

UNDERSTANDING THE EFFECTS OF WILDFIRE ON THE FUNCTIONAL TRAITS
OF PLANTS AND BEES

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Biological Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 2018

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DEDICATION

For all the strong and wonderful women in my life that continue to inspire me

ACKNOWLEDGEMENTS

Thank you to all DISPRO technicians, my technicians, Brad Cachopo & Ben Sisson, and lab assistants for all your hard work and dedication. A huge thanks to Elizabeth Reese for identifying all bees measured in this thesis. My project wouldn't have happened without all your efforts through the years. A big thanks to Laura Burkle for taking a chance on me and sticking with me throughout the process. In addition, thank you to my committee member Travis Belote and Matt Lavin for guiding me through this process. Thank you to the National Science Foundation and Montana State University for the funds to complete this thesis.

TABLE OF CONTENTS

1. INTRODUCTION	1
2. METHODS	8
Study Area and Site Selection.....	8
Plant Functional Trait Measurement Collection	9
Plant Species Selection	9
Plant Trait Field Collection.....	10
Bee Collection and Functional Trait Measurements.....	11
Bee Species Selection for Trait Analysis	11
Bee Laboratory Trait Measurements	12
Statistical Analysis.....	12
3. RESULTS	17
Plant Functional Traits	17
Functional Trait Mean Comparison	17
Inter- and Intra-specific Trait Variation for All and Common Species	21
Bee Functional Traits	23
Functional Trait Mean Comparison	23
Inter- and Intra-specific Trait Variation for All and Common Species	24
4. DISCUSSION.....	43
Plant Functional Traits	45
Plant Height	46
Inflorescence Type.....	47
Number of Flowers	48
Flower Symmetry.....	49
Flower Volume	49
Specific Leaf Area	50
Bee Functional Traits.....	50
Intertegular Distance.....	52
Nesting Behavior	54
Sociality	55
Functional Trait Means and Variation among Wildfire.....	55
Concluding Remarks and Future Directions.....	56
REFERENCES CITED.....	58
APPENDICES	68

TABLE OF CONTENTS CONTINUED

APPENDIX A: Bee Sampling Effort & Plant and Bee Species and Abundance
Lists.....69

LIST OF TABLES

Table	Page
1. Plant Functional Traits	15
2. Bee Functional Traits	16
3. Variation Equations	16
4. Number of Plant Species and Individuals Collected.....	25
5. Plant and Bee Model Results for All Species	26
6. Plant and Bee Model Results for Common Species	27
7. Plant Trait Variation Results.....	28
8. Plant Trait Variation Results: Univariate Analysis.....	29
9. Number of Bee Species and Individuals Measured	30
10. Bee Trait Variation Results.....	31

LIST OF FIGURES

Figure	Page
1. Mean Plant Trait Values	32
2. Inflorescence Type Distribution	33
3. Flower Symmetry Distribution	34
4. Plant Height Variation	35
5. Flower Number Variation	36
6. Flower Volume Variation	37
7. Specific Leaf Area Variation	38
8. Mean Bee Trait Values	39
9. Nesting Behavior Distribution	40
10. Sociality Distribution	41
11. Intertegular Distance Variation.....	42

ABSTRACT

Diversity, often assessed by species richness, fosters ecosystem success, promoting ecosystem services, stability, and adaptation. Evaluations of functional trait composition are a better indicator of ecological process dynamics. Functional trait variation of species within a community (i.e., inter-specific variation) and of individuals within a species (i.e., intra-specific variation) may reflect adaptations and phenotypic variation contributing to the functional diversity of a community in the face of change.

Wildfires have shifted from mixed-severity to frequent high-severity fires, due to fire suppression and climate change, modifying ecosystem function, trait selection pressure, and species sorting. Traits involved in plant-pollinator interactions can be used to understand the mechanisms underlying shifting interactions across communities and how post-wildfire environmental conditions affect community assembly, structure, and stability. We tested how productivity, time-since-burn, and wildfire severity influenced mean functional trait values and inter- and intra-specific functional trait variation of plants and bees known to interact in southwestern Montana, USA.

Fieldwork was conducted from 2013-2017 in two locations that differed in productivity with similar fire histories of recent-mixed-severity, recent-high-severity, older-high-severity burns, and unburned areas. Functional traits involved in plant-bee interactions were selected and measured among plant and bee species observed across these various productivity, time-since-burn, and fire severity levels.

We found that as productivity and time-since-burn increased, the mean functional trait values and inter- and intra-specific functional trait variation of plants and bees increased. In addition, productivity, time-since-burn, and fire severity affected the functional trait values and variation of plant species more than bee species.

