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Living on the Edge: Assessing the Effects of Catastrophic Fire on Plants Utilized by Two Endemic Subspecies of Spring Mountains Butterflies

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LIVING ON THE EDGE: ASSESSING THE EFFECTS OF CATASTROPHIC FIRE ON
PLANTS UTILIZED BY TWO ENDEMIC SUBSPECIES OF SPRING MOUNTAINS
BUTTERFLIES

By

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Vassar College
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A thesis submitted in partial fulfillment
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Abstract

In the past few decades there has been an increase in catastrophic, high-intensity, large-scale wildfires globally due to the combination of climate warming with more than a century of fire suppression policy. One region that has been drastically affected is the Western United States, as there has been an increase in ‘mega-fires’ in the past few decades. The 2013 Carpenter 1 Fire in the Spring Mountains, Nevada was the largest fire in recorded history in these mountains, spreading out over 11,137 hectares. Catastrophic fire like the Carpenter 1 Fire can have potentially devastating effects on endemic species inhabiting refugia on ‘sky-islands.’ The understory response to this catastrophic fire was measured using 52-1m² plots in a burn area that supports two endemic butterfly subspecies, the Mount Charleston blue butterfly and Morand’s checkerspot, to test for resistance and resilience of sky-island species to catastrophic fire. Plots were placed in unburned, low severity burn, and high severity burn areas. The species richness of the understory was measured in the varying degrees of burn severity, while the specific nectar and larval host plant abundances of the two butterflies were measured to determine if the fire increased habitat by opening up high pre-fire tree density areas. Three years post-fire I found total species richness of understory vegetation to be greatest in unburned areas, only one species less in low severity burn areas, and significantly less in high severity burn areas. The plant community that existed pre-fire was found to have a legacy effect, as areas of high pre-fire tree density, resulting in high severity burns, were biased towards shade-tolerant plants. In contrast, areas of low pre-fire tree density, resulting in low severity burns, were biased towards plants that occur in more open, sunny conditions. The nectar plants of both butterfly species, *Erigeron clokeyi* and *Hymenoxys lemmonii*, recovered past plant densities capable of supporting the butterflies in the low severity burn. However, only *Hymenoxys lemmonii* has recovered enough to support the butterflies in high severity burn areas. Two of the three larval host plants of the

Mount Charleston blue butterfly, *Astragalus calycosus* and *Oxytropis oreophila* have surpassed unburned densities in the low severity burn. However, only *Astragalus calycosus* has recovered in sufficient plant densities to support the butterfly in the high severity burn. Neither larval host plant for the Morand's checkerspot, *Castilleja martinii* and *Penstemon leiophyllus* have recovered in either burn severity in sufficient plant densities to support the butterfly. The larval host plants of the Morand's checkerspot may be later successional species, as *Castilleja martinii* occurs in old burn areas. Grasses have not surpassed unburned densities, which is important for the butterflies as high densities of grasses can impede flight behavior. Non-native species were absent throughout the study in all burn severities. These results provide insight into the resistance and resiliency of sky-island refugia to catastrophic fire.

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Dedication

I would like to dedicate this to my parents, Charles and Deanna Herrmann, who have always pushed me to do what I love. I would not be who I am today without their support and love.

Table of Contents

ABSTRACT	III
ACKNOWLEDGEMENTS	V
DEDICATION	VI
LIST OF TABLES.....	IX
LIST OF FIGURES.....	X
INTRODUCTION	1
METHODS.....	8
STUDY ORGANISM.....	8
<i>Habitat</i>	8
<i>Larval Host Plants</i>	10
<i>Nectar Plants</i>	11
LOCATION	11
SUB-SITES	12
East Slope	12
Main Slope.....	16
West Ridge	16
Old Burn	16
SAMPLING.....	16
BURN SEVERITY	20
TREE DENSITY	20
STATISTICS	20

Regressions.....	20
Multivariate Analysis of Covariance (MANCOVA).....	20
Analysis of Covariance (ANCOVA).....	21
RESULTS.....	22
TREE DENSITY	22
SPECIES RICHNESS.....	24
LOW SEVERITY BURN.....	30
HIGH SEVERITY BURN	34
NECTAR AND LARVAL HOST PLANT RESPONSES WITHIN BURNED AREAS.....	39
OLD BURN	42
GRASSES.....	42
DISCUSSION.....	44
TREE DENSITY	44
SPECIES RICHNESS.....	46
PATHWAYS OF RECOVERY RELATIVE TO BURN SEVERITY	48
<i>Two Different Trajectories</i>	54
OLD BURN	54
OTHER ABIOTIC INFLUENCES	55
CONSERVATION IMPLICATIONS.....	56
CONCLUSIONS.....	57
BIBLIOGRAPHY.....	60
CURRICULUM VITAE	66

List of Tables

Table 1: Species richness and biodiversity in unburned, low severity burn, and high severity burn plots in 2016.	25
Table 2: Wilks' Lambda test of the effect of slope, northness, eastness, burn severity, year, and the interaction between burn severity and year on the nectar and larval host plant density of the Mount Charleston blue butterfly from 2014 to 2016. Burn severity and year were used as fixed factors, while slope, northness, and eastness were used as covariates. An asterisk indicates significance.....	27
Table 3: MANCOVA results showing the effects of burn severity, slope, northness, and eastness on plant density using year (2014-2016) and burn severity as fixed factors. Burn severity was broken into 3 classes: unburned, low severity burn, and high severity burn. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.....	28
Table 4: MANCOVA results comparing the effects of burn severity, slope, northness, and eastness on plant densities of unburned plots and low severity burn plots. Year (2014-2016) and burn severity were used as fixed factors. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.	31
Table 5: MANCOVA results comparing the effects of burn severity, slope, northness, and eastness on plant densities of unburned plots and high severity burn plots. Year (2014-2016) and burn severity were used as fixed factors. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.	38

List of Figures

- Figure 1: All of the plots measured in this study. Old burn plots were established in 2014 and surveyed in 2014 and 2015. The six clustered, northeastern West Ridge plots and Main Slope plots were established in 2012 and measured from 2014-2016. The southwestern West Ridge plots were established in 2016 and measured in 2016. The East Slope plots were established in 2014 and measured from 2014-2016. 13
- Figure 2: All vegetation plots surveyed relative to soil burn severity resulting from the Carpenter 1 Fire. Soil burn severities of 0 were unburned, severities of 1 or 2 were categorized into a low severity burn, and severities of 3 and 4 were categorized into a high severity burn. All West Ridge and Old Burn plots were outside of the burn perimeter. Main Slope plots were either unburned or had a low severity burn. 20 of the 24 East Slope plots were in the high severity burn, with the other 4 were in the low severity burn. 14
- Figure 3: Morand's Checkerspot and Mount Charleston blue butterfly observations from 2010-2012 at the South Loop Population Area. Most observations were on the West Ridge, with fewer on the Main Slope, and only two observations of Mount Charleston blue butterfly and one of Morand's checkerspot on the East Slope. The Old Burn is not depicted, but has few observations of Mount Charleston blue butterflies. The Morand's checkerspot is abundant in the Old Burn. 15
- Figure 4: All vegetation plots surveyed relative to a Mount Charleston blue butterfly habitat layer created by Sever 2011 prior to the Carpenter 1 Fire. 8 of the 12 plots on the West Ridge were in either good or moderate quality habitat, with the other 4 in non-habitat. All 6 Old Burn plots were within either good or moderate quality habitat. West Ridge and Old Burn plots are not within the fire perimeter, so these plots have the same habitat quality. 11 of the 12 Main Slope plots were within either pre-fire good or moderate quality habitat, with the

last one in pre-fire non-habitat. 12 of the 24 East Slope plots were within pre-fire moderate quality habitat, with the other 12 in pre-fire non-habitat.....19

Figure 5: Each point on the graph represents the total number of understory plants (all species excluding trees) recorded in a 1 m² plot, in 2014 and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Plots at or above the threshold value of 11 trees per plot (155.6 trees per hectare) have little to no plant emergence post-fire. Only burned plots are included, with yellow symbols representing the 13 low severity burn plots and red symbols representing the 20 high severity burn plots.23

Figure 6: The three larval host plants of the Mount Charleston blue butterfly A) *Astragalus calycosus* B) *Oxytropis oreophila* and C) *Astragalus platytropis*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are +/- 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.26

Figure 7: The two larval host plants of the Morand's checkerspot A) *Penstemon leiophyllus* and B) *Castilleja martinii*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are +/- 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.29

Figure 8: The two nectar plants of both the Morand's checkerspot and Mount Charleston blue butterfly A) *Erigeron clokeyi* and B) *Hymenoxys lemmonii*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are +/- 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.32

Figure 9: Percent recovery of low severity burn areas. Percent recovery was calculated by dividing the average plant density in low severity burn plots each year by the average plant density in unburned plots across all three years. Nectar plants have circle icons, larval host plants of the Mount Charleston blue butterfly have triangle icons, and the larval host plants of the Morand's checkerspot have square icons.	33
Figure 10: Percent recovery of high severity burn areas. Percent recovery was calculated by dividing the average plant density in low severity burn plots each year by the average plant density in unburned plots across all three years. Nectar plants have circle icons, larval host plants of the Mount Charleston blue butterfly have triangle icons, and the larval host plants of the Morand's checkerspot have square icons.	36
Figure 11: Picture of <i>Astragalus calycosus</i> individuals in the high severity burn in 2016. Stars label plants. In 2015, this spot had fewer than five individuals.	37
Figure 12: Each point on the graph represents the total number of <i>Astragalus calycosus</i> (blue triangles) or <i>Oxytropis oreophila</i> (green triangles) recorded in a 1 m ² plot in 2016 and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Only unburned and low severity burn plots are included with 15 plots from unburned and 13 plots from low severity burn areas.	40
Figure 13: Each point on the graph represents the total number of <i>Erigeron clokeyi</i> (purple triangles) or <i>Hymenoxys lemmonii</i> (yellow triangles) recorded in a 1 m ² plot in 2016 and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Only unburned and low severity burn plots are included with 15 plots from unburned and 13 plots from low severity burn areas.	41

Figure 14: Average grass density in unburned, low severity burn, and high severity burn areas in
2016. Standard errors of the mean bars are +/- 1 standard error.43

Introduction

In the past few decades there has been an increase in catastrophic, high-intensity, large-scale wildfires globally (Westerling et al. 2006, Adams 2013, Ryan et al. 2013). From 1997 to 2011 wildfires burned over 300 million hectares globally each year, increasing the need for fire research (Giglio et al. 2013). Some of the most drastically affected areas are western forests in the United States, as the combination of climate warming with more than a century of fire suppression policy has resulted in multiple “mega-fires” (Cocke et al. 2005, Miller et al. 2009, Falk et al. 2011, Adams 2013, Ryan et al. 2013). These large, high-intensity fires can have a myriad of effects on forest ecosystems lasting for decades or centuries (Coop et al. 2010, Knox and Clarke 2012, Adams 2013, Abella and Fornwalt 2015). One of those effects is the response and recovery of the understory plant community. Fire has been found to promote germination in many species of understory plants from both chemical and physical cues (Dixon et al. 1995, Van Staden et al. 2000, Flematti et al. 2004, Abella et al. 2007). However, fire in western and southwestern forests has been found to have both a negative effect (Turner et al. 1997, Griffis et al. 2001a, Dodge and Fule 2008) and a positive effect on understory plant species richness (Foxy 1996, Crawford et al. 2001, Keeley et al. 2003, Huisinga et al. 2005). Determining how ecological processes contribute to the magnitude and direction of change in understory communities can be important knowledge for conservationists and land managers in predicting how the plants and associated animals respond to catastrophic fire.

Butterflies are often used as indicator species to determine the health of an ecosystem because their abundance is highly sensitive to changes in nectar and larval host plants (Huntzinger 2003, Hanula et al. 2016). The positive effects of fire on butterfly species richness and abundance are generally thought to be mediated by the effects of decreased tree cover on understory plants and increased heterogeneity in nectar and larval host plants (Kerr et al. 2001,

Fartmann et al. 2013, Hanula et al. 2016). Often warmer temperatures and greater light availability are cited as reasons for observed increases in butterfly species richness because warmer, sunnier conditions help to extend daily flight activity (Douwes 1976, Waltz and Covington 2004, Hanula et al. 2016). However, fire also has been found to have negative effects on butterflies in several studies of rainforest ecosystems (Cleary and Genner 2004, Hirowatari et al. 2007). Fire can have both positive and negative effects on butterfly species richness in grasslands although the restoration of native forbs appears to be an important factor promoting increased butterfly species richness (Swengel 1998, Swengel and Swengel 2007, Vogel et al. 2007, Moranz et al. 2012). Some studies in coniferous forest have found no difference between species richness in burned and unburned areas (Fleishman 2000, Griffis et al. 2001b) while others find significant increases in butterfly species richness in burned areas (Huntzinger 2003, Waltz and Covington 2004). This study will aim to determine the response of two endemic subspecies of butterfly to a catastrophic fire in the Spring Mountains, Nevada.

The biota of the Spring Mountains experienced a significant perturbation, unprecedented in the known history of the region, which has provided an opportunity to study how catastrophic fire impacts understory and alpine plants along with the butterflies they support. During July of 2013, the largest fire in recorded history in the Spring Mountains occurred, designated as the Carpenter 1 Fire. Although originally thought to have started in Carpenter Canyon, it was later determined to have started in Trout Canyon, spreading out over 11,137 hectares. In high altitude coniferous forest, fire can create heterogeneity in the habitat, help to release nutrients into the soil, and open up tree canopies (Romme 1982, Turner et al. 1997, Brown et al. 1999). While many high elevation coniferous forests receive these benefits from fire, bristlecone pine forests have a more complex relationship with fire. Keeley (2012) labeled bristlecone pine trees as “fire-

avoiders,” as they are not particularly adept at resisting fire. However, some studies have found that low severity, surface fires do occur in bristlecone pine forest, while stand-replacing fires occur much less frequently (McCune 1988, Baker 1992, Cocke et al. 2005, Coop and Schoettle 2009). These forests often have discontinuous and lower fuel loads, which explains why there are only rare cases of stand-replacing fires (McCune 1988, Baker 1992, Cocke et al. 2005, Coop and Schoettle 2009). The Carpenter 1 Fire, one of those rare cases, was a large scale, high-intensity fire that consumed all standing bristlecone trees within its perimeter and greatly affected the forest and alpine flora and fauna of the Spring Mountains.

The Spring Mountains are home to a high level of biodiversity, including many endemic plant and animal species and subspecies, due to their isolation from other ranges beginning approximately 10,000 years ago with the loss of conifer woodland connections across intervening valleys (Spaulding 1985, Van Devender 1990, Grayson 2011). As sky islands, the mountain top communities of the desert southwest, isolated and small in area, are particularly vulnerable to catastrophic fires (Ganey et al. 1996, Koprowski et al. 2006). With increases in high-intensity, large-scale fires, sky islands are increasingly threatened as many provide refuge to endemic and rare species, like the Spring Mountains (Westerling et al. 2006, Sakulich and Taylor 2007, Adams 2013, Ryan et al. 2013). Given the large numbers of threatened or endangered species that occur in sky island conifer and alpine communities, it is critical to understand post-fire ecological patterns and processes to facilitate management of endangered species and biodiversity (Ganey et al. 1996, Koprowski et al. 2005, Koprowski et al. 2006). This study of the recovery of butterfly plants following the Carpenter 1 Fire serves as a snapshot of the short-term effects of severe fire on bristlecone pine forest understory plants and provides insight into how catastrophic fires may impact endemic species inhabiting sky islands.

