of ambient-nitrogen plots containing BCB nectar host species.

Q<sub>3</sub>: How does grazing affect nectar resource presence in the plots?

- H<sub>0</sub>: The proportion of grazed plots that contain native plant species used by the Bay Checkerspot Butterfly as shoulder-season nectar resources will not differ from the proportion of ungrazed plots containing such nectar plant

species.

Q4: How does N enhancement and grazing affect abundance of native shoulder-season nectar resources?

- H<sub>0</sub>: Percentage cover of native vegetation in N-enhanced plots will not differ between the ungrazed and the grazed plots.
- H<sub>0</sub>: Percentage cover of shoulder-season nectar resource species in N-enhanced plots will not differ between the ungrazed and the grazed plots.

## Methods

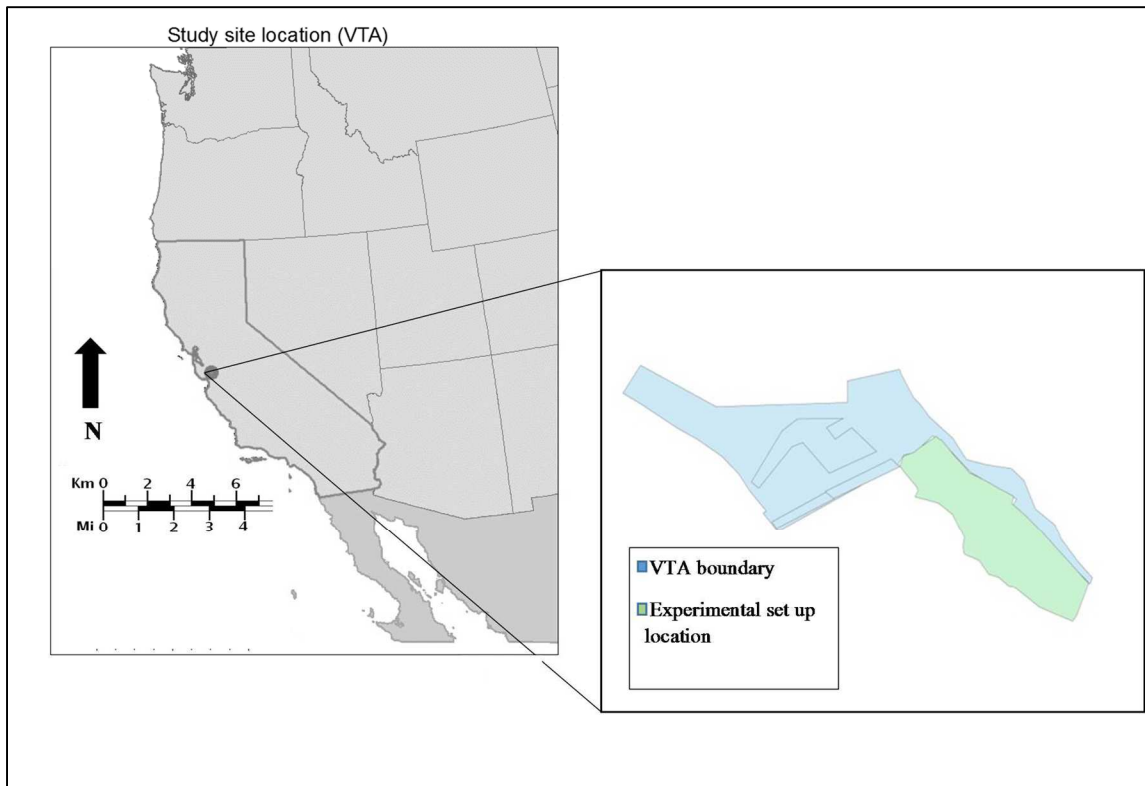
### Study Site

Coyote Ridge is located between southern San Jose and Morgan Hill, adjacent to Highway 101, in Northern California. It covers an area of about 2833 ha, about 21 km in diameter (San & Evens, 2014). The area experiences mostly Mediterranean climate with wet, rainy winters with an average rainfall of 50 cm, and warm summers, characterized by temperatures reaching up to 32°C (San & Evens, 2014). Because of considerable variability in elevation, ranging from 80 m to 450 m, Coyote Ridge is characterized by multiple microclimates. Serpentine grassland, native to California, is the primary vegetation in the ridge and supports many native animal species as well as shrubs and some exotic grasses. The area is covered by serpentintic soils, as well as some riparian wetlands, which provide habitats for the California red-legged frog (*Rana draytonii*) and the California tiger salamander (*Ambystoma californiense*), both



of which are federally threatened species (Fox & Nino-Murcia, 2005). Coyote Ridge is a unique location due to its abundance and diversity of wildflowers; it is also an important refuge for rare and endangered species. About 200 plant species have been identified and animal sightings include badgers (*Taxidea taxus*), elk (*Cervus Canadensis*), coyotes (*Canis latrans*), bald eagles (*Haliaeetus leucocephalus*), falcons (*Falco peregrines*), California gulls (*Larus californicus*), kestrels (*Falco sparverius*) and bobcats (*Lynx rufus*), amongst others.