These results suggest that as productivity and time-since-burn increases so does trait diversity - promoting ecosystem function and stability. The increased effect of productivity and time-since-burn on plant functional traits compared to bee traits suggests the dispersal abilities of bees allow them to cope with the effects of fire, while plant species are more prone to productivity and time-since-burn habitat filtering and species sorting, potentially due to limited mobility. Our results support previous findings that shifting wildfire regimes from mixed to high-severity burns increases species sorting and limits trait variation after wildfire regardless of productivity but trait variation increases as time-since-burn and productivity increases.

INTRODUCTION

Diversity fosters ecosystem success, promoting ecosystem services, stability, and adaptation in the face of change (Coux, Rader, Bartomeus, & Tylianakis, 2016; Hooper et al., 2005; Oliver et al., 2015). Therefore, declines in diversity due to changes in climate, disturbance regimes, and land use, among other factors, are concerning since they may lead to increased rates of species co-extinctions (Pimm et al., 2014) and altered ecosystem function (Cardinale et al., 2012). Diversity is traditionally assessed by species richness (i.e., the number of species present), but evaluations based on functional trait composition are better indicators of the dynamics of ecological processes (Gagic et al., 2015; Ricotta & Moretti, 2011).

A functional trait is a measurable characteristic (morphological, physiological, phenological, and/or behavioral) of a species that is related to its ecological roles and function within an ecosystem and that strongly influences its fitness (i.e. growth, survival, and reproduction) (de Bello et al., 2010; Diaz & Cabido, 2001; Violle et al., 2007; Webb, Hoeting, Ames, Pyne, & LeRoy Poff, 2010). Variation in functional traits of species within a community (i.e., inter-specific trait variation) and of individuals within a species (i.e., intra-specific trait variation) may reflect adaptations and phenotypic variation (de Bello et al., 2010) that contribute to the functional diversity of a community.

It is hypothesized that with increased functional trait diversity there is increased community stability and ecosystem function due to co-occurring species acquiring different resources temporally and spatially (Gross et al., 2017) and thus fulfilling different niches or roles in species interaction networks (Loreau, 1998; David Tilman,

1999). Habitats with differing environmental conditions and resources may select for individuals and species with particular traits (i.e., habitat filtering) (Cornwell, Schwilk, & Ackerly, 2016; Weiher & Keddy, 2004), thereby influencing distributions of locally adapted traits among species across environmental gradients, functional trait variation, species interactions, and ecosystem function (Cornwell & Ackerly, 2009; Genung et al., 2011; Kraft, Godoy, & Levine, 2015; Moretti et al., 2010). The identification of over- or under-represented suites of traits under various environmental conditions can indicate individuals and species that are particularly successful (i.e. high fitness) or not (i.e., poor competitors) in those communities (Weiher & Keddy, 2004). Thus, evaluating patterns of inter-specific and intra-specific functional trait variation is valuable for understanding drivers of community assembly (e.g., habitat filtering, species sorting, and competition) (Bolnick et al., 2011), biodiversity maintenance (e.g., high trait variation) (Spasojevic, Turner, & Myers, 2016), the effects of environmental changes across trophic levels (e.g., wildfire disturbances), and for identification of the suites of traits that likely contribute to stability in ecosystem function (Boersma et al., 2016).

Wildfire is a naturally occurring disturbance (Bowman et al., 2010) that is increasing in severity, (Westerling, Hidalgo, Cayan, & Swetnam, 2006) due to fire suppression, timber harvesting, grazing, and climate change (Pierce, Meyer, & Jull, 2004). As a result of increasing wildfire severity, ecosystem function (Wardle, Zackrisson, Hornberg, & Gallet, 1997; Weber & Flannigan, 1997), trait selection pressure (Keeley, Pausas, Rundel, Bond, & Bradstock, 2011; Moretti, De Bello, Roberts, & Potts, 2009; Moretti & Legg, 2009; Pausas & Keeley, 2009), and species sorting (Bond &

Keeley, 2005; Burkle, Myers, & Belote, 2015; Questad & Foster, 2008) have also been modified. Historically, wildfires in the western United States burned in a heterogeneous pattern (mixed-severity) across landscapes, with patches of unburned, low-, moderate-, and high-severity burns within a fire's perimeter (Belote, 2014; Hessburg, Agee, & Franklin, 2005). This wildfire-severity pattern fosters species diversity (Belote, 2014; Odion et al., 2014) and generates diverse habitats and resources (Kelly & Brotons, 2017). It has been observed fire has a positive response on species diversity and composition of bee and plant communities (Moretti et al., 2009). However, there is currently limited knowledge on how mixed-severity wildfires influence the functional trait diversity of plant and insect communities. Due to altered fire regimes, homogenous high-severity fires that burn from the ground to the tree canopy (Odion et al., 2014) have become more prevalent (Westerling et al., 2006) due to increased fuel loads (Ansley et al., 2000). These high-severity fires limit trait presence and variation by sorting individuals that are more capable of thriving in these environments and expelling those that are not (Moretti & Legg, 2009), thereby creating a funnel towards highly specialized traits and decreasing functional trait diversity (Coux et al., 2016).