One of these endemic subspecies is the endangered Mount Charleston blue butterfly (*Icaricia shasta charlestonensis*), identified as a new subspecies in 1980 by George Austin (Austin 1980) and listed in 2013 (US Fish and Wildlife Service 2013). The first recorded observations were in the 1920s by Frank Morand (Garth 1928). Throughout the 20th century there were sporadic population monitoring records that showed wide fluctuation in numbers (Austin 1980). From these records it is hard to draw any definitive conclusions about abundance or health of the population. However, multiple studies conducted in the past decade have considerably expanded knowledge of the Mount Charleston blue butterfly (Sever 2011, Thompson 2015). In the Sever (2011) and Thompson et. al. (2014) studies, it was established that a consistently abundant population of the butterfly, varying between 50 and 100 total observations between 2010 and 2012, was found along the South Loop Trail, approximately one mile southeast of Charleston Peak. This population is named the South Loop Population and is an important stronghold for the Mount Charleston blue butterfly. The butterflies also occur in upper Lee Canyon within the Lee Canyon ski area and along Bonanza trail to the north. Prior to 2015 the South Loop Population consistently had the most butterfly observations. However, in 2015 and 2016 there has been a surge in butterfly observations along the Bonanza Trail. This increase in population numbers supports the possibility that this subspecies can diapause for long periods of time, which has been found in *Icaricia shasta* (Emmel and Shields 1978). The area where the butterfly occurs on Bonanza Trail was not affected by fire though, so this study will focus on the South Loop Population.

A second endemic butterfly lives in the South Loop Population area– the Morand’s checkerspot (*Euphydryas anicia morandi*). Some of the first recordings and collection of the butterfly were made by Frank Morand, who the butterfly was named after in the 1920s (Garth

1928). Similar to the Mount Charleston blue, there is little knowledge on the full extent of the Morand's checkerspot distribution throughout the Spring Mountains (Boyd et al. 1999, Boyd and Austin 2000). However, three general localities, with a different phenotype in each, have been distinguished – Lee Canyon at 2,900 meters in elevation, Wallace Canyon at 2,050 meters, and Kyle Canyon ranging from 2,000 meters up to the South Loop Population area (Austin and Murphy 1998). The Lee Canyon phenotype is the darkest, with broad black markings and is bright orange on the dorsal surface (Austin and Murphy 1998). The Wallace Canyon phenotype is the largest in size, with bright orange wing color and less black coloring than the other two phenotypes (Austin and Murphy 1998). The Kyle Canyon phenotype extending up to the South Loop Population area, which is the focus in this study, is a dull brownish-orange color with broad black marks on the wings (Austin and Murphy 1998). Other checkerspot butterflies are known to have metapopulations, which may be the case here as these populations are not far from each other, but have distinct differences between them in terms of color and size (Ehrlich et al. 1975, Williams et al. 1984, Ehrlich and Murphy 1987, Austin and Murphy 1998, Boggs et al. 2006). These phenotypic variations likely resulted from long periods of isolation, which is consistent with other studies that have found infrequent colonizing events of rapid surges in populations, followed by rapid contractions in populations (Ehrlich et al. 1980, Boggs et al. 2006). Similar to the Mount Charleston blue butterfly, *Euphydryas* species have been found to diapause for varying amounts of time (Williams et al. 1984, Ehrlich and Murphy 1987, Boggs et al. 2006).

The Carpenter 1 Fire directly impacted both the Mount Charleston blue butterfly and Morand's checkerspot, burning through nearly half of the known habitat of the South Loop Population area. In areas with high burn severity, the initial mortality of all nectar and larval

host plants has resulted in a catastrophic loss of habitat for endemic butterflies inhabiting sky islands. With 2014 post-fire germination in some areas and subsequent recovery of the plants essential for butterflies, it is possible that the species composition of the understory is not as sensitive to disturbance as might be expected. This study set out to quantify the effects of varying degrees of burn severity, using the butterflies' plants as indicator species, to determine the post-fire health and resiliency of a portion of the Spring Mountains sky island ecosystem.

Disturbance can have varying effects on communities and ecosystems depending on the severity of perturbation (Johnson and Miyanishi 2010, Walker 2012). A study done by Camac et al. (2013) proposed three general models to predict the response of plant communities to varying degrees of fire: a linear model, the intermediate disturbance hypothesis, and a null model. The linear model proposed that species richness either increases or decreases with respect to burn severity. The intermediate disturbance hypothesis, based on Huston (1979), postulates that species richness will be greatest at intermediate levels of burn severity. For the null model the prediction is no relationship between burn severity and resulting species richness. Although these models are simplistic and non-mechanistic (Camac et al. 2013), I will determine if any fit the results of the Carpenter 1 Fire.

In a study of understory responses to mega-fire, Abella and Fornwalt (2015) proposed several expectations and potential patterns for resistance and resilience in cover and species richness of short-lived annual and biennial plants and long-lived perennial plants across several levels of burn severity. Ecological resistance of a community is proportional to the similarity of the immediate post-fire community and the pre-fire community and resilience is the magnitude of change through time post-fire in the recovery of similarity to pre-fire species composition. As in Abella and Fornwalt (2015), the following expectations were examined: with increases in fire

severity, understory plant community resistance and resilience and native plant richness were expected to decline while the proportion of exotic or early succession species would increase in the short-term. Legacy species, those present pre-fire, would increase over time and the rate of increase, or resiliency, would be inversely related to fire severity.

Along with these general expectations of responses to disturbance, there are several pathways of plant recovery that inform the ecological hypotheses I investigate. Initial plant resistance to disturbance and recovery depends upon germination from the surviving seed bank, regrowth from surviving roots of plants, or seed dispersal from unburned areas. In addition, species composition and abundance of post-fire plants could result from species-specific burn responses and/or from the influence of pre-fire environments on regrowth, seed banks, and seed sources (legacy effects). Pre-fire environments with low tree density were expected to have soils with low burn severity, greater survival of the seed bank post-fire and more re-sprouting roots or below ground plant parts. The species composition of seeds and re-sprouts in low tree density areas was expected to be biased towards plants that occur in sunny, open canopy conditions. In contrast, pre-fire environments with high tree density were expected to have soils with high burn severity, low survival of the seed bank post-fire and reduced incidence of re-sprouting roots. The species composition of seeds and re-sprouts in high tree density areas were expected to be biased towards shade tolerant plants that occur in forested areas.

I hypothesized that areas with a low severity burn would have a portion of the seed bank and/or plants remaining from pre-burn conditions, therefore there would be relatively high resistance to fire and a fast initial recovery of all plants, proportional to the surviving species in the seed bank. Local dispersal would also play an important role in the continued recovery of all plants. In areas with a high severity burn I hypothesized that there would be little to no seed bank

or plants remaining from pre-burn conditions, therefore resistance would be low and initial recovery would rely on areas of lower tree densities imbedded within these burned areas. Dispersal from areas of low tree density within the high severity burn would likely play an important role in continued recovery, with the species method of dispersal affecting the magnitude of recovery. Butterfly nectar plants in the Asteraceae family were expected to have the highest dispersal rates post-fire. I also hypothesized that grasses and/or exotic species would invade fire-affected areas because the nutrient release, soil disturbance, and increased light availability caused by the fire would be favorable to colonization or invasion. Finally, it was expected that the rate of plant recovery for all species would be affected by increased soil erosion, a high input of nutrients, and a change in soil texture.

Methods

Study Organism

Habitat

Mount Charleston blue butterflies have four main requirements for good quality habitat – the presence of their larval host and nectar plants, open areas with little tree canopy cover, and low grass cover (Thompson 2015). *Astragalus calycosus* var. *calycosus* (Torrey’s milkvetch), *Oxytropis oreophila* (mountain oxytrope), and *Astragalus platytropis* (broadkeel milkvetch) are the three known larval host plants of the butterfly (Austin and Leary 2008, Thompson 2015). *Erigeron clokeyi* (Clokey’s fleabane) and *Hymenoxys lemmonii* (Lemmon’s rubberweed) are the two primary nectar plants visited by the Mount Charleston blue butterfly at higher elevations, however the butterflies have been observed to nectar on their larval host plants and other plants at lower elevations (Weiss et al. 1997, Thompson 2015). Habitat sufficient to sustain butterflies must have at least one of the larval host plants at densities above two plants per m² (Thompson and Abella 2016). Nectar plants must exist near the larval host plants in densities of at least two

plants per m² for small nectar plants like *Erigeron clokeyi* and at least 0.1 plants per m² for larger plants like *Hymenoxys lemmonii* (Thompson and Abella 2016). While it is necessary to have these plants present, the habitat also must have an open tree canopy with plenty of sun (Austin and Austin 1980, Weiss et al. 2002, Boyd and Murphy 2008, Thompson and Abella 2016). Low canopy cover from trees or shrubs is vital, as butterflies need sun to warm themselves to remain active during the day, especially in high elevation environments (Douwes 1976, Boggs and Murphy 1997). It is also important for there to be little grass cover because the Mount Charleston blue butterfly is a small butterfly, with a wingspan of about 2-2.5 centimeters (Austin and Austin 1980, Weiss et al. 2002, Boyd and Murphy 2008, Thompson and Abella 2016). They are low fliers so grasses can impede flight. It is very rare to find any Mount Charleston blue butterfly in areas of high grass cover (Sever 2011, Thompson 2015).

The Morand's checkerspot has similar habitat requirements to the Mount Charleston blue butterfly – both the larval host and nectar plants must be present along with open tree canopy and low grass cover (Weiss et al. 1997, Austin and Murphy 1998, Thompson et. al. 2014). The Morand's checkerspot have been observed to use five larval host plant species, only two of which occur at the high elevations found at the South Loop Population area – *Castilleja martinii* var. *clokeyi* (Clokey paintbrush) and *Penstemon leiophyllus* var. *keckii* (Charleston beardtongue) (Weiss et al. 1997, Austin and Murphy 1998, Thompson et. al. 2014). Habitat sufficient to sustain butterflies must have *Penstemon leiophyllus* in densities above four plants per m², while interspersed with *Castilleja martinii* above densities of 0.1 plants per m² (Thompson et. al. 2014). *Penstemon leiophyllus* is viewed as the butterfly's primary larval host plant, but it has been observed ovipositing on *Castilleja martinii* (Weiss et al. 1997, Austin and Murphy 1998, Thompson et. al. 2014). At high elevations, the Morand's checkerspot has been observed to

nectar on five plants – *Hymenoxys lemmonii*, *Erigeron clokeyi*, *Astragalus calycosus*, *Potentilla concinna* (elegant cinquefoil), and *Lesquerella hitchcocki* (Hitchcock’s bladderpod) (Thompson et. al. 2014). However, *Hymenoxys lemmonii* and *Erigeron clokeyi* have been identified as the primary nectar plants for the butterfly. Being a smaller nectar plant, *Erigeron clokeyi* must occur in densities above two plants per m², whereas *Hymenoxys lemmonii* must occur at densities above 0.1 plants per m² (Thompson et. al. 2014). Similar to the Mount Charleston blue butterfly, open tree canopy is vital because the butterflies need sun to warm themselves and increase their time of daily flight activity (Douwes 1976, Weiss et al. 1997). The Morand’s checkerspot also is found in areas with low grass cover, perhaps due to their use of rock and soil surface sites for basking (Thompson et. al. 2014).

Larval Host Plants

All three larval host plants of the Mount Charleston blue are part of the family Fabaceae, commonly known as legumes. *Astragalus calycosus* and *Astragalus platytropis* are within the *Astragalus* genus, while *Oxytropis oreophila* is within the *Oxytropis* genus, the primary difference between the two genera is the keel of the flower (Barneby 1952). *Oxytropis* has a narrow pointed keel that looks like a beak, whereas an *Astragalus* keel is much less pointed (Barneby 1952). Besides the difference in flower keel, these three plants are similar in many ways. They all are low-growing perennials, only growing a few centimeters tall (Andrew et al. 2013). Each species uses a seedpod as its dispersal method (Andrew et al. 2013). *Astragalus calycosus* has a flat long pod, *Oxytropis oreophila* has a beaked, teardrop shaped pod with no obvious markings, and *Astragalus platytropis* has a much larger inflated, balloon-like seed pod with red-brown speckles (Andrew et al. 2013). What further sets them apart, however, is where they occur (Thompson and Abella 2016). *Astragalus calycosus* is a generalist; it has been

observed to occur in both shady and open areas at both low and high elevations. *Oxytropis oreophila* is more specialized in that it has been observed to occur mainly in areas of open tree canopies at high elevations. *Astragalus platytropis* is the most specialized, as it occurs on steep, rocky, sunny slopes at high elevations.

The primary larval host plant of the Morand's checkerspot is *Penstemon leiophyllus*, which is part of the Scrophulariaceae family. It is a low-growing perennial with a basal rosette of leaves and a relatively short flowering stalk. *Castilleja martinii* is also in the Scrophulariaceae family. It is a tall, skinny perennial, reaching 20 centimeters or more in height. The entire *Castilleja* genus is hemiparasitic on roots of other forbs and grasses (Heckard 1962). *Castilleja martinii* also does well in older burn areas (Weiss et al. 1997). Both plants are not wind-dispersed and have larger seeds than the nectar and larval host plants of the Mount Charleston blue butterfly.

Nectar Plants

The two primary nectar plants of the Mount Charleston blue butterfly and Morand's checkerspot are *Erigeron clokeyi* and *Hymenoxys lemmonii*. Both are part of the Asteraceae family. *Erigeron clokeyi* is a low growing perennial, similar to the larval host plants, with flowers that grow to about 2-5 centimeters in height. *Hymenoxys lemmonii* is a taller perennial, with flower stalks on a mature plant that can reach 15-20 centimeters in height. Both plants have wind-dispersed seeds.

Location

The South Loop Population is located in the Spring Mountains of Southern Nevada along the South Loop Trail, about a mile southeast of Charleston Peak. The area is part of the Humboldt-Toiyabe National Forest managed by the US Forest Service, in a designated wilderness area. The site is located approximately 30 miles northwest of Las Vegas. The study was conducted during

the summer months of 2014, 2015, and 2016. The South Loop Population area was divided into four distinct “sub-sites” – the East Slope, Main Slope, West Ridge, and Old Burn area, ordered roughly east to west (Figure 1).

Sub-Sites

East Slope

This site has an elevation ranging from 3,265 – 3,350 meters. The northern extent of the slope was one of the most heavily affected areas, while the southern end was affected slightly less along the top of the ridge because of lower tree density. Of the four sub-sites, the East Slope had the highest density of trees, resulting in highest soil burn severity throughout. Twenty-four vegetation plots were located on the East Slope, designed to quantify the post-fire succession in heavily burned areas (Figure 1; Figure 2). The East Slope had the lowest density of butterflies prior to the fire (Figure 3).