Land on Coyote Ridge is owned by several stakeholders, including the Valley Transportation Authority (VTA), the Kirby Canyon disposal facility, the City of San Jose, the Santa Clara Valley Water District (SCVWD) and individual private owners. Part of this area is managed by the Open Space Authority (OSA), which also conducts several educational docent-led trips. Due to continuous efforts by conservationists, a majority of the land has been acquired by the VTA for protection and conservation (see Figure 2).



*Figure 2.* Study Region. Experimental set up location in Coyote Ridge, California (Map by N. Jain).

Coyote Ridge’s landscape is dominated by serpentine rock, which is California’s state rock (Oze et al., 2008). Serpentinite is characterized by high concentrations of iron and magnesium, with low levels of other nutrients, particularly nitrogen. The plants that have evolved in serpentine communities have adapted to tolerate these unusual nutrient levels. Due to the presence of several distinct microclimates and frequent disturbances, many species have colonized the area in metapopulations (Harrison, 1991).

Metapopulations are populations of species that are spatially separated from other populations consisting of the same species due to either physical or temporal barriers. Much of the land surrounding Coyote Ridge is privately owned by ranchers and small businesses. A large disposal facility is located on the lower portion of the land of the Coyote Ridge and

Highway 101 runs adjacent to the property. Extensive development and associated traffic emissions has increased the nitrogen content in the atmosphere, which has changed the nutrient profile of the serpentine soils and has created an imbalance of the delicate ecosystem of Coyote Ridge (Fenn et al., 2010). Due to this increase in nitrogen levels, native plants that are adapted to low nutrient content are declining in population, whereas exotic species, such as the grass *Lolium multiflorum*, have benefitted and outcompeted native plants. Similar studies over the past twenty years have shown that this imbalance is accelerating the decline in native insect populations that depend on these plants as a food or host source, in particular the Bay Checkerspot Butterfly (Weiss, 1999).

Since the 1930s, most of the Coyote Ridge area has been grazed, and still is, as this is seen as a viable management method for non-native plants. Proliferation of unwanted plant species could also be curbed by controlled burning, herbicide treatments and physical removal, which have also been historically used in Coyote Ridge (Suding et al., 2014). Since the area is highly sensitive to disturbance, human activity in the protected areas of the Coyote Ridge is limited and controlled, whereby public access is restricted.

### **Study Design**

The growing season of the rare annual species is usually very short. As the species of interest for this investigation is rare, patchy and threatened, the study adopted a design that allowed testing the previously developed hypotheses. In addition, the results yielded by the study were intended for use as baseline data to formulate questions and pave the way for future work. The research was designed to study

shoulder-season nectar resource availability, as resources are limited in the beginning and end of the season relative to the peak biomass.

The plots used in this study were set up by Dr. Jae Pasari and Dr. Daniel Hernandez. Ten sites were chosen at different topographies to create experimental locations. Plots covering an area of 5 m × 5 m were fenced to exclude cattle grazing. Each fenced plot was adjacent to a non-fenced 5 m × 5 m plot to allow grazing. By 2009, a total of 10 blocks (each comprised of a pair of fenced and unfenced plots) were established on varying topographies in Coyote Ridge, San Jose. Every plot also had poles adjacent to each plot with a motion sense camera mounted on to track grazing activity.

Each plot was further divided into subplots, whereby the downward sloping side was typically fertilized by adding (NH<sub>4</sub>NO<sub>3</sub>) 5 grams Nm<sup>-2</sup> yr<sup>-1</sup> in 14.1 gL<sup>-1</sup> of dissolved fertilizer each year to enhance nitrogen content (Pasari et al. 2014). This set up was created and maintained by Pasari et al. (2014), as shown in Figure 3.