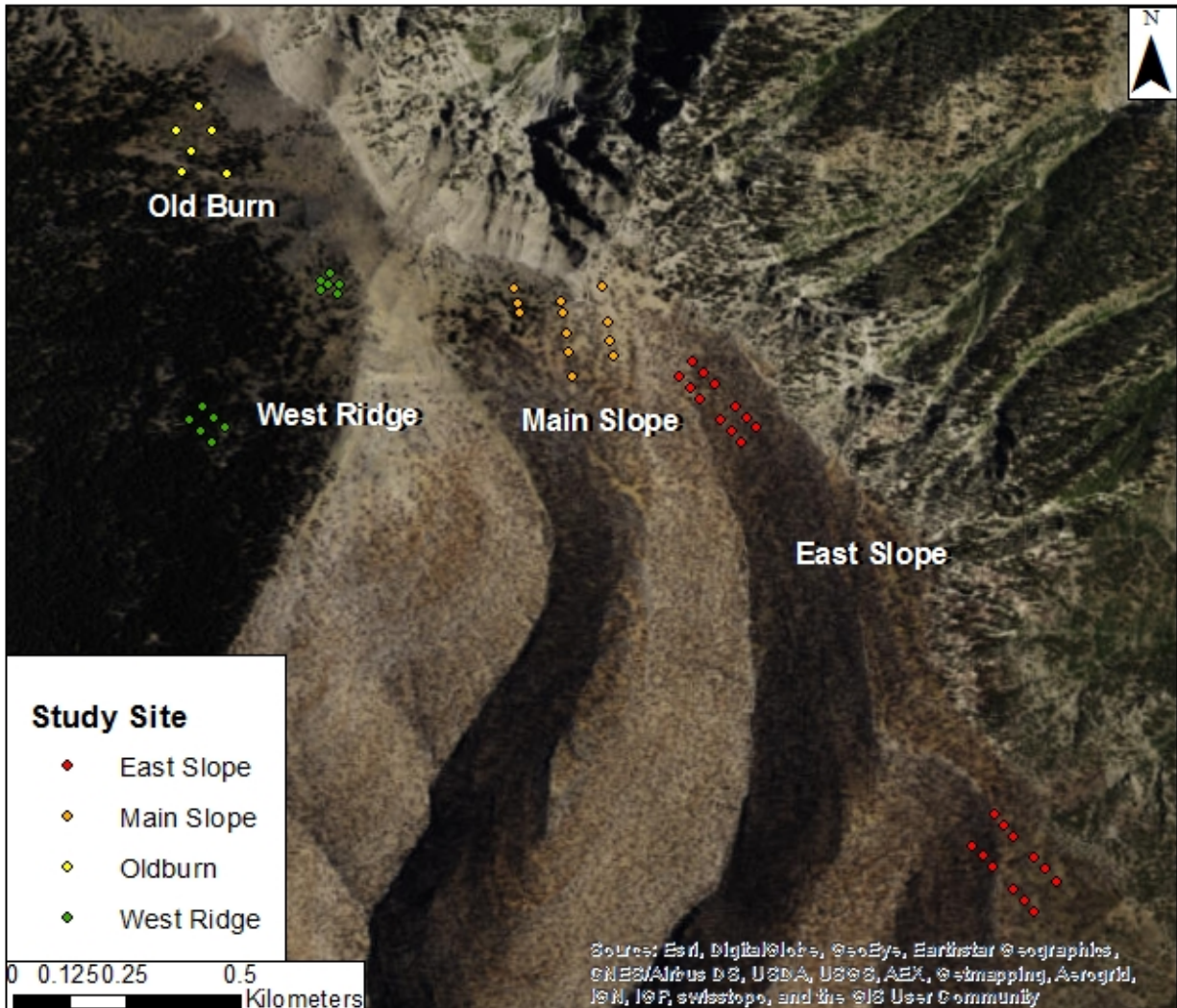


Figure 1: All of the plots measured in this study. Old burn plots were established in 2014 and surveyed in 2014 and 2015. The six clustered, northeastern West Ridge plots and Main Slope plots were established in 2012 and measured from 2014-2016. The southwestern West Ridge plots were established in 2016 and measured in 2016. The East Slope plots were established in 2014 and measured from 2014-2016.

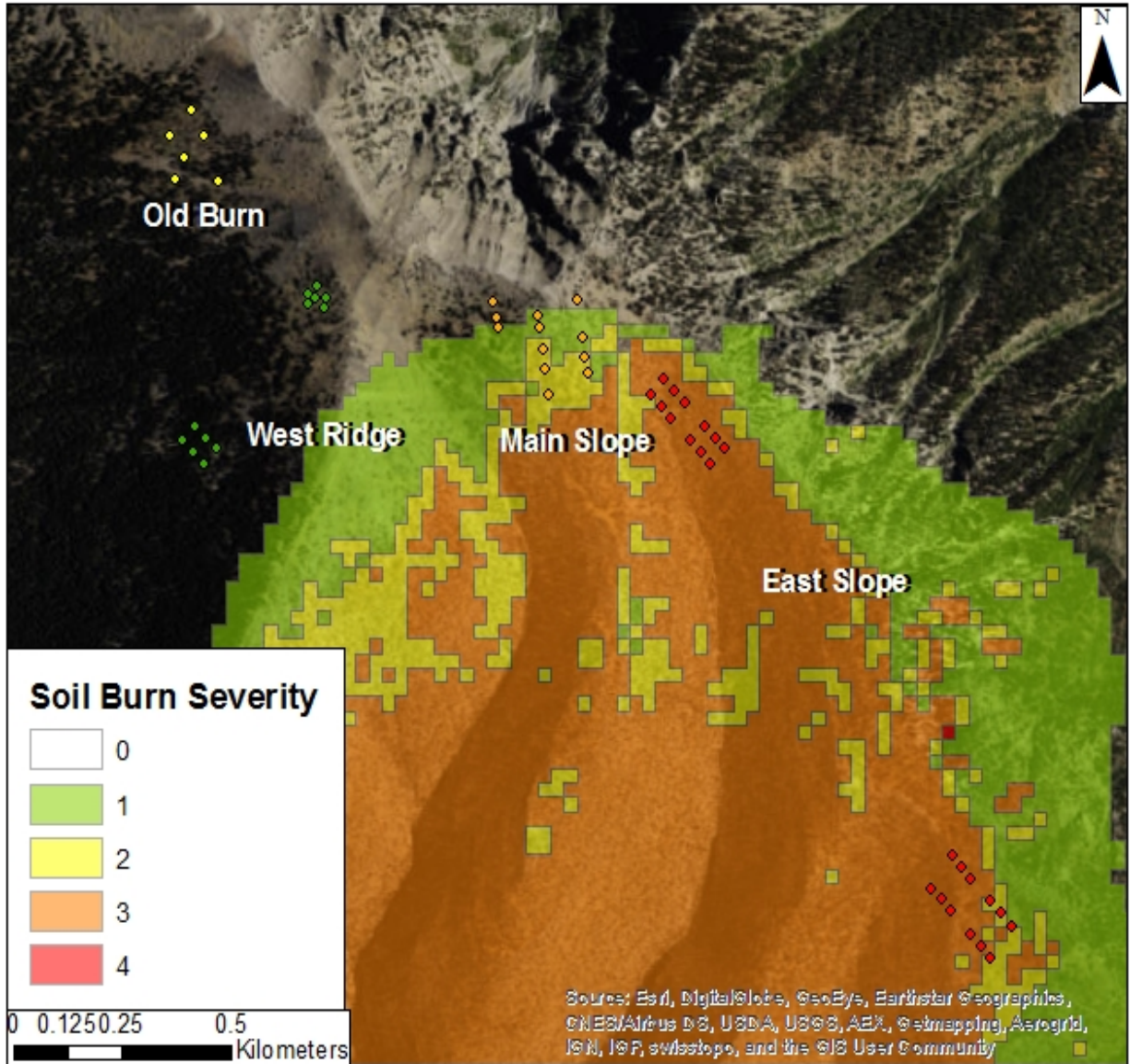


Figure 2: All vegetation plots surveyed relative to soil burn severity resulting from the Carpenter 1 Fire. Soil burn severities of 0 were unburned, severities of 1 or 2 were categorized into a low severity burn, and severities of 3 and 4 were categorized into a high severity burn. All West Ridge and Old Burn plots were outside of the burn perimeter. Main Slope plots were either unburned or had a low severity burn. 20 of the 24 East Slope plots were in the high severity burn, with the other 4 were in the low severity burn.

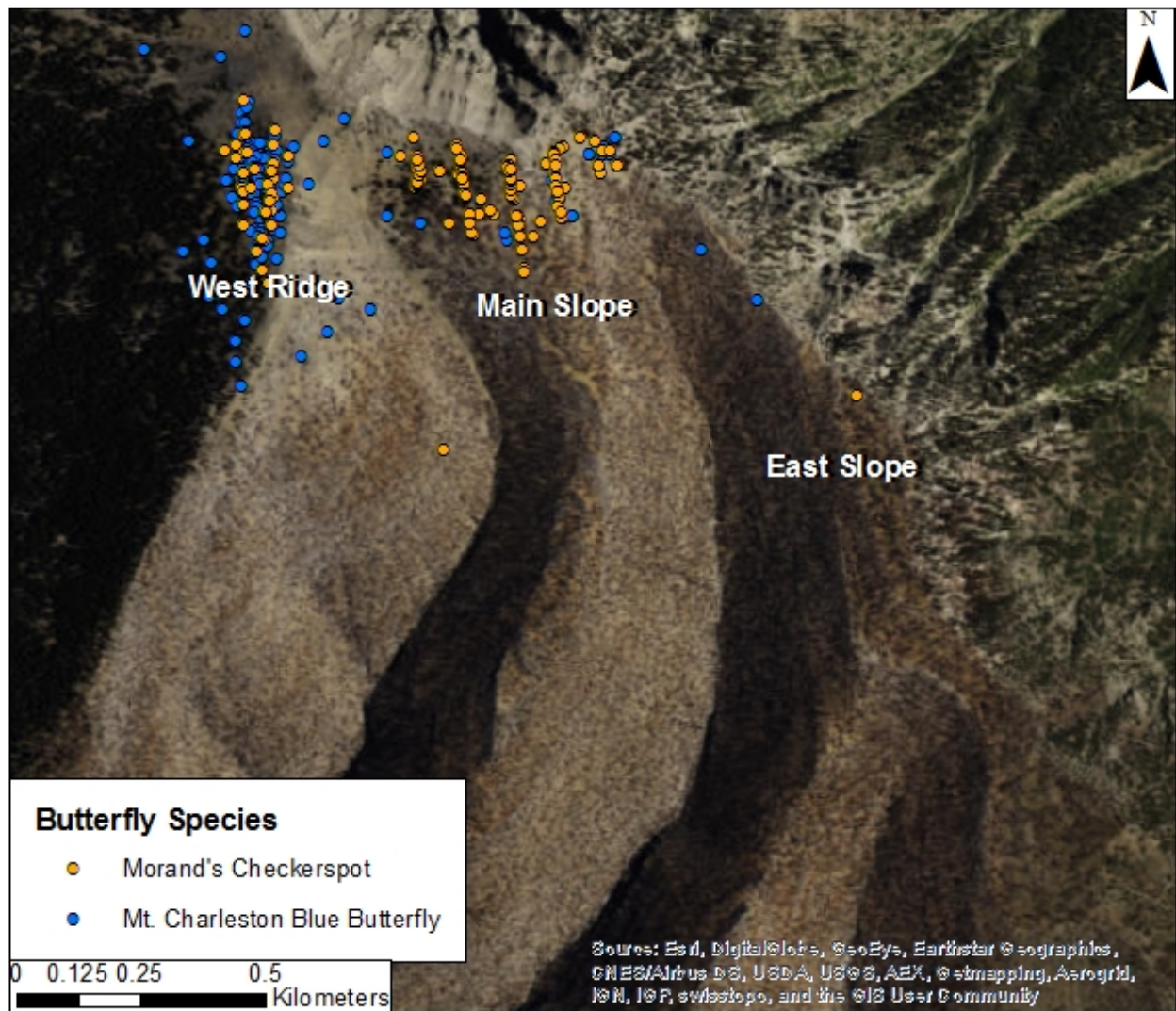


Figure 3: Morand's Checkerspot and Mount Charleston blue butterfly observations from 2010-2012 at the South Loop Population Area. Most observations were on the West Ridge, with fewer on the Main Slope, and only two observations of Mount Charleston blue butterfly and one of Morand's checkerspot on the East Slope. The Old Burn is not depicted, but has few observations of Morand's checkerspot. The Morand's checkerspot is abundant in the Old Burn.

Main Slope

This site has an elevation ranging from 3,347 – 3,381 meters. The Main Slope has a gradient of burn severity; the north end has a low degree of burn severity because of a low tree density, while the southern end has a higher degree of burn severity because of high tree density. Twelve vegetation plots are located on the Main Slope that were set up in a study done by Thompson (2015) and measured in 2013 before the fire (Figure 1; Figure 2). The Main Slope had a moderate number of butterfly observations from 2010-2012 (Figure 3).

West Ridge

This site has an elevation ranging from 3,445 – 3,476 meters. Very little of this habitat had any first order fire effects, with only a small portion of the ridge having low soil burn severity. The West Ridge has some of the most open habitat for the butterfly and is where a large majority of them tend to occur (Figure 3). Four vegetation plots are located on the West Ridge that were also set up in a study done by Thompson (2015) and measured in 2013 before the fire (Figure 1; Figure 2). In addition to these four plots, eight more plots were established in 2016 to increase sample size; two were previously set up by Thompson (2015), while I set up the other six.

Old Burn

This site has an elevation ranging from 3,319 – 3,474 meters. It was not affected by the Carpenter 1 Fire, but was affected by a fire that burned an unknown number of years ago. Six vegetation plots are located on this sub-site, with the hope that they could serve as a glimpse into what burned areas may look like in the future (Figure 1).

Sampling

Sampling design was largely drawn from a study done by Thompson (2015), which was done prior to the fire, with a focus on Mount Charleston blue butterfly habitat. I resurveyed sixteen of

the vegetation plots from the Thompson (2015) study—twelve on the Main Slope and four on the West Ridge. Nine of the twelve surveyed on the Main Slope were within the burn perimeter (Figure 1). I found all of the vegetation plots using coordinates on a Trimble handheld GPS device. Plots were spaced at regular intervals along transects going through habitat in the Thompson (2015) study. The transects were similarly spaced at regular intervals. This method was chosen to ensure that vegetation plots are located in host plant patches, as systematic sampling can be most accurate and robust (Hirzel and Guisan 2002).

I added four 200 m transects with six plots along each on the East Slope to determine the succession of vegetation in burned areas (Figure 1). They were placed using Mount Charleston blue butterfly habitat boundaries from Sever (2011) (Figure 4). The starting point for each transect was determined by creating a random point along the habitat boundary, the transect run perpendicular to the boundary line between habitat and non-habitat. For each transect, three plots were within previous suitable habitat and three plots were outside what was considered suitable habitat, prior to the fire. Plots were spaced 33 m away from the boundary to ensure they were definitively either within previous suitable habitat or outside previous suitable habitat. These plots were intended to determine whether non-habitat or poor quality habitat would become habitat, or higher quality habitat, post-fire, and also compare the succession process between previous good habitat and previous non-habitat. Results have shown that it is likely too early in the recovery process to determine whether previous non-habitat will turn into good quality habitat. Six vegetation plots were added in 2016 on the West Ridge similar to how the East Slope plots were established (Figure 1; Figure 4). The starting point for each transect was determined by creating a random point along the habitat boundary, the transect runs perpendicular to the boundary line between habitat and non-habitat. Two of the plots are in moderate quality habitat

and four are in non-habitat. I added these plots to get a more accurate representation of the West Ridge habitat, as my data was notably skewed because the original West Ridge plots were in open, good quality habitat. These plots were also set up to mimic pre-fire conditions on the Main Slope and East Slope. Two other plots were measured in 2016 that were set up by Thompson (2015) in the same area as the original four plots that were re-measured from the same study.

Each vegetation plot was 1 m², which is further split into four quadrants (25 cm²). All individuals of each species of plant found within the plot were counted. If canopies or basal rosettes overlapped, they were counted as separate canopies if less than 20 percent of the canopies overlap with each other (Thompson 2015). The Mount Charleston blue butterfly nectar plants *Hymenoxys lemmonii* and *Erigeron clokeyi*, and the Mount Charleston blue butterfly larval host plants *Astragalus calycosus*, *Oxytropis oreophila*, and *Astragalus platytropis* were counted in each quadrant. For each of those plant species, five were chosen systematically to have their height, length, and width measured. The closest plant to the middle of each quadrant was measured, along with the plant closest to the middle of the entire plot. The Morand's checkerspot larval host plants *Penstemon leiophyllus* and *Castilleja martinii* were not measured, only counted, because the original design of this study was focused on the Mount Charleston blue butterfly.