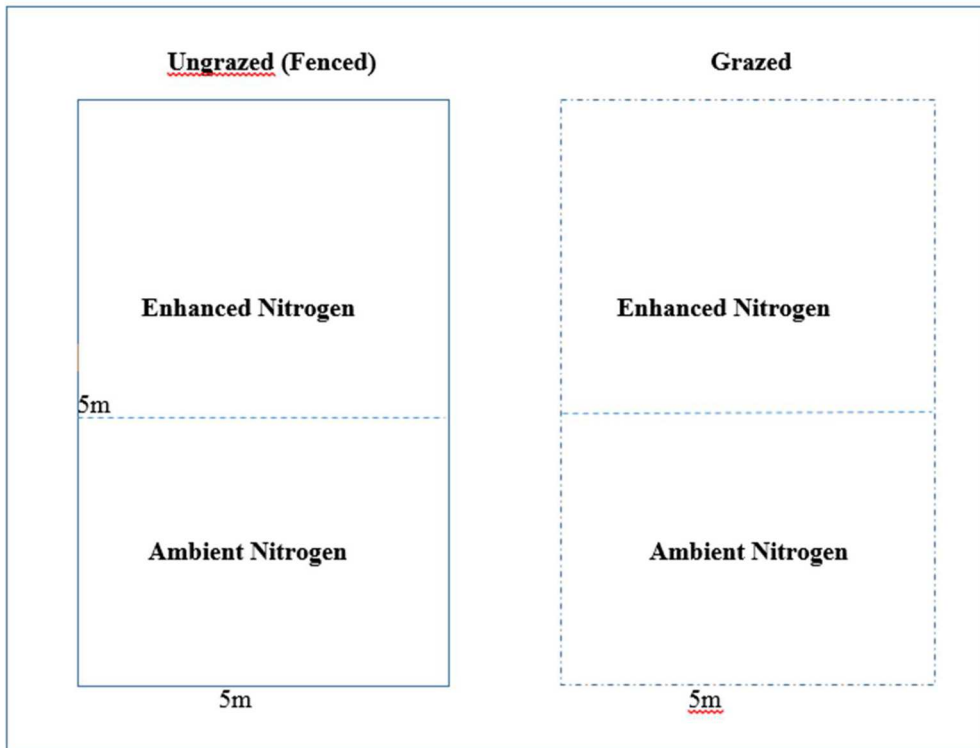


Figure 3. Split-block experimental set up

### Data collection

Vegetation (veg) quadrats were mapped out for each treatment, comprising of grazed and fertilized (GF), grazed and non-fertilized (GUF), ungrazed and fertilized (UGF) and ungrazed and unfertilized (UGUF).

Initial work for the present study started in January 2014 and included mapping the plots and vegetation bars that distinguished the fertilized from the non-fertilized side. Once the mapping was completed, data collection began in the spring of 2014. Specific plant species that serve as important nectar sources for the BCB were identified. This group was further divided into early (February-March), mid (March-April) and late flowering (after May) sets, as the aim was to understand the importance

of seasonality and the blooming period of potential nectar resources for the BCB.

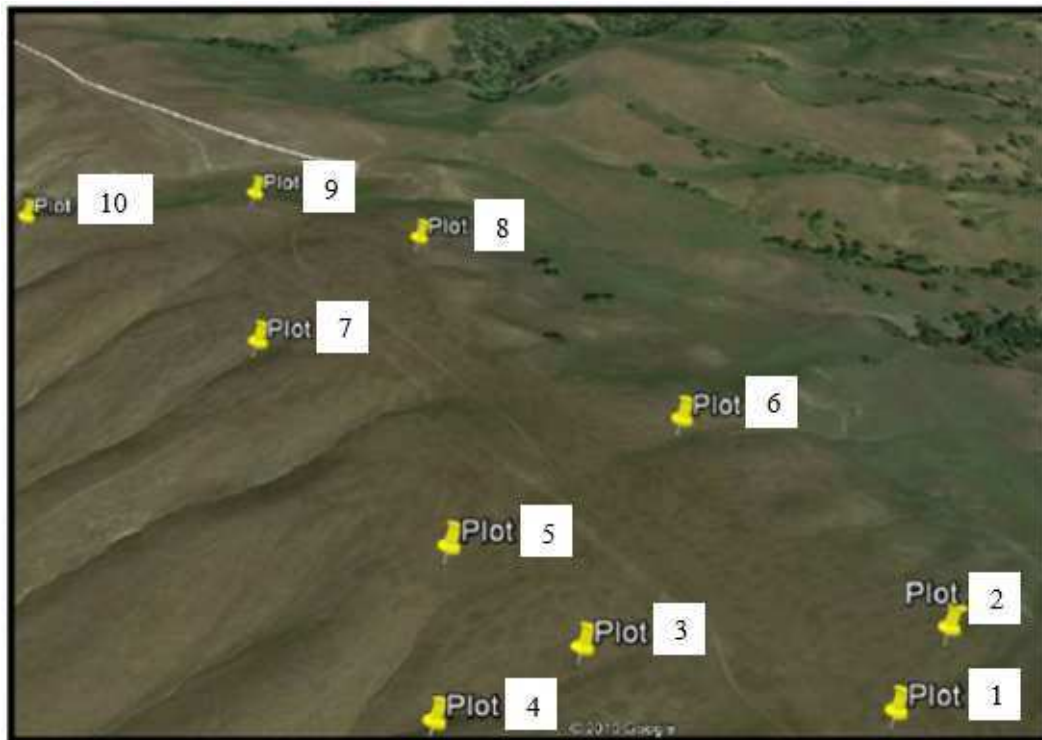
Data were collected from each plot and sub-plot with four treatments and ten replicates ( $n = 40$ ). In order to ensure that the data was collected from the same area on each occasion, a 0.5 m  $\times$  0.5 m quadrat was placed over each sub-plot's marked bar. On February 21<sup>st</sup>, March 18<sup>th</sup> and March 21<sup>st</sup>, presence or absence of vegetation was recorded. For the data collection that took place on March 23<sup>rd</sup>, March 28<sup>th</sup> and April 10<sup>th</sup>, this quadrat was further divided into nested quadrats, which generated 16 sub-quadrats, allowing the percentage cover of each growing plant to be accurately measured. This procedure was repeated for each of the four treatments in seven different replicates (plots 1-5, 9 and 10,  $n = 28$ ).

To complement the data collected on existing adult food resources, direct butterfly observations were also performed. In addition, a review of pertinent literature on previous adult nectar resource utilization was also conducted (see Figure 7). On March 27<sup>th</sup>, the first adult BCB was sighted, allowing the observations to be made with respect to plant species the butterfly was landing on and possibly utilizing as a nectar source. These observations were repeated on March 29<sup>th</sup> and April 3<sup>rd</sup>, April 22<sup>nd</sup> and May 1<sup>st</sup>, resulting in a total of six hours of data collection by direct observation.

The population of butterflies that emerged as adults in 2013 and 2014, both years of extended drought, was relatively small and scattered; thus, field observation time was short and the potential for data collection was limited.

In addition to the above, data loggers (Offset Electronics<sup>TM</sup>) were mounted onto the camera trap poles in early February at every plot. Each data logger collected

temperature and humidity data until April 5<sup>th</sup> for plots 1-10. This arrangement allowed temperature and humidity data to be sampled in four-hour increments, whereby the data loggers were replaced every three days to download the existing data. Plot locations were located at different topographies (Figure 4).



*Figure 4.* Distribution of plots on Coyote Ridge, San Jose (Image source: Google Earth™ 2015).

### **Analytical methods**

All raw data was input into MS Excel and processed using SYSTAT 13.1 and SPSS. Percentage cover data obtained on March 23<sup>rd</sup> and 28<sup>th</sup> was analyzed using a repeated measures analysis of variance (ANOVA) approach. In addition, a General Linear Model (GLM) was used for detecting trends between the effects of four different treatments on flower resource and native vegetation growth. A non-parametric, chi-

square ( $\chi^2$ ) test was performed on the data pertaining to presence/absence on February 21<sup>st</sup>, March 18<sup>th</sup>, and March 21<sup>st</sup>. I used an alpha of 0.1 to detect statistical differences to accommodate variability and a small sample size. Data yielded by direct butterfly observations was qualitatively analyzed. Finally when temperature and humidity were included as covariates with the different treatments against abundance (percentage cover), no correlations were detected, and the power of the tests was correspondingly weakened, hence, the variables were not included in any further results.

### **Results**

Vegetation was surveyed and identified in three seasons: early, mid and late season. The majority of the vegetation identified in the area comprised of native herbs, perennials and bulbs, whereas grasses and forbs were predominantly non-native vegetation (see Table 2).