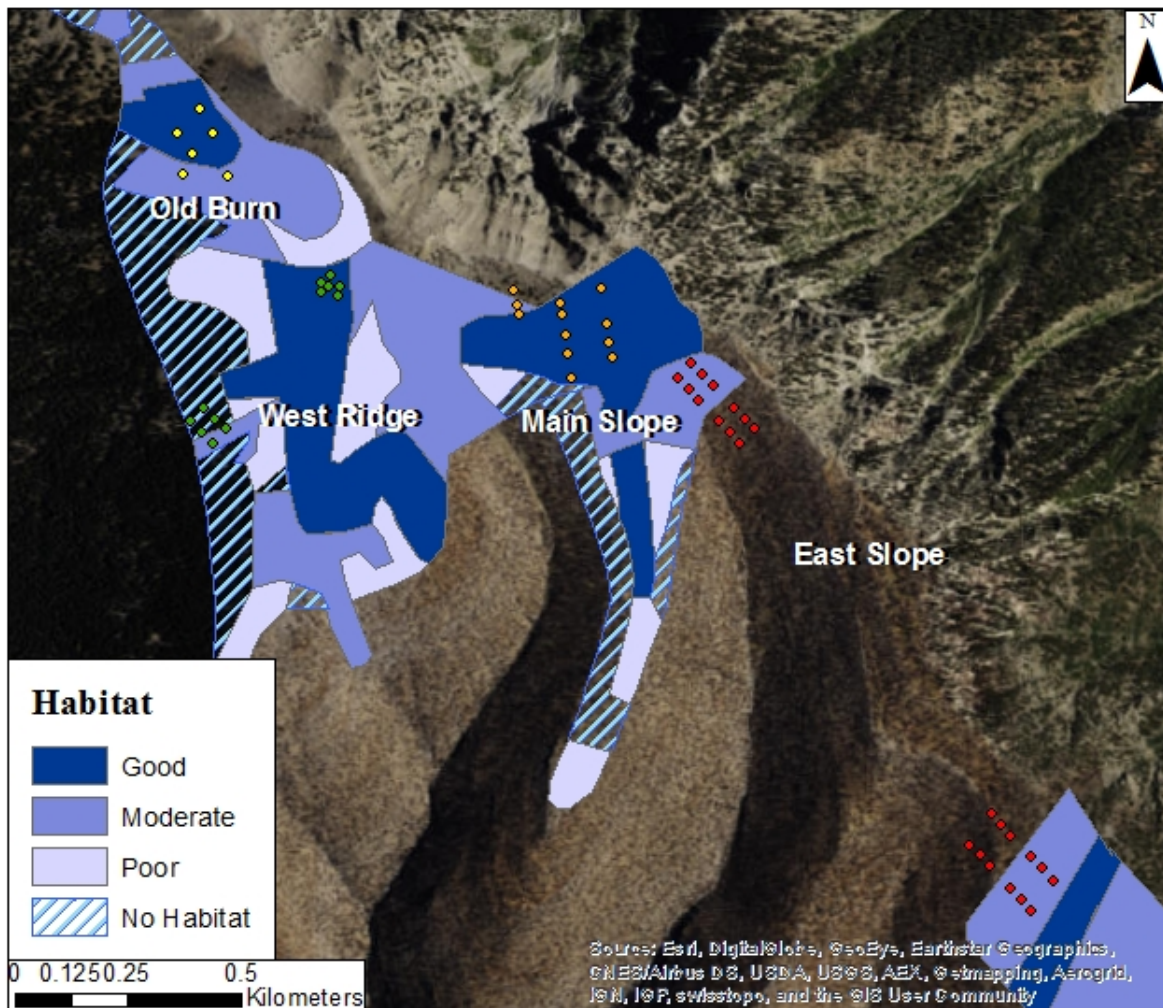


Figure 4: All vegetation plots surveyed relative to a Mount Charleston blue butterfly habitat layer created by Sever 2011 prior to the Carpenter 1 Fire. 8 of the 12 plots on the West Ridge were in either good or moderate quality habitat, with the other 4 in non-habitat. All 6 Old Burn plots were within either good or moderate quality habitat. West Ridge and Old Burn plots are not within the fire perimeter, so these plots have the same habitat quality. 11 of the 12 Main Slope plots were within either pre-fire good or moderate quality habitat, with the last one in pre-fire non-habitat. 12 of the 24 East Slope plots were within pre-fire moderate quality habitat, with the other 12 in pre-fire non-habitat.

Burn Severity

Soil burn severity is separated into five categories, ranging from zero to four, with four being the most severe burn. Zero is considered unburned, one is considered very low burn, two is a low burn, three is a moderate burn, and four is a high severity burn (Figure 2) (RSAC 2013). For data analysis, burn severity was categorized into three groups: unburned, low burn severity, and high burn severity. Unburned plots were outside of the fire perimeter, low burn severity plots included plots with a soil burn severity of one or two, and high burn severity plots included plots with a soil burn severity of three or four.

Tree Density

Tree density was calculated by creating a circular buffer on ArcGIS around each plot with a radius of 15 meters, resulting in a total area of 0.0707 hectares. The number of trees within the buffer was then counted on ArcGIS. Tree density for plots within the burn perimeter was calculated using pre-fire layers.

Statistics

Regressions

I used linear regressions to test the relationship between plant densities and surrounding tree density. Only plots from 2016 were used so I could include the eight additional West Ridge plots to mitigate the sampling bias for that sub-site. High severity burn plots were excluded because many of them had no plants or few plants in them due to the fire. Low burn severity plots were included because they had high recovery rates.

Multivariate Analysis of Covariance (MANCOVA)

A MANCOVA of all data was used to determine significant effects of burn severity, year, slope, northness, and eastness while controlling for experiment-wide error. The MANCOVA used all

Main Slope and East Slope plots, but only West Ridge plots set up by Thompson (2015) in 2012 because only in 2016 were the additional six plots on the West Ridge measured. The plots used in the MANCOVA were measured in all three years. Burn severity and year were used as fixed factors, whereas slope, northness, and eastness were used as covariates. The densities of all species of larval host and nectar plants (total of five species) were used as the dependent variables. An alpha p-value of 0.05 was used to determine significance. Following the multivariate analysis approach of (Scheiner and Gurevitch 2001) to control experiment-wide error, the ANCOVAs of each dependent variable are explored to determine the variables that are contributing to significant effects in the overall MANCOVA. Although the data were skewed due to the large numbers of low or zero values, MANCOVA is known to be robust to the violation of the assumption of a normal distribution. In addition, non-parametric Kruskal-Wallis H tests of the same data produced nearly identical results for significance.

Analysis of Covariance (ANCOVA)

ANCOVA was used to determine significant effects of burn severity, slope, northness, and eastness. ANCOVAs done for the years 2014 and 2015 used all Main Slope and East Slope plots, but only West Ridge plots set up by Thompson (2015) in 2012. ANCOVAs done for the year 2016 used those same plots and the additional six plots on the West Ridge added in 2016. Burn severity was used as a fixed factor, whereas slope, northness, and eastness were used as covariates. An alpha p-value of 0.05 was used to determine significance. Although the data were skewed due to the large numbers of low or zero values, one-way ANCOVA is known to be robust to the violation of the assumption of a normal distribution. In addition, non-parametric Mann-Whitney U tests of the same data produced nearly identical results for significance.

Results

Tree Density

The number of plants (all plant species, excluding trees) in burned plots was dependent on tree density prior to the fire, with a very distinct threshold of 155.6 trees per hectare (11 trees per 0.0707 hectare plot; Figure 5). Plots that had a tree density below this threshold did not have any apparent limit on post-fire plant density whereas plots with a tree density above the threshold had few to no plants emerging in 2014 (Figure 5). This finding makes sense because the higher the tree density, the hotter the fire would burn and the deeper the burn would go into the soil. In the first year after the fire, all burned plots with a tree density above 155.6 trees per hectare had a total of only 10 plants (16 plots) and those plots below the threshold had a total of 571 plants (18 plots). Of the 16 burned plots above the threshold, 10 had no plants. It can be concluded that plots with a tree density above the 11 trees per 0.0707 hectares had almost no remaining plants or seed bank post-fire. Further proving this result, all low severity burn plots had tree densities below the threshold (Figure 5). The low severity burn is a direct result of the reduced fuel load at lower tree densities. Burn plots most likely had enough of the seed bank remaining and/or plants that survived the fire to recover at the fast rate observed. Most of the high severity burn plots had tree densities above 11 trees per 0.0707 hectares, subsequently resulting in little to no recovery (Figure 5). However, five high severity burn plots were below the tree density threshold (Figure 5), three of which had comparable numbers of plants to low burn severity plots. Those three plots also had the lowest tree densities of all the severely burned plots and are in what was a more open area imbedded within dense bristlecone forest.

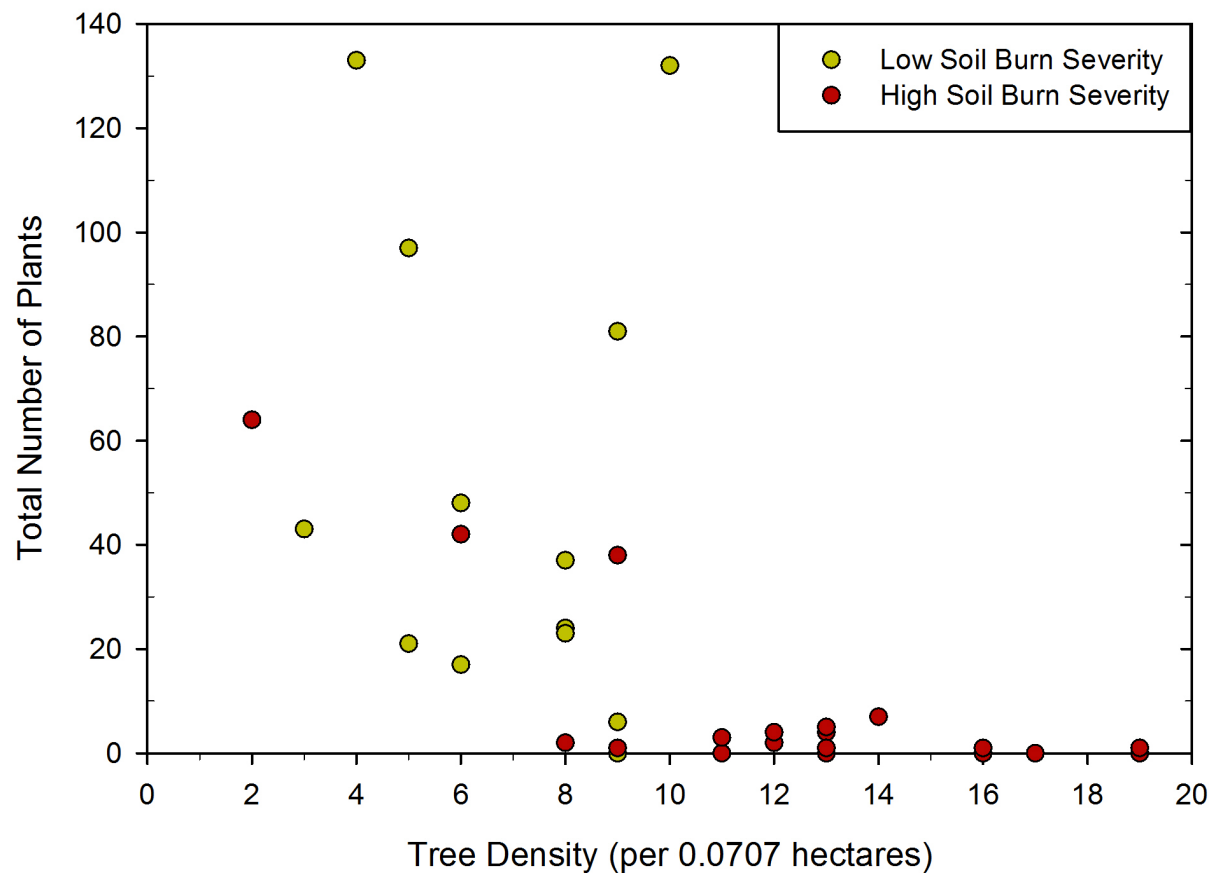


Figure 5: Each point on the graph represents the total number of understory plants (all species excluding trees) recorded in a 1 m² plot, in 2014, and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Plots at or above the threshold value of 11 trees per plot (155.6 trees per hectare) have little to no plant emergence post-fire. Only burned plots are included, with yellow symbols representing the 13 low severity burn plots and red symbols representing the 20 high severity burn plots.

Species Richness

Species richness is lowest in the high severity burn areas, while the low severity burn and unburned areas are almost identical with one less species in the low severity burn than unburned areas (Table 1). The Shannon index reflects these findings of species richness – high severity burn areas are lower than the low severity burn and unburned areas, the latter two having very similar diversity indices (Table 1). The high severity burn areas unsurprisingly had the lowest Shannon index, as many plots had no plants or only a few species in the first year post-fire (Table 1). Species evenness was inversely related to burn intensity (Table 1), with the larval host and nectar plants of the Mount Charleston blue butterfly being disproportionately abundant where the burn intensity was highest. Species richness in low severity burns did not increase above unburned levels, but abundances of *Astragalus calycosus* and *Oxytropis oreophila* increased past unburned levels (Figure 6).

I found a significant effect from the fire on larval host and nectar plant densities of the Mount Charleston blue butterfly across all three years (Table 2; Table 3). A burn effect was expected for all plants, however, *Astragalus calycosus* showed no significant difference between the three burn classes (Table 2; Table 3; Figure 6).

The larval host plants for the Morand's checkerspot are less common species, which was evident in the results (Figure 7). *Castilleja martinii* is almost non-existent in both low severity and high severity burns, with only one plant found in the low severity burn in 2015 (Figure 7). *Penstemon leiophyllus* had a rapid initial recovery in low severity burn areas, but declined sharply after 2014. In the high severity burn there was no recovery until 2016 when six plants were recorded (Figure 7).

Table 1: Species richness and biodiversity in unburned, low severity burn, and high severity burn plots in 2016.

2016			
	Unburned	Low Severity Burn	High Severity Burn
Species Richness	16	15	10
Shannon Index	2.19	2.056	1.715
Equitability Index	0.7898	0.7594	0.7446

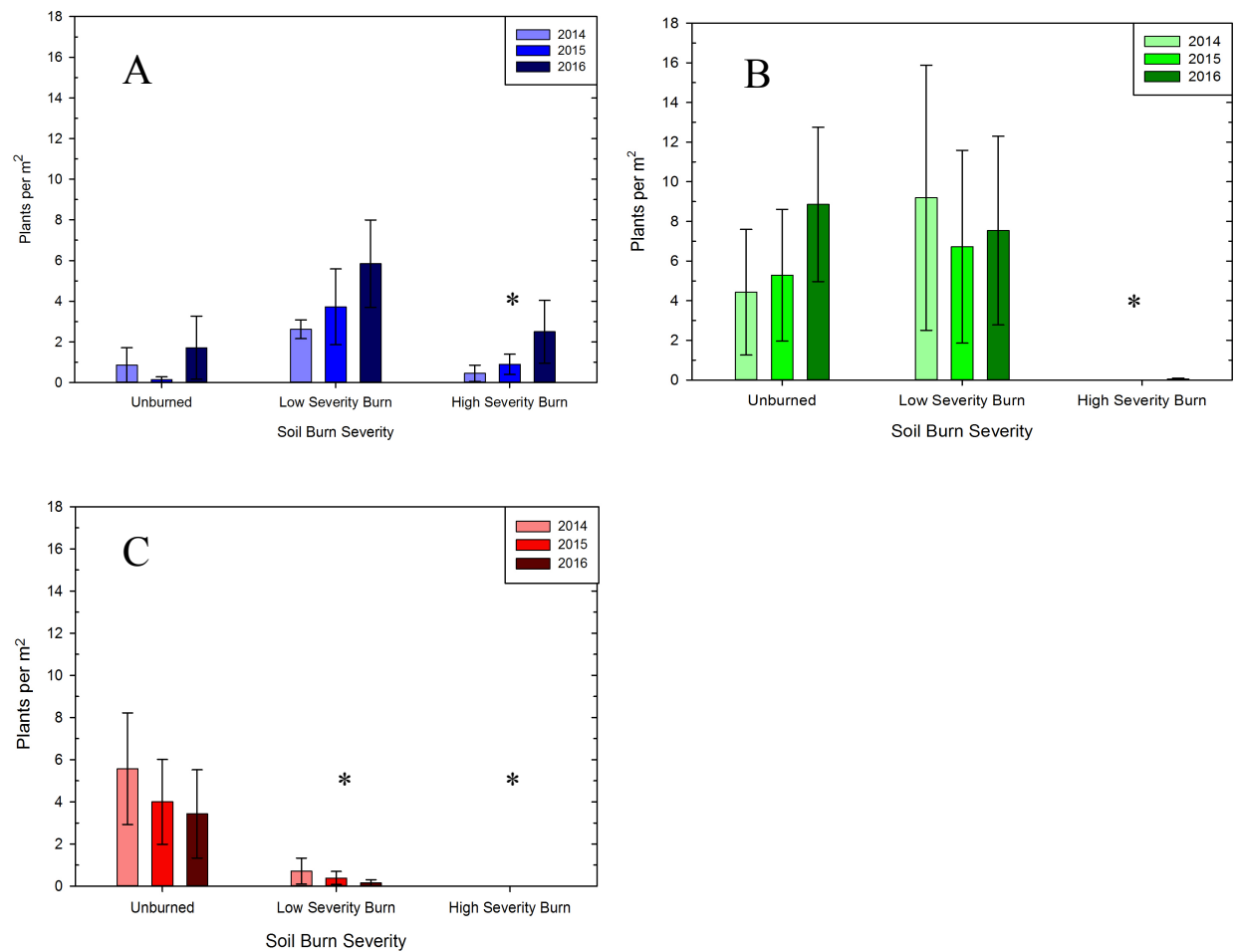


Figure 6: The three larval host plants of the Mount Charleston blue butterfly A) *Astragalus calycosus* B) *Oxytropis oreophila* and C) *Astragalus platytropis*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are ± 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.