Table 2

*All Vegetation Identified in Surveys Between February and May 2014*

Season	Vegetation name	Native/Non-native
Early Season (Feb-March)	<i>Calandrinia cilata</i>	Native
	<i>Hesperevax sparsiflora</i>	Native
	<i>Lasthenia californica</i>	Native
	<i>Lepidium nitidum</i>	Native
	<i>Lomatium macrocarpum</i>	Native
	<i>Microseris douglasii</i>	Native
	<i>Microsteris gracilis</i>	Native
	<i>Ranunculus californicus</i>	Native
	<i>Stipa pulchra</i>	Native
	<i>Acmispon wrangelius</i>	Native
	<i>Bromus berterioanus</i>	Non-native
	<i>Castilleja densiflora</i>	Native
	<i>Cryptantha flaccida</i>	Native
	<i>Eschscholzia californica</i>	Native
Mid-Season (March-April)	<i>Festuca perennis</i>	Non-native
	<i>Layia gaillardiodioides</i>	Native
	<i>Leptosiphon ambiguus</i>	Native
	<i>Plantago erecta</i>	Native
	<i>Nasella pulchra</i>	Native
	<i>Achillea millefolium</i>	Native
	<i>Allium sera</i>	Native
	<i>Calandrinia cilata</i>	Native
	<i>Muilla maritima</i>	Native
	<i>Ranunculus californicus</i>	Native
	<i>Calystegia subacaulis</i>	Native
Late Season (>May)	<i>Chlorogalum pomeridianum</i>	Native
	<i>Cryptantha flaccida</i>	Native
	<i>Eriogonum fasciculatum</i>	Native
	<i>Festuca perennis</i>	Non-native
	<i>Hemizonia congesta</i>	Native
	<i>Hemizonia luzulifolia</i>	Native
	<i>Lactuca virosa</i>	Non-native

Q<sub>1</sub>: Does the adult Bay Checkerspot Butterfly utilize a wide range of nectar resources available on Coyote Ridge?

During the course of the six hours of direct observation, carried out on March 27<sup>th</sup>, March 29<sup>th</sup>, April 3<sup>rd</sup>, April 22<sup>nd</sup> and May 1<sup>st</sup>, 2014, BCB fed from all eight plant species recorded in this study (see Table 3). The bay checkerspot butterfly adult consumes almost all available nectar resources on Coyote Ridge.

Table 3

*Adult Butterfly Observation of Nectar Utilization Between March 27<sup>th</sup>, 2014 and May 1<sup>st</sup>, 2014*

Plants flowering	Number of times
<i>Amsinckia</i>	6
<i>Cryptantha</i>	2
<i>Layia</i>	3
<i>Lessingia</i>	3
<i>Agoseris</i>	3
<i>Microseris</i>	2
<i>Allium</i>	2
<i>Sannicle</i>	2

Q<sub>2</sub>: How does nitrogen enhancement affect the presence of early and late (shoulder- season) nectar resources for the Bay Checkerspot Butterfly?

- H<sub>0</sub>: The relative number of nitrogen-enhanced plots that contain shoulder season nectar resources of the Bay Checkerspot Butterfly will not differ from the relative number of ambient-nitrogen plots containing BCB nectar host species.

During the plant survey period (February 21<sup>st</sup> and March 21<sup>st</sup>), seven native plant species were in bloom (see Table 4).

Table 4

*Flowering Vegetation Present on the First Three Survey Dates*

Flower resource	Day 1	Day 2	Day 3
	February	March	March
<i>Muilla</i>	Y	Y	Y
<i>Chlorogalum</i>	N	Y	Y
<i>Cryptantha</i>	N	Y	Y
<i>Eschscholzia</i>	N	Y	Y
<i>Microseris</i>	N	N	Y
<i>Allium</i>	N	N	Y
<i>Calystegia</i>	N	N	Y

On the first survey date, February 21<sup>st</sup>, 2014, a smaller number of the N-enhanced plots supported the growth of the native perennial flower *Muilla maritima* (see Figure 5). The difference was only marginally significant with a  $\chi^2$  *p*-value of 0.091, where (1, *N* = 20) and ( $\alpha$  = 0.1).