Table 2: Wilks' Lambda test of the effect of slope, northness, eastness, burn severity, year, and the interaction between burn severity and year on the nectar and larval host plant density of the Mount Charleston blue butterfly from 2014 to 2016. Burn severity and year were used as fixed factors, while slope, northness, and eastness were used as covariates. An asterisk indicates significance.

	F	Hypothesis df	Error df	p-value
Intercept	5.490	5	103	0.000*
Slope	2.727	5	103	0.024*
Northness	2.223	5	103	0.058
Eastness	6.028	5	103	0.000*
Burn Severity	10.927	10	206	0.000*
Year	1.218	10	206	0.281
Burn Severity * Year	0.799	20	342.562	0.715

Table 3: MANCOVA results showing the effects of burn severity, slope, northness, and eastness on plant density using year (2014-2016) and burn severity as fixed factors. Burn severity was broken into 3 classes: unburned, low severity burn, and high severity burn. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.

	p-value			
	Burn Severity	Slope	Northness	Eastness
<i>E. clokeyi</i>	0.000*	0.077	0.602	0.346
<i>H. lemmonii</i>	0.005*	0.632	0.014*	0.000*
<i>A. calycosus</i>	0.686	0.290	0.113	0.309
<i>O. oreophila</i>	0.018*	0.242	0.756	0.224
<i>A. platytropis</i>	0.000*	0.028*	0.676	0.638

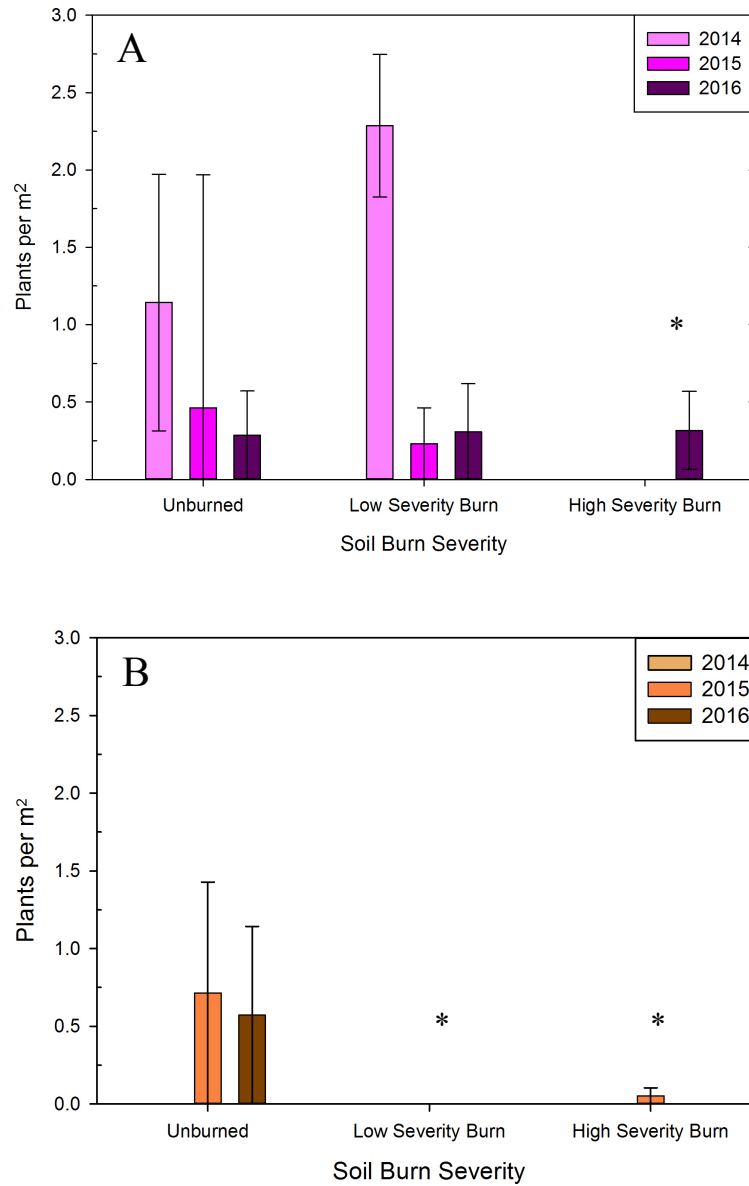


Figure 7: The two larval host plants of the Morand's checkerspot A) *Penstemon leiophyllus* and B) *Castilleja martinii*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are ± 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.

Low Severity Burn

To understand the specific burn effects for each burn class, I used a MANCOVA comparing only the unburned plots and the low severity burn plots for Mount Charleston blue butterfly nectar and larval host plants (Table 4). I found that all the nectar and larval host plants of the Mount Charleston blue butterfly, excluding *Astragalus platytropis*, did not significantly differ in plant density between unburned and low severity burn plots (Table 4; Figure 6; Figure 8). *Astragalus platytropis* may be the exception because it is the most specialized, occupying steep, rocky slopes. I calculated percent recovery by comparing burned plots with unburned plots and found that *Astragalus calycosus* and *Oxytropis oreophila* fully recovered by 2016 (Figure 9). *Erigeron clokeyi* and *Hymenoxys lemmonii* did not recover to 100% (Figure 9), however figure 8 shows they recovered to levels that are considered suitable butterfly habitat (Thompson 2015).

The Morand's checkerspot larval host plants have been slow to recover or have not recovered at all in low severity burn areas (Figure 7). *Castilleja martinii* has not recovered at all in low severity burn areas, potentially showing adverse effects to fire (Figure 7). *Penstemon leiophyllus* had a strong initial recovery in 2014, but declined in the subsequent years (Figure 7).

Table 4: MANCOVA results comparing the effects of burn severity, slope, northness, and eastness on plant densities of unburned plots and low severity burn plots. Year (2014-2016) and burn severity were used as fixed factors. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.

	p-value			
	Burn Severity	Slope	Northness	Eastness
<i>E. clokeyi</i>	0.429	0.027*	0.225	0.658
<i>H. lemmonii</i>	0.410	0.974	0.159	0.035*
<i>A. calycosus</i>	0.731	0.499	0.376	0.851
<i>O. oreophila</i>	0.182	0.085	0.201	0.193
<i>A. platytropis</i>	0.022*	0.105	0.718	0.516

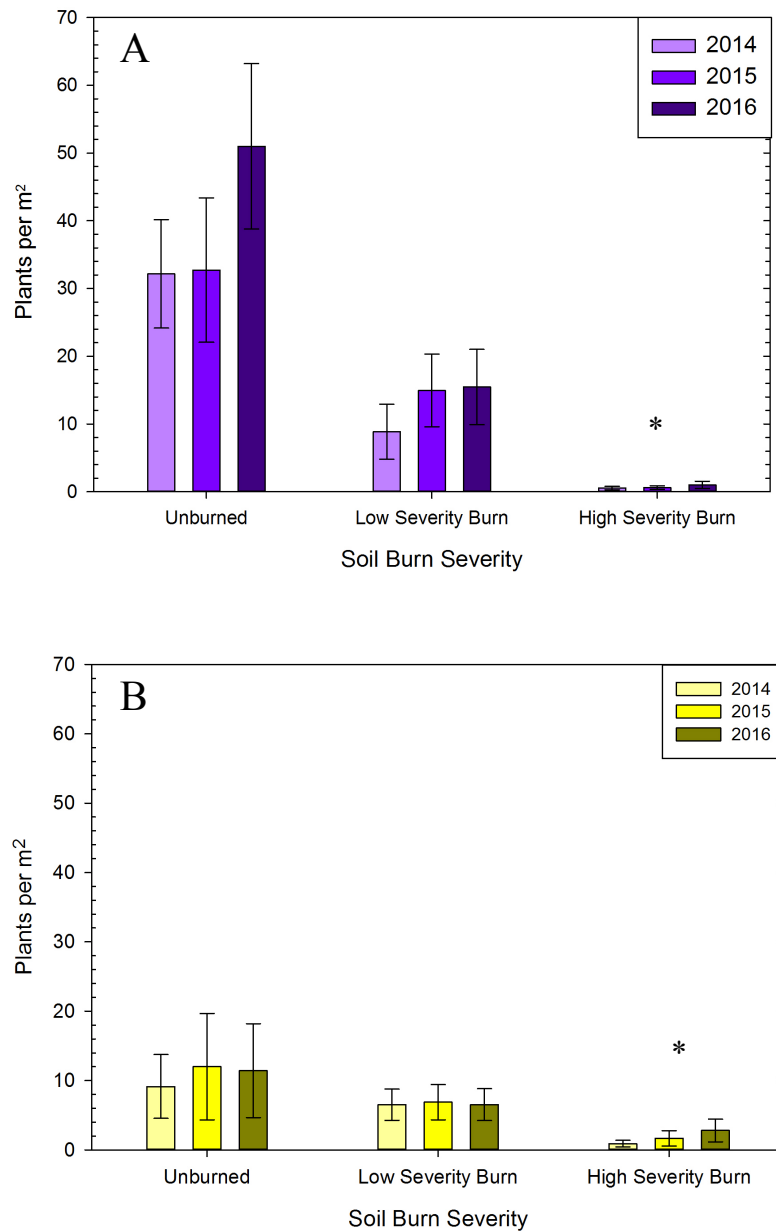


Figure 8: The two nectar plants of both the Morand's checkerspot and Mount Charleston blue butterfly A) *Erigeron clokeyi* and B) *Hymenoxys lemmonii*. Average plant densities from 2014 to 2016 in unburned, low severity burn, and high severity burn areas. Standard errors of the mean bars are ± 1 standard error. An asterisk indicates a significant difference from unburned plots from 2014-2016.

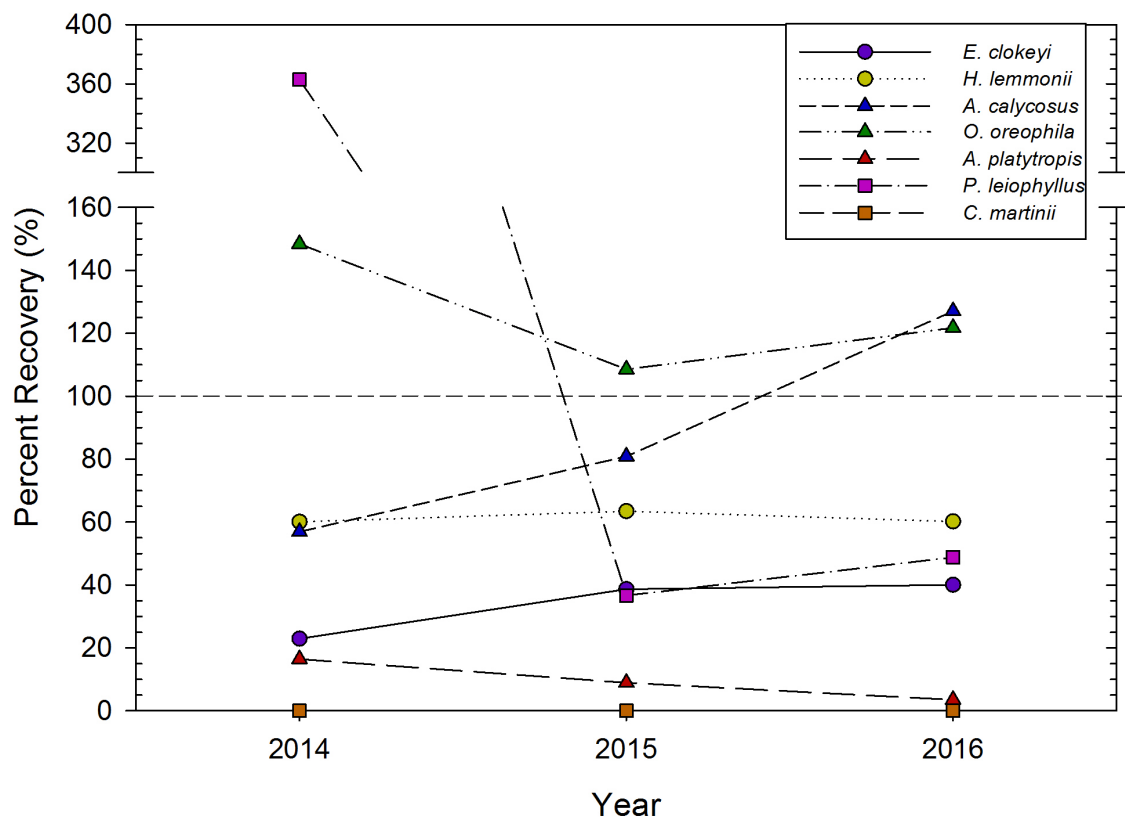


Figure 9: Percent recovery of low severity burn areas. Percent recovery was calculated by dividing the average plant density in low severity burn plots each year by the average plant density in unburned plots across all three years. Nectar plants have circle icons, larval host plants of the Mount Charleston blue butterfly have triangle icons, and the larval host plants of the Morand's checkerspot have square icons.

High Severity Burn

Based on the results from the low severity burn MANCOVA, most of the burn effect found in the MANCOVA comparing all three burn groups across all years (Table 2; Table 3) came from the high severity burn plots. To determine these burn effects I used a MANCOVA comparing unburned and severely burned plots (Table 5). The results showed that all severely burned plot plant densities significantly differed from unburned plots except for *Astragalus calycosus* (Table 5). For the plants that did have significant differences, this result was expected. Most of or the entire soil seed bank was presumably eliminated, along with the plants that had been there prior to the fire. I would expect these severely burned areas to have a longer recovery time than the low burn severity areas, which is supported by long term studies (Keeley et al. 2003, Coop et al. 2010, Shive et al. 2013). However, *Hymenoxys lemmonii* numbers have steadily increased year to year and *Astragalus calycosus* numbers have increased rapidly from year to year. *Astragalus calycosus* started at a recovery percentage of about 10% in 2014 and climbed to over 60% by 2016. *Astragalus calycosus* made a steady recovery between 2014 and 2015 (Figure 6), but recovered rapidly from 2015 to 2016. Figure 11 shows a high severity burn area close to a plot that shows the rapid recruitment by *Astragalus calycosus*; in 2015 there were less than five plants in this spot.