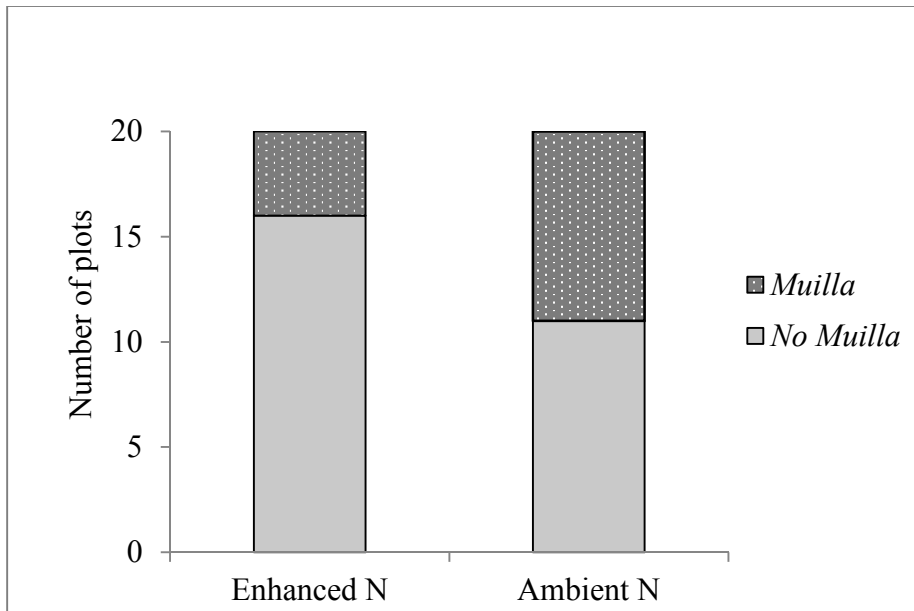


Figure 5. Presence/Absence of Perennial herb *Muilla maritima* in Enhanced N/Ambient N plots on February 21<sup>st</sup>, 2014.

On the third survey date, March 21<sup>st</sup>, 2014, a greater number of the N-enhanced plots supported the growth of the native flower *Allium serra*, with a  $\chi^2$  p-value of 0.072 where (1,  $N = 20$ ). However, once again, the difference had negligible statistical significance (see Figure 6).

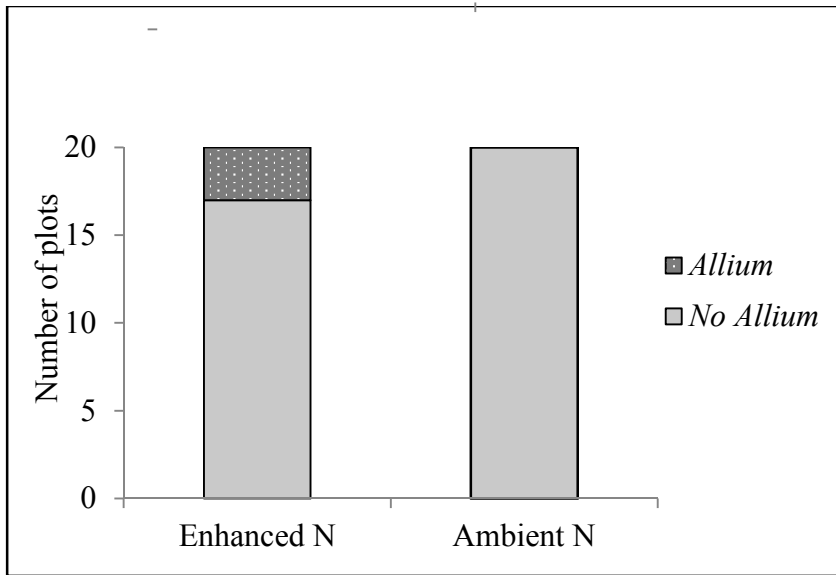


Figure 6. Presence /Absence of Perennial herb *Allium serra* in Enhanced N/Ambient N plots on March 21<sup>st</sup>, 2014.

Q3: How does grazing affect nectar resource presence in the plots?

- H<sub>0</sub>: The proportion of grazed plots that contain native plant species used by the Bay Checkerspot Butterfly as shoulder-season nectar resources will not differ from the proportion of ungrazed plots containing such nectar plant species.

On the second survey date, March 18<sup>th</sup>, a smaller number of the grazed plots supported the growth of the native bulb *Chlorogalum pomeridianum*, with a  $\chi^2$  *p*- value of 0.077 where (1, *N* = 20). Once again, the difference had negligible statistical significance see (see Figure 7).

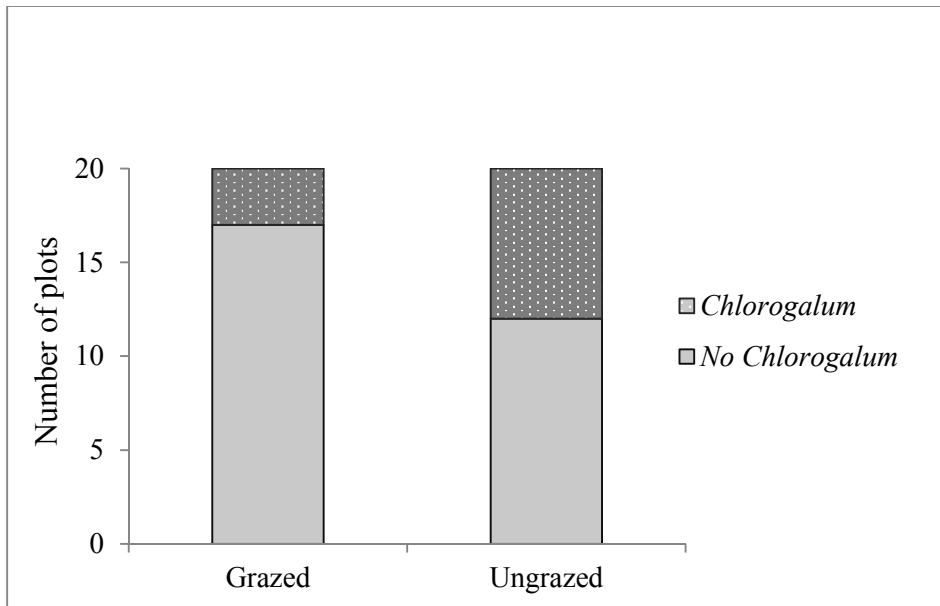


Figure 7. Presence/Absence of Perennial bulb *Chlorogalum pomeridianum* in Grazed/Ungrazed plots on March 18<sup>th</sup>, 2014.

Q4: How does N enhancement and grazing affect abundance of native shoulder-season nectar resources?

- H<sub>0</sub>: Percentage cover of native vegetation in N-enhanced plots will not differ between the ungrazed and the grazed plots.
- H<sub>0</sub>: Percentage cover of shoulder-season **nectar resource** species in N-enhanced plots will not differ between the ungrazed and the grazed plots.

The nitrogen enhancement reduced the abundance of flowering resources in both grazed and ungrazed plots (see Figure 8). The abundance of flowering vegetation on the first sampling date (March 23<sup>rd</sup>, 2014) tended to be higher in the sub-plots that had ambient nitrogen and had not received grazing,  $F(1, 14) = 0.89$ ,  $p = 0.36$  and a marginally

significant interaction,  $F(2, 14) = 3.08, p = 0.096$ . These subtle differences were not detectable on the second and third sampling dates.

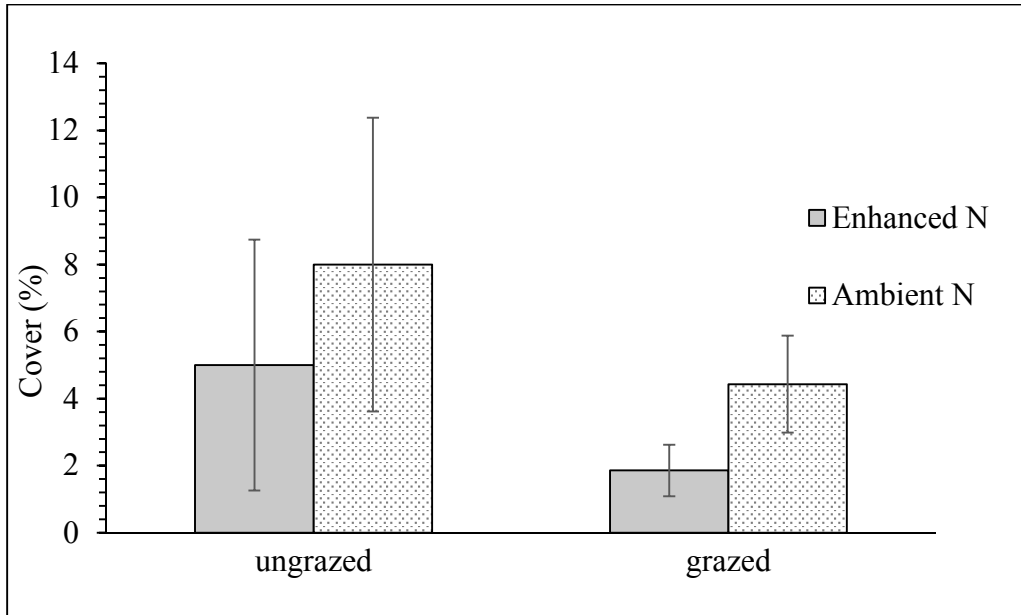


Figure 8. Effects of enhanced N and grazing on flower resource on March 23<sup>rd</sup>, 2014. Error bars represent standard error.