The finding of no significant difference between unburned and severely burned plots for *Astragalus calycosus* across all years was unexpected (Table 5). These results were confirmed by using only the 2016 data, to include the six additional plots on the West Ridge added in 2016, and also by using a nonparametric Kruskal-Wallis H test ($p\text{-value} < 0.05$). This result may be due to the high variability in plots along with the heterogeneity of the landscape. Although it may have a patchy distribution in the high severity burn, it is coming back in high enough numbers to support the butterfly.

The Morand's checkerspot larval host plants showed little to no recovery in high severity burn areas (Figure 7). *Castilleja martinii* was only present in 2015, but otherwise has had no recovery in the high severity burn area (Figure 7). This may be because it is hemiparasitic, relying on other plants to become established before increasing in density (Heckard 1962). *Penstemon leiophyllus* was first recorded in the high severity burn in 2016, but in very low numbers that would not sustain the Morand's checkerspot (Figure 7).

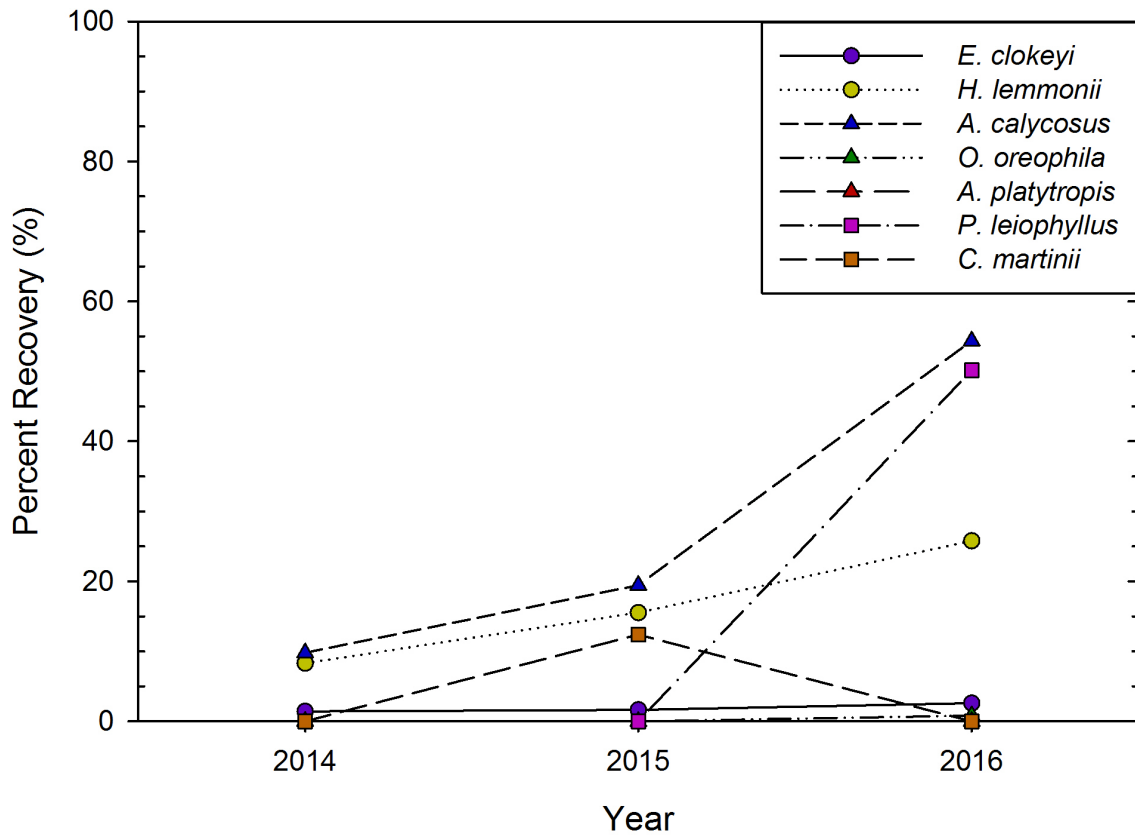


Figure 10: Percent recovery of high severity burn areas. Percent recovery was calculated by dividing the average plant density in low severity burn plots each year by the average plant density in unburned plots across all three years. Nectar plants have circle icons, larval host plants of the Mount Charleston blue butterfly have triangle icons, and the larval host plants of the Morand's checkerspot have square icons.



Figure 11: Picture of *Astragalus calycosus* individuals in the high severity burn in 2016. Stars label plants. In 2015, this spot had fewer than five individuals.

Table 5: MANCOVA results comparing the effects of burn severity, slope, northness, and eastness on plant densities of unburned plots and high severity burn plots. Year (2014-2016) and burn severity were used as fixed factors. Slope, northness, and eastness were used as covariates. An asterisk indicates significance. Year was not found as a significant factor, nor was the interaction between year and burn severity.

	p-value			
	Burn Severity	Slope	Northness	Eastness
<i>E. clokeyi</i>	0.000*	0.672	0.001*	0.000*
<i>H. lemmonii</i>	0.000*	0.103	0.000*	0.000*
<i>A. calycosus</i>	0.973	0.234	0.525	0.132
<i>O. oreophila</i>	0.000*	0.065	0.711	0.092
<i>A. platytropis</i>	0.000*	0.013*	0.964	0.038*

One of the most striking results from my data was that within the high severity burn areas the plants observed almost entirely consisted of *Erigeron clokeyi*, *Hymenoxys lemmonii*, and *Astragalus calycosus*. In fact, 72% of the 175 plants recorded in 2016 high severity burn plots were those three plants, all either a nectar or larval host plant for the Mount Charleston blue butterfly. Alternatively, *Erigeron clokeyi*, *Hymenoxys lemmonii*, and *Astragalus calycosus* constituted 55% of both unburned and low severity burn plots in 2016. It is important to note that the only larval host plant for the Mount Charleston blue butterfly found in high severity burn areas (until 2016 when one *Oxytropis oreophila* was recorded) was *Astragalus calycosus*. Another study had observed *Oxytropis oreophila* dominating sunny, open tree canopy areas, while *Astragalus calycosus* was observed in both sunny open areas and shaded areas with higher tree density (Thompson 2015). I quantified these observations using my own data, running a regression for both *Oxytropis oreophila* and *Astragalus calycosus* against tree density in all of my unburned and low burn severity plots (Figure 12). These results show *Astragalus calycosus* as less sensitive to shade with moderate densities across a range of tree densities (slope = 0.559; p-value > 0.05), while *Oxytropis oreophila* is more restricted, occurring in open areas with low tree density (slope = -1.113; p-value = 0.041; Figure 12). *Astragalus platytropis* had no significant relationship with tree density. Both larval host plants for the Morand's checkerspot also had no significant relationship with tree density.

Erigeron clokeyi has a negative relationship with tree density, similar to *Oxytropis oreophila*, which could explain the slow initial recovery in 2014 (slope = -3.083; p-value = 0.006; Figure 13). *Hymenoxys lemmonii* is similar to *Astragalus calycosus*, it is more of a generalist therefore it is not unexpected to see a steady recovery in the high severity burn areas (slope = -0.585; p-value > 0.05; Figure 13).

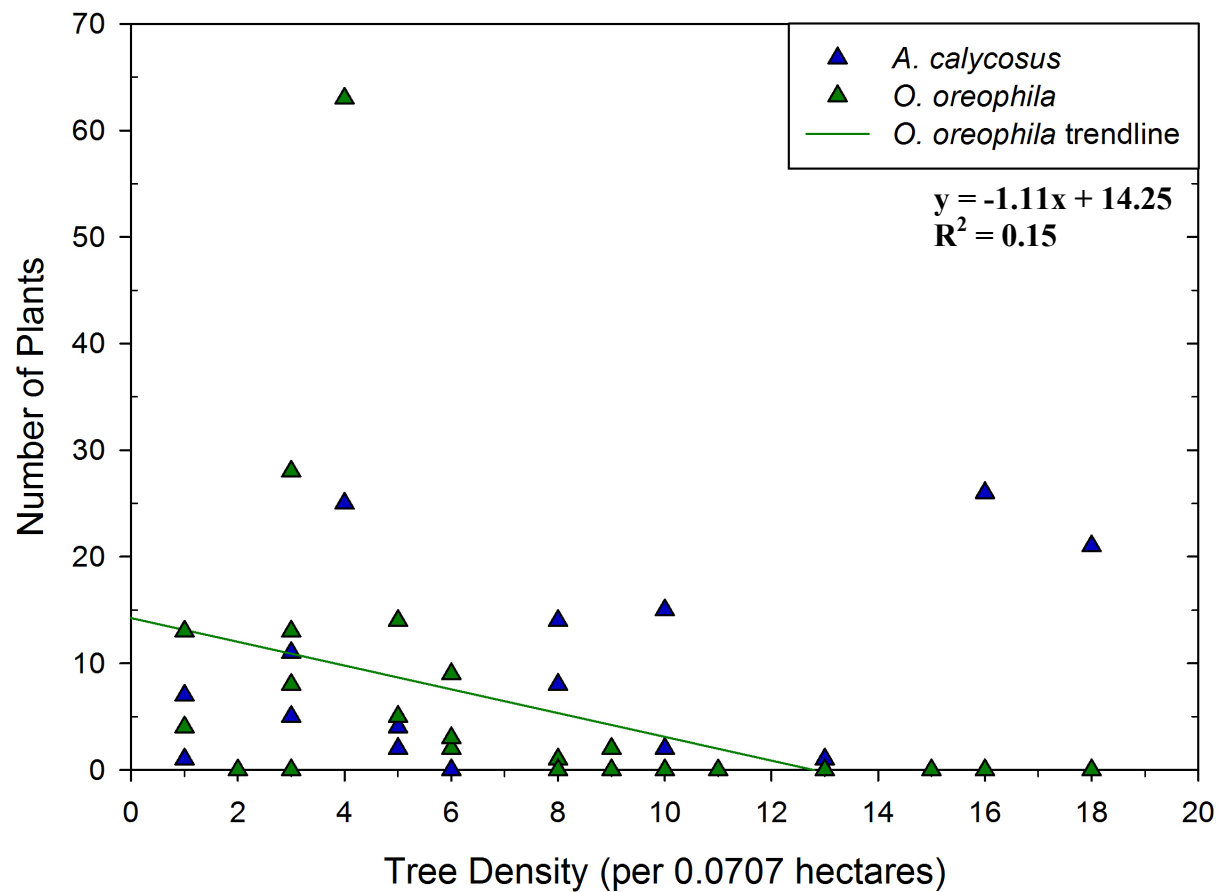


Figure 12: Each point on the graph represents the total number of *Astragalus calycosus* (blue triangles) or *Oxytropis oreophila* (green triangles) recorded in a 1 m² plot in 2016 and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Only unburned and low severity burn plots are included with 15 plots from unburned and 13 plots from low severity burn areas.

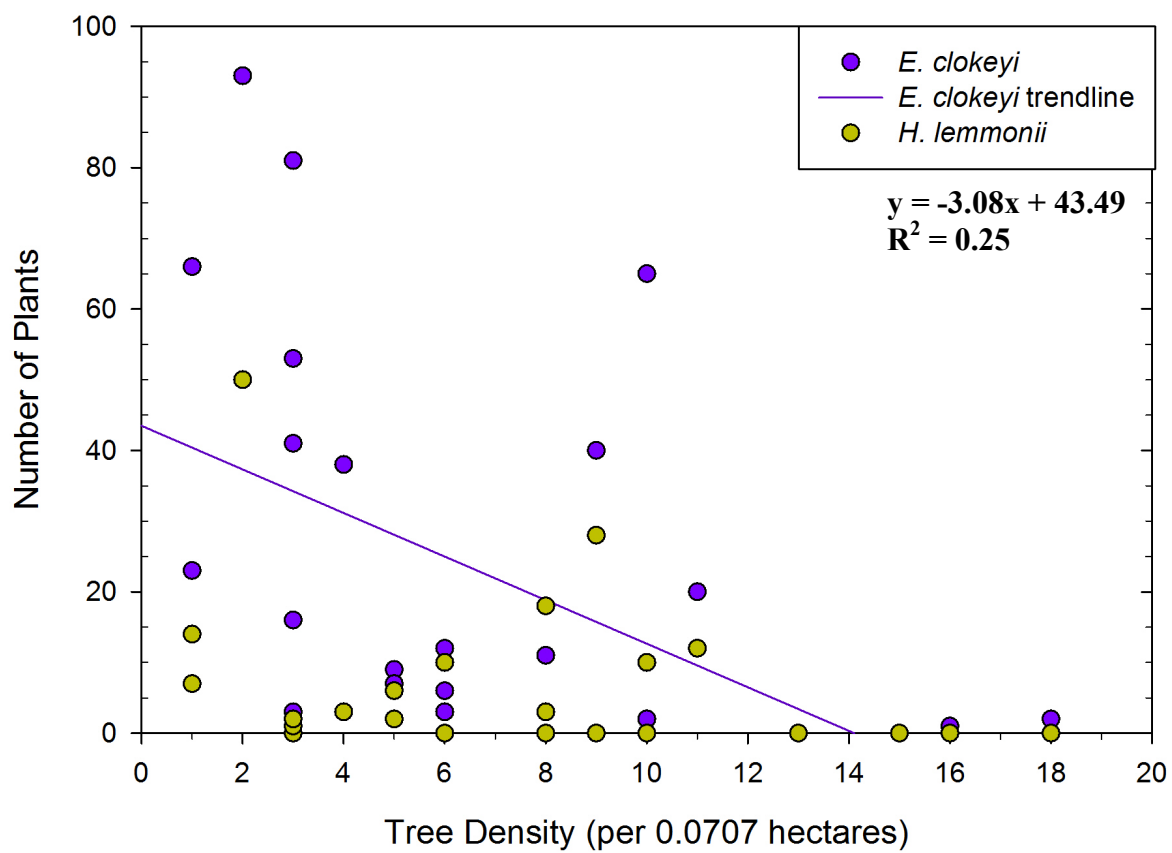


Figure 13: Each point on the graph represents the total number of *Erigeron clokeyi* (purple triangles) or *Hymenoxys lemmonii* (yellow triangles) recorded in a 1 m² plot in 2016 and pre-burn tree density measured in a 15 m radius surrounding each plot (a density of 2 trees per plot is 28.29 trees per hectare). Only unburned and low severity burn plots are included with 15 plots from unburned and 13 plots from low severity burn areas.

Old Burn

The Old Burn is an area where a small fire occurred an unknown number of years ago. It was on a much smaller scale than the Carpenter 1 Fire, but could be used to give an idea as to what post-fire recovery could look like. Focusing on the Morand's checkerspot, *Castilleja martinii* had an average plant density of 0.67 m² and *Penstemon leiophyllus* had an average plant density of 7.5 m² in 2015¹. Weiss et. al. 1997 stated that *Castilleja martinii* does well in old burn areas. While 0.67 plants per m² does not seem like a large number, good habitat for the Morand's checkerspot is characterized as being above 0.1 plants per m² (Thompson et. al. 2014). Interestingly, the Old Burn has higher *Penstemon leiophyllus* densities than unburned areas by a large margin. These high numbers of Morand's checkerspot host plants in an Old Burn area could indicate that in future years burned areas from the Carpenter 1 Fire may become good Morand's checkerspot habitat.

Grasses

Grasses in both low and high severity burn areas remained below unburned densities (Figure 14). Low grass cover indicates the potential for good quality Mount Charleston blue butterfly and Morand's checkerspot habitat, as there will be no flight impediment for any colonizing butterfly.

¹ 2015 is the most recent year these plots were surveyed, due to an unfortunate knee injury in 2016.

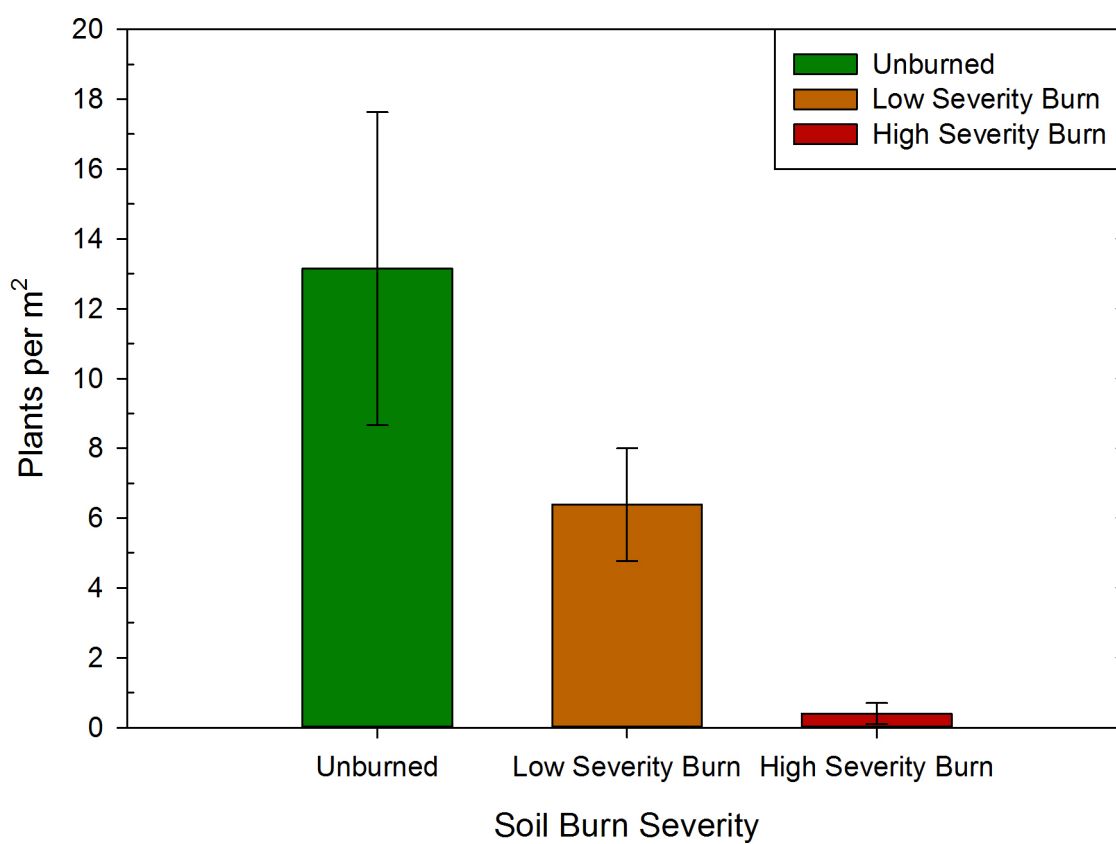


Figure 14: Average grass density in unburned, low severity burn, and high severity burn areas in 2016. Standard errors of the mean bars are ± 1 standard error.

Discussion

The Carpenter 1 Fire was a high-intensity, large-scale fire burning through hundreds of hectares of bristlecone pine forest. Fortunately for the Mount Charleston blue butterfly and Morand's checkerspot, the fire did not burn through the entire South Loop population habitat. The West Ridge, the location with the greatest number of butterfly observations in the past, was not within the burn perimeter. The Main Slope and East Slope had varying degrees of burn severity, which had a significant effect on what plants were able to recover and/or persist through the fire. Overall there was a high degree of resistance to disturbance in low severity burn areas, particularly with respect to the perennial plant community associated with butterflies. Most of the legacy plant species were present and moderately abundant in the first year post-fire. Although, as expected, the high burn severity areas had low resistance to disturbance, the high rate of recovery of a subset of the legacy species has revealed a high degree of resiliency for important butterfly plant species. However, the pattern of recovery appears to be species-specific such that, there is resiliency and recovery of butterfly habitat for the Mount Charleston blue butterfly, but not for the Morand's checkerspot.

Tree Density

High intensity, large-scale fires, as exemplified by the Carpenter 1 Fire, can cause 100% tree mortality. The combustion of trees resulted in severely burned soil, the loss of surface plants, and loss of the seed bank in a roughly two to four meter radius around the base of each tree. There was no plant emergence of any species within this burned zone in the first year and most trees were still surrounded by bare soil in 2016. A study of the effects of slash pile burning, on arbuscular mycorrhizae and the soil seed bank found that slash pile burnings almost completely eliminated soil seeds (Korb et. al. 2004). The soil within the burn perimeter of the piles became

sterilized, potentially providing insight into the effects of combusted trees in the Carpenter 1 Fire. Combustion of a bristlecone pine tree most likely has a similar effect as a slash pile, so areas of high tree density likely have a higher percentage of sterilized soil compared to areas of low tree density. In fact, with respect to the 0.0707 hectare area tree plots (15 m radius around the 1 m² sampling plots), the threshold value of 155.6 trees per hectare (Figure 5), above which few plants emerged, has on average of approximately 78.2% of the soil surface burned (assuming a 4m radius of burn around the tree). It is subsequently unsurprising that any plot with a tree density of 155.6 trees per hectare or greater had little to no recovery as a large portion of the soil seed bank is presumably destroyed. Also unsurprisingly, low soil burn severity areas had the lowest tree densities (below the 155.6 trees per hectare threshold) and presumably an appreciable amount of the seed bank and below surface plant matter remained viable during the fire. This pattern of tree-centered combustion resulted in a mosaic of scorched patches of depleted soil seed banks within a larger matrix of relatively intact soils with re-sprouting plants and germination of seeds from a relatively intact seed bank.

High soil burn severity areas had high tree densities with little to no recovery in areas at or above the 155.6 trees per hectare threshold. However, imbedded within the high severity burn were areas of lower tree density, which retained intact seed banks. One such area was captured within this study, having higher recovery rates than the pre-fire high tree density areas that surround it. Low tree density areas imbedded within high severity burn areas can have a lasting legacy effect, as they are pockets of relatively low severity burn seed banks and/or re-sprouting plants. The species of surviving seeds and plants in these source patches are disproportionately shade tolerant, thus plants dispersing into surrounding high severity burn areas are also shade tolerant because of pre-fire tree density conditions. This pattern is seen in a large portion of the

high severity burn plots that have abundant *Astragalus calycosus* but no shade intolerant *Oxytropis oreophila*. The species composition of recovering plant communities in high severity burn areas may exhibit a shade tolerant legacy effect if they are in close proximity to these source patches whereas there will be an unbiased legacy effect for high severity burn areas close to the perimeter of the fire where source patches of all plant species are present.

Species Richness

In studies determining the response of understory plants to fire in western and southwestern coniferous forests results have been mixed with respect to species richness and composition. Unburned areas have been found to have higher species richness than burned areas in some studies (Griffis et al. 2001a, Dodge and Fule 2008), whereas the opposite has been observed in others (Foxx 1996, Crawford et al. 2001, Keeley et al. 2003, Huisinga et al. 2005). In terms of burn severity, studies have found either no species richness difference between severities (Crawford et al. 2001, Abella and Fornwalt 2015), species richness being greatest in low severity burns (Dodge and Fule 2008), or species richness being greatest in high severity burns (Keeley et al. 2003, Kuenzi et al. 2008, Coop et al. 2010, Shive et al. 2013). I found that three years post-fire, species richness was nearly identical in unburned and low severity burn areas, whereas species richness in high severity burn areas was lower. Three of the four studies that found highest species richness in high severity burns were long term studies (Keeley et al. 2003, Coop et al. 2010, Shive et al. 2013), therefore it may be too early in the recovery process in high severity burn areas to determine whether species richness will increase or remain low. High severity burn areas also had the highest tree densities, resulting in higher coverage of sterilized soils, as discussed earlier, potentially lengthening the process of recovery and decreasing resiliency. With respect to the models of Camac et al. (2013), the changes in understory plant

species richness I observed did not match the linear or the intermediate disturbance models of burn severity. Continued monitoring would be necessary to determine the long-term effects of burn severity as my conclusions about species richness and resilience may change with continued seed dispersal and recovery.

Future recovery of the understory will determine the response of butterfly species richness in burned areas, which is important because there are multiple endemic species other than the Mount Charleston blue butterfly and Morand's checkerspot that could benefit from the loss of trees (Austin 1981). Generally butterflies are found in greater numbers and richness in non-forested areas, which can be attributed to greater insolation, greater availability of nectar and host plants, along with warmer temperatures (Hanula et al. 2016). These three variables of insolation, availability of nectar and host plants, and warmer temperatures are often found in early successional stages. It has been shown that early successional stages, after coppicing in French woodlands, resulted in greater species richness and abundance of butterflies, more specifically increasing levels of resident and threatened species (Fartmann et al. 2013). Studies have shown that prescribed burning and tree thinning can be beneficial for maintaining heterogeneity in the landscape, benefiting butterflies by maintaining diversity in forbs (Wagner et al. 2003, Campbell et al. 2007, Strahan et al. 2015, Hanula et al. 2016). Heterogeneity itself was found to be the most important variable in determining butterfly species richness, more so than climate (Kerr et al. 2001). Based on the literature, it seems likely that butterfly species in the Spring Mountains will benefit from this fire, despite the extensive loss of understory plants. In terms of the two endemics in this study, the Mount Charleston blue butterfly has declined at lower elevations as tree cover increased and understory plants shifted to later successional stages (Boyd et al. 1999). Both butterflies also avoided the closed canopy stage of dense bristlecone

pine forest in the South Loop area prior to the fire. Another *Euphydryas* butterfly was observed to do well in burned areas after eggs were transplanted into burned patches of forest, potentially indicating the ability of the genus to respond favorably to fire (Williams 1995, Boggs et al. 2006). If butterfly host plants continue to increase in the newly opened landscape, the long-term consequence of the severe Carpenter 1 fire is likely to be large-scale increases in sky island butterfly habitat.

Pathways of Recovery Relative to Burn Severity

Low severity burn areas had an overall high resistance to fire disturbance in terms of species richness, although not as much in terms of plant density or cover. Both nectar plant species used by the butterflies have recovered to sufficient densities in the low severity burn to support the butterflies. Other *Hymenoxys* (Overby et al. 2000) and *Erigeron* (Christensen and Muller 1975, Howe 1995) species have been found to respond well to fire, however in different habitat types. Based on my results, it seems *Hymenoxys lemmonii* also has a positive response to fire in low severity burns due to its rapid first year recovery. However, it did not continue to recover at a high rate, despite being a wind-dispersed plant, which could be the result of varying climatic factors from year to year. The other nectar plant, *Erigeron clokeyi*, also saw a rapid recovery in low severity burn areas, indicating a positive response to low severity fire. It had a steady continued recovery from year to year, unlike *Hymenoxys lemmonii*, which would be expected from a wind-dispersed plant.

The Mount Charleston blue butterfly larval host plants have also recovered in sufficient densities in the low severity burn to sustain the butterfly. *Astragalus calycosus* has been found to have no response to fire cues (Carvajal-acosta et al. 2015). My results support this, as there was modest initial recovery by the species in the low severity burn. However, there was rapid

continued recovery in the low severity burn such that by 2016 average host plant densities were greater than unburned densities. This rapid recovery was unexpected because the species employs barochory as its dispersal method. The reasons for this post-fire surge in plant numbers are unknown. For *Oxytropis oreophila* there was a similar rapid recovery following low severity burn as its abundance exceeded unburned levels in the first year post-fire. Another species of grassland *Oxytropis* also has been reported to respond well to fire (Safaian et al. 2005). It is possible that both *Astragalus calycosus* and *Oxytropis oreophila* had roots that persisted through the fire as they have deep taproots. The re-sprouting of these plants could explain the fast recovery observed in 2014. Both *Astragalus calycosus* and *Oxytropis oreophila* surpassed unburned plant densities demonstrating that two larval host plants of the Mount Charleston blue butterfly contribute to perennial plant resistance to low severity fire in this community.

Astragalus platytropis responded poorly to the low severity burn and declined from 2014 to 2016. This decline may be the result of the specialized nature of the plant, as they typically occur on rocky steep slopes in open areas. The slope and soil characteristics may be inhibiting the plant rather than the burn.

The larval host plants of the Morand's checkerspot have not recovered in sufficient densities to support the butterflies, despite a rapid initial recovery by *Penstemon leiophyllus*. *Penstemon* species have been found to respond positively to fire cues (Keeley and Fotheringham 1998, Abella et al. 2007). The first year post-fire, my results supported these studies with a rapid initial increase past unburned levels. However, both in the unburned and low burn severity areas there was a sharp decline in numbers in 2015 and 2016. This decline could indicate there were other variables influencing plant densities, such as climatic variability or herbivory. An important note to make was that in low severity burn areas in 2014 I observed that many of the

Penstemon leiophyllus counted were very small, whereas in subsequent years there were fewer, larger plants. It may be that the fast response the first year resulted in a large number of seedlings in close proximity to each other that subsequently impeded growth of all plants and low first year survival. In terms of *Castilleja martinii*, there was no recovery at all in the low severity burn. Another grassland species of *Castilleja* has been found to have no response to fire (Krock et al. 2016), however I found a negative response. *Castilleja martinii* is known to be hemiparasitic, therefore it may require its host plants to become established before it can recover (Heckard 1962). Interestingly, it has been found that *Penstemon* species can act as good hosts for some *Castilleja* species (Nelson 2005). It is plausible that once *Penstemon leiophyllus* becomes established in sufficient numbers, it will facilitate post-burn recovery of *Castilleja martinii*. Unlike the Mount Charleston blue butterfly, the host plants of the Morand's checkerspot are not contributing to understory community resistance or resilience to fire, indicating that the patterns and pathways of response to disturbance are taxon specific.

Contradictory to what I expected, grasses did not invade in high numbers in low severity burn areas. Grasses are often associated with disturbance and fire, having the ability to quickly invade into areas of increased insolation and nutrient release (D'Antonio and Vitousek 1992). There was likely a nutrient release from the Carpenter 1 Fire because of the ash production, which, in conjunction with increased light availability, was expected to encourage grasses to invade. Other factors, such as below average precipitation, during the growing season or elevated post-fire erosion of soil and nutrients may have contributed to the relatively low densities of grasses in burned areas. The low grass cover is a positive finding for the butterflies though, as grass densities are below those found in unburned areas that sustain both butterflies.

Overall, low severity burn areas have sufficient nectar and larval host plant availability for the Mount Charleston blue butterfly to colonize. Not only are densities of these plants high enough, the proportion of all understory plants (total density) that are either nectar or larval host plants for the butterfly, 65% for low severity burn, was similar to the unburned proportion, 62%, in 2014. These similar proportions in the first year indicate that the germination of the remaining seed bank and regrowth of surviving plants, rather than dispersal, is the main pathway of resistance and recovery in the low severity burn.

Unlike the Mount Charleston blue butterfly, Morand's checkerspot larval host plants have not recovered in sufficient numbers for the butterfly to colonize the burn area. Even though *Penstemon leiophyllus* was abundant in 2014, it declined in subsequent years. There may be other variables besides the fire affecting *Penstemon leiophyllus*, as it had similar annual trends in both the low severity burn and unburned areas. However, the absence of such trends for *Castilleja martinii* indicate that this species had an adverse response to the low severity burn.