On the second sampling date (March 26<sup>th</sup>, 2014), nitrogen enhancement had reduced native plant cover in the grazed plots, as reflected by a significant interaction effect,  $F(2, 14) = 3.87, p = 0.061$  (see Figure 9). In the ungrazed plots, on the other hand, nitrogen enhancement did not change, or if anything it increased, the overall native plant cover  $F(1, 14) = 0.53, p = 0.48$ .



Figure 9. Effects of enhanced N and grazing on native plant growth on March 26<sup>th</sup>, 2014. Error bars represent standard error.

### Discussion

Because adult butterfly nutrition can be a crucial component of butterfly fecundity (Murphy et al., 1988), even a slight change in adult nutrition could potentially affect fecundity, shifting the reproductive success of the adult butterflies and further threatening the population of the threatened BCB. As in Weiss (1999), the adult BCB was observed feeding from all the available flowering resources upon emergence, suggesting that it is indeed functioning as an opportunistic nectar generalist. Therefore each nectar resource could count toward the BCB's energy resource.

In this study, nitrogen enhancement did appear to reduce overall flower resource availability and native plant cover in grazed plots, consistent with previous research (Huenneke et al. 1990). Since enhanced nitrogen in this study tended to hinder



growth of flowering resources, even though the change was only marginally detectable, the trend could be contributing to the negative effects of nitrogen on the butterfly population.

Although any source of food would be an important energy resource for the adult BCB, shoulder-season nectar resources, in particular, could play an especially key role in the survival of the BCB population. The very first, or the very last BCB could be the individual carrying forward the population in a given year. If nitrogen enhancement is hindering growth of these shoulder-season flower resources, it may prove even more detrimental to BCB's populations than differences in peak season nectar abundances. The effects of nitrogen on flower resources were shown to be complex, however.

*Muilla maritima* was more abundant in ambient nitrogen plots than enhanced nitrogen plots in mid-February, when the very earliest butterflies emerged and nectar resources (flowers in bloom) were still very scarce in the community. It is equally important to note that at least one flower resource, *Allium serra*, was encountered, paradoxically, in a greater number of nitrogen-enhanced plots by mid-March.

According to Weiss (1999), grazing is an effective way to reduce the cover of nitrophilic non-native in the serpentine ecosystem at Coyote Ridge. Grazing as a nitrogen management strategy had complex effects on adult nectar resources, however. One key native plant, *Chlorogalum*, was found to be present in a greater number of ungrazed plots overall in mid-March, an unexpected finding that could be of critical importance to the primary approach currently used to control nitrogen pollution. Furthermore, in ungrazed plots alone, the effects of nitrogen enhancement on flower

resources and native plant cover in general were undetectable, and nitrogen enhancement had a stronger negative effect on flower resources and native plant cover in grazed plots.

There was some interaction between the nitrogen enhancement and the grazing herbivores (mostly cows). Enhancing nitrogen could have increased the grass cover which possibly led to more grazing and eventually consumption of the natives as well. If so, balancing the needs of the adult BCB against the needs of the larvae may require subtle management than has previously been identified. Enclosure experiments are somewhat limited by fenced plot sizes (Hester et al., 2000), given the great variability of plant distributions in the serpentine ecosystem, the fact that there were some differences detected in this study, is alarming. To confirm the validity of these trends, a larger number of plots should be developed, in order to increase the power to detect effects of nitrogen enhancement on nectar resources, especially key resources that support the butterfly at the beginning and end of its season. Furthermore, additional research on shoulder-season nectar resources and their impact on the adult bay checkerspot butterfly population growth is critical.

Finally, and importantly, climate change could further exacerbate the effects of increasing nitrogen in the atmosphere by pushing adult emergence dates earlier, potentially faster than the nectar resources respond to the changing environment. Further studies in this field should thus focus specifically on the interaction of the climate change with the increased nitrogen deposition and different grazing regimes.

## **Conclusion and Management Implications**

Effects of increased anthropogenic nitrogen on flower resources for the adult BCB thus appear to be more complex than effects on the larval host plant. Grazing as a management strategy might not be sufficient to mitigate the adverse nitrogen deposition effects due to current fossil fuel combustion levels on flower species that the Bay Checkerspot Butterfly utilizes as nectar resources. Managing grazing is essential to avoid damage to early and late season floral resources, it is also essential to maintain an appropriate level of grazing to protect the overall flower resource base will require careful monitoring and management. These findings suggest that strict policies for nitrogen emissions reduction are critical to supporting the continuous existence of this biodiversity hotspot; serpentine ecosystem at Coyote Ridge, in addition to other management efforts.

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