High severity burn areas negatively affected both species richness and abundances of the nectar and larval host plants for both butterflies, as 10 out of the 16 plots I measured had no plants of any species in them. This result was primarily due to seed losses in the soil due to intense heat radiating from burning trees in areas with high tree density. A majority of the high burn severity recovery took place in areas with relatively low pre-fire tree densities imbedded within high pre-fire tree density areas. The forest patches below the 155.6 trees per hectare threshold likely had seed banks that persisted through the fire. The two plants that had appreciable recovery, and likely persisted in the seed bank, were *Hymenoxys lemmonii* and *Astragalus calycosus*, a nectar plant for both butterflies and larval host plant for the Mount Charleston blue butterfly, respectively. Other *Hymenoxys* species have been found to have

positive responses to fire (Overby et al. 2000), which is what was observed in *Hymenoxys lemmonii*. It had the fastest response to the high severity burn in the first year post-fire, with a steady recovery in subsequent years. Germination of *Astragalus calycosus* is not known to respond to fire (Carvajal-acosta et al. 2015), yet it recovered relatively quickly in the first year post-fire. Similar to the low severity burn, there was surprisingly fast-continued recovery for *Astragalus calycosus* despite its characteristic of barochary seed dispersal.

The three other butterfly plant species that responded well to the low severity burn, *Erigeron clokeyi*, *Oxytropis oreophila*, and *Penstemon leiophyllus* had little to no recovery in high severity burn areas. These three species did not have appreciable recovery either because they were not able to disperse into the high severity burn from outside the burn and/or they were not present in the seed bank prior to the fire. Because all three species persisted in the low severity burn seed bank, it is likely that the lack of recovery in these three species may be due to legacy effects remaining from the plant community that existed in the high severity burn prior to the fire. The high severity burn areas had high pre-fire tree densities, potentially biasing the seed bank towards shade tolerant species such as *Hymenoxys lemmonii* and *Astragalus calycosus*. Both *Erigeron clokeyi* and *Oxytropis oreophila* were found to have negative correlations with tree density though, which may be why they had little recovery in high severity burn areas. I did not find *Penstemon leiophyllus* to have a significant negative correlation with tree density, however it has been found to occur in sunnier, open areas, similar to *Erigeron clokeyi* and *Oxytropis oreophila* (Thompson et. al. 2014). The response of *Castilleja martinii* in high severity burn areas was similar to low severity burn areas. This species may need more time to reestablish because it is hemiparasitic, relying on a host plant to establish first (Heckard 1962). Also similar to the low severity burn, *Astragalus platytopis* may be absent because of its occurrence on

steep, rocky, sunny slopes. Similar to the low severity burn, grass densities in the high severity burn were lower than unburned areas. The scorched soils of the high severity burn or high erosion may have played a role limiting grasses, however, as discussed earlier, below average precipitation also may have suppressed grass response to the fire.

Overall, the high severity burn has high enough densities of nectar and larval host plants to support the Mount Charleston blue butterfly in the patches of low pre-fire tree density imbedded within the larger matrix of high pre-fire tree density. In the long-term, these patches of low pre-fire tree density and lower burn severity may be the main determinants of recovery in high severity burn areas, as they apparently have been the main source of dispersing seeds. In the short-term, it is plausible that Mount Charleston blue butterflies will colonize the patches of recovery because the butterfly often persists in small, isolated populations (Boyd et al. 1999). The plant recovery that is occurring in the high severity burn is primarily due to only a few species, *Hymenoxys lemmonii* and *Astragalus calycosus*, with some *Erigeron clokeyi*. These three plants constitute 72% of all plants recorded in 2016, compared to 55% in both the unburned and low severity burn areas. The high percentage of larval host and nectar plants of the Mount Charleston blue butterfly provide a positive outlook for potential colonization of these areas. The Morand's checkerspot larval host plants on the other hand have had little recovery in the high severity burn, making it unlikely for a population to establish itself. The patches of low pre-fire tree density imbedded within the high severity burn could potentially be an ecological trap for dispersing Morand's checkerspot butterflies because their larval host plants have not recovered to densities sufficient to sustain the butterfly.

Two Different Trajectories

The differences in recovery that were observed between low severity and high severity burn areas seem to be caused by legacy effects stemming from the plant communities that existed prior to the fire. Low severity burn areas had lower tree densities and, presumably, a high frequency of plant species able to tolerate and thrive in high light environments similar to the unburned plots in areas of butterfly habitat. In contrast, high severity burn areas had high tree densities prior to the fire and, presumably a plant community that was more shade tolerant. The legacy effects caused by seed sources within the high severity burn have influenced the species composition in the initial post-fire recovery and will likely play a large role in shaping future plant communities as well. An example of this from my results relates to the recovery of *Astragalus calycosus* and *Oxytropis oreophila*. Because *Astragalus calycosus* is more shade tolerant than *Oxytropis oreophila*, I found that it is recovering in high severity burn areas of high pre-fire tree density, whereas there is almost no recovery of *Oxytropis oreophila*. Consequently, a unique plant community may be assembled post-fire, dominated by shade tolerant plants in what is now completely open habitat. The duration of this post-fire combination of plants is presumably dependent on the time scale of colonization from the nearest unburned or low severity burn sites that had open canopies and shade intolerant species prior to the fire.

Old Burn

The Old Burn site may give insight into the future of the Morand's checkerspot larval host plants, as they are abundant there. How long it will take the two larval host plants to reestablish is unknown, but *Castilleja martinii* is known to occur in old burn areas (Weiss et al. 1997). Therefore, *Castilleja martinii* may be a later successional plant. Continued monitoring is needed

to determine how long the larval host plants of the Morand's checkerspot will take to recover, if they do in fact recover to sufficient levels to sustain the butterfly.

Other Abiotic Influences

The three years in which this study was conducted there was below average annual precipitation. Below average annual precipitation may have had an effect on the species specific responses observed. Plants with greater drought tolerance would likely recover in higher numbers than plants with lower drought tolerance. Below average precipitation may have also impeded grasses from invading in higher densities.

Snowpack and snowdrifts can alter species-specific recovery in burned areas because of the availability of moisture. Fire can affect where snow accumulates by altering wind patterns due to the loss of trees (Billings 1969). Subsequently, some areas may have received greater amounts of water and moisture. Differences in moisture availability can affect species-specific growth responses, as less moisture is detrimental to species that are less drought tolerant (Knight et al. 1979). Future study of where snowdrifts accumulate in burned areas could provide insight into the effect snowpack post-fire can have on understory vegetation.

Throughout all three years erosion was a factor in the high severity burn, although less so in the low severity burn. In the short-term high severity burns reduce below ground plant matter, like roots, that hold the soil in place, causing increased surface runoff (Pierce et al. 2004). In the long-term, combusted tree roots will begin to decompose and break apart causing more erosion (Pierce et al. 2004). Erosion was apparent in the high severity burn, as some plants were found to be partially or completely buried in soil. Erosion could serve as a limiting factor in the recovery of the high severity burn.

Along with erosion of soils, soil properties are altered after fire. A water repellent layer is often formed on the soil surface or right below the soil surface, affecting the persistence of moisture in the soil available to plants (DeBano 2000). Not only water availability can be affected, but nutrient availability as well (DeBano 1990). The creation of ash could increase readily available nutrients, like nitrogen and phosphorus, for plants to utilize. The different soil characteristics caused by the burn could have played a role in the recovery of burned areas.

Conservation Implications

In the South Loop Population area in the Spring Mountains, the future is promising thus far for the Mount Charleston blue butterfly and uncertain for the Morand's checkerspot. The Carpenter 1 Fire opened up the tree canopy in previously poor quality and non-habitat, while reducing grasses. At the same time, the plants with the strongest recovery are the larval host and nectar plants of the Mount Charleston blue butterfly. It is only three years after the fire, but new habitat has opened up for the Mount Charleston blue. There is still promise for the Morand's checkerspot, as their nectar plants have returned in burned areas. However, the larval host plants for the Morand's checkerspot have not responded well to fire thus far, but have been known to do well in old burns (Weiss et al. 1997). Colonization of burned areas has not been observed yet, unsurprisingly for the Morand's checkerspot due to the lack of larval host plants. However, colonization events may be infrequent for both butterflies. Another mountain *Euphydryas* species has also been found to inhabit small habitat patches of mountain meadows that experience infrequent local extinction and re-colonization (Williams 1995). The same species was observed to have a large surge in population numbers, going from less than 200 individuals to over 3,000 individuals in four years, followed by a fast contraction of population size in the following two years (Boggs et al. 2006). Other checkerspot species have also been found in metapopulations

that have surging colonization events followed by contracting of populations (Ehrlich et al. 1975, Ehrlich and Murphy 1987) Interestingly, similar observations have been made in the Mount Charleston blue butterfly in the past few years. Before 2015 there were three known populations of Mount Charleston blue butterflies that all had less than 100 individuals. However, in 2015 there was a population surge in the Bonanza Trail population where hundreds of individuals were observed. Therefore, both butterflies may have infrequent colonization events of rapid surges and contractions that lead to occupation of new, small isolated habitat patches. In this case, it may take one of these population surges before colonization of burned areas occurs. Infrequent population surges may work in the favor of both of these butterflies, as the burned areas will continue to recover with the potential to become increasingly suitable habitat.

Even though the Carpenter 1 Fire was a catastrophic fire, the results of this study provide hope for endemic butterfly species on sky islands like the Spring Mountains. The nectar plants of both butterflies and the larval host plants of the Mount Charleston blue butterfly are dominating initial re-vegetation. Morand's checkerspot larval host plants may need more time to recover, but it is still early on in succession. Future monitoring of the South Loop Population is necessary to determine long-term recovery, however, thus far this study provides hope for the response of endemic sky island flora and fauna to catastrophic fire.

Conclusions

Three years after catastrophic fire, understory vegetation has recovered to varying degrees based on the severity of burn. Unburned areas had the highest species richness, low severity burn areas had slightly lower species richness, and high severity burn areas had the lowest species richness. Although general models relating species richness to the severity of disturbance (Camac et. al. (2013) do not seem to fit these results, the resistance and resilience of the understory plant community was inversely related to burn severity (Abella and Fornwalt 2015). Unburned areas

and low severity burn areas were nearly identical in species richness, while high severity burn areas had lower species richness and recovery. Despite the occurrence of a stand-replacing fire, the relatively high resistance of understory plant composition to low severity burn was apparently due to persistence of the seed bank. In high severity burn areas the lack of resiliency following the loss of seed bank was not due to invasion of a different set of exotic or disturbance related species. Rather the moderate resiliency of the understory plant community was the result of dispersal and germination of only a subset of legacy or pre-fire plant species. Taxon-specific dispersal ability by itself did not seem to account for the preponderance of two members of Asteraceae and one legume species, suggesting that some unmeasured aspect of post fire conditions was at play. There was however an effect of dense, pre-fire forest canopies on sources of seed dispersal in that high burn severity areas were not yet exhibiting colonization of the shade intolerant species *Oxytropis oreophila*.

High elevation coniferous forests have slow tree regeneration after fires, resulting in light availability remaining high for many years to come (Coop et al. 2010). The slow regeneration of the dominant climax species, bristlecone pine, will result in burned areas remaining in earlier successional stages, which is beneficial to both understory and butterfly species richness and abundance (Fartmann et al. 2013). Grasses have remained at low levels in burned areas, meaning there will be no flight impediment for any potential colonizing butterflies. However, grasses still have the potential to invade because of the complete opening of the tree canopy (D'Antonio and Vitousek 1992, Coop et al. 2010). If they do invade in future years, they could impede future colonization and persistence of both butterflies in burned areas.

Overall there was a high degree of resistance to disturbance in low severity burn areas, particularly with respect to the perennial plant community associated with butterflies. Most of

the legacy plant species were present and moderately abundant in the first year post-fire.

Although, as expected, the high burn severity areas had low resistance to disturbance, the high rate of recovery of a subset of the legacy species has revealed a high degree of resiliency for important butterfly plant species. However, the pattern of recovery appears to be species specific such that, there is resiliency and recovery of butterfly habitat for the Mount Charleston blue butterfly, but not for the Morand's checkerspot.

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Curriculum Vitae

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Education

University Of Nevada, Las Vegas, Las Vegas, NV May 2017
Master of Science in Biology
GPA: 3.93

Vassar College, Poughkeepsie, NY May 2015
Bachelor of Arts in Biology
GPA: 3.29

The School for Field Studies, Queensland, Australia August - December 2013
Academic semester abroad
GPA: 3.65

Relevant Coursework

Intro/Biological Investigation (with lab)	Global Change/Sustainability
Grasslands	Arctic Environmental Change
Introduction to Statistics	Soils/Sustainable Ecosystems (with lab)
Paleoecology and Global Change	Animal Physiology (with lab)
Animal Behavior	Evolutionary Genetics (with lab)
Rainforest Ecology (with lab)	Principles of Forest Management (with lab)
Organic Chemistry (with lab)	Conservation Biology
Topics in Ecosystem Ecology	Mammalogy (with lab)
Restoration Ecology	Biogeography

Research Experience

Directorate Resource Assistant Fellow, US Fish and Wildlife Service June - August 2014
Mentor: Corey Kallstrom

- Created sampling design for Mount Charleston Blue Butterfly (*Icaricia shasta charlestonensis*) habitat and population monitoring on Mount Charleston, Nevada
- Analyzed data collected during the summer of 2014, creating a status report for the US Fish and Wildlife Service on the endangered Mount Charleston Blue Butterfly.
- Concluded that the butterfly is making a recovery after a forest fire destroyed a large portion of its critical habitat.

Research Experience, Cont.

Research Assistant, Vassar College Department of Biology September - December 2014
Mentor: Glenn Proudfoot

- Handled Northern Saw-Whet Owl (*Aegolius acadicus*) and learned how to use mist-nets in order to collect fecal and blood samples to research the diversity of parasites.
- Gained experience identifying parasites using microscopy.

Independent Research, Vassar College Department of Biology January - May 2014
Mentor: Lynn Christenson

- Observed and collected data on a beaver dam on the Vassar College Ecological Preserve
- Utilized GIS to predict the future dispersion of beaver kits away from the dam by analyzing variables such as water depth, slope gradient, and tree cover, subsequently determining prime habitat for beavers.

Conservation Intern, NYSDEC January - May 2014
Mentor: Chris Bowser

- Assisted in the capture and monitoring of American Eels (*Anguilla rostrata*) in Hudson Valley estuaries for the Hudson Valley Eel Project.
- Worked alongside eel researchers to determine the status of the American Eel in New York, as very little is known about them.

Directed Research Project, The School for Field Studies August - December 2013
Mentor: Catherine Pohlman

- Collected data on seedling composition in the Robson Creek Rainforest in Queensland, Australia
- Analyzed Commonwealth Scientific and Research Organization data to assess the impact of logging on rainforest tree composition
- Confirmed hypothesis that silviculture has a negative effect on rainforest tree biodiversity

Presentation Experience

Oral Presentation, "Is there a silver lining in silviculture; measuring biodiversity and forest function in simple notophyll vine forest." Presentation open to the public of Yungaburra, Queensland

Oral Presentation, "Effects of the Carpenter 1 Fire on the Mount Charleston Blue Butterfly (*Plebejus shasta charlestonensis*) and its habitat." Presented to the US Fish and Wildlife Service, Las Vegas and US Forest Service, Las Vegas

Presentation Experience, Cont.

Oral Presentation, “Living on the Edge: Assessing the Effects of Catastrophic Fire on Plants Utilized by Two Endemic Subspecies of Spring Mountains Butterflies.” Presentation for the Mt. Charleston Symposium, UNLV, Las Vegas

Research Skills

Arc GIS; mist-netting; IBM SPSS Statistics; Microscopy; Sampling design

Activities and Leadership

Swim Coach, Las Vegas Swim Club August 2015 - April 2017

- Coached a group of 11-14 year old swimmers
- Instilled values of respect, hard work, and determination

Swim Team Captain, Vassar College September 2014 - May 2015

- Organized and ran team events and fundraisers
- Lead and motivated team during practice and meets

School for Field Studies Campus Representative, Vassar College January 2014 - May 2015

- Engaged in active outreach on campus
- Promoted SFS study abroad programs by sharing experiences, organizing and attending events, and contacting prospective students