Landscape productivity may also be considered when investigating the influence of wildfire severity on functional trait diversity. Productivity (Tilman, 1997) and wildfire (Moretti & Legg, 2009) affect functional diversity through species sorting, selecting for certain traits that thrive under these particular productivity and wildfire severity conditions. It has been observed that the evolutionary relationships of species, which allow us to understand how species partition resources post-wildfire, can explain patterns

of productivity (Cadotte, Cavender-Bares, Tilman, & Oakley, 2009). This suggests that productivity and wildfire potentially interact to influence patterns of functional trait diversity. Furthermore, time-since-burn influences the successional phase of a community (Moretti et al., 2009), thereby affecting trait diversity and variation among communities (Ricotta & Moretti, 2011). For example, Moretti and Legg (2009) examined plant and invertebrate traits and observed that large-bodied pollinators and annual, ruderal, light-seeking plant species with prolonged flowering periods were associated with more recent fires, with fires and time-since-burn selecting traits associated with proficient dispersal and colonizing abilities. This suggests that fire-severity and time-since-burn potentially interact to affect functional trait presence.

Wildfire regime intervals (i.e. the interaction of severity and time-since-burn) at various productivity levels influence the successional phase of communities. As time-since-burn increases, the successional phase of communities advance (Ansley et al., 2000). Further, it has been observed that more severe wildfires slow rates of succession (Ansley et al., 2000). With increased species sorting from altered fire regimes and various levels of productivity, the variation of species traits is limited following a fire but increases as time-since-burn (Mouillot, Graham, Villéger, Mason, & Bellwood, 2013) and productivity increase (Zhang, Chen, & Reich, 2012). There is a need to conduct more research to better understand the effects of mixed-severity fires on the functional trait variation of plant-pollinator interactions, a vital process for overall ecosystem function and stability.

Plant-pollinator interactions are important ecological interactions that contribute to biodiversity, with over 350,000 plant species interacting with pollinators (Burkle & Alarcon, 2011; Ollerton, Winfree, & Tarrant, 2011). Pollinators play a crucial role in ecosystem function, with 60-90% of naturally occurring plants benefiting from pollinators (Aguirre-Gutiérrez, 2016; Kremen et al., 2007; Ollerton et al., 2011).

Changing environmental conditions and population declines are contributing to decreased diversity, pollination services, and plant reproduction (Biesmeijer et al., 2006; Burkle & Alarcon, 2011; Fontaine, Dajoz, Meriguet, & Loreau, 2006; Klein, Steffan-Dewenter, & Tschamtker, 2003). Using a functional trait framework, traits involved in plant-pollinator interactions can be used to understand the mechanisms underlying shifts in plant-pollinator interactions across communities (Burkle, Delphia, & O'Neill, 2017) and may help predict the effects of post-wildfire environmental conditions on community assembly, structure, and stability across multiple trophic levels (Boersma et al., 2016).

Understanding which floral traits are prominent and their variation among various environmental conditions on an inter- and intra-specific level as a result of wildfire is important for understanding the effects environmental change may have on pollination processes. Further, identifying the various flowering plant and bee traits present among different wildfire environmental conditions may shed light on the effects of habitat filtering on pollination. Phenotypic variation can differ among populations, thereby affecting competition, resource use, defensive capabilities, tolerance or adaptability (Bolnick et al., 2011) for both the flowering plants and native bees. Understanding and determining the effects of wildfire severity and productivity on trait variation and

pollination processes aids in disentangling patterns of response in species composition critical for managing diverse plant-pollinator interactions (Moretti & Legg, 2009).

We tested how productivity, time-since-burn, and wildfire severity influenced mean functional trait values and inter- and intra-specific functional trait variation of flowering plants and bees known to interact with one another in southwestern Montana, USA. First, we hypothesized that unburned areas would have larger mean values for certain plant traits (e.g. specific leaf area) to increase the amount of light captured, increasing relative growth rate and plants present in recent fires in moderately productive areas would have larger mean values for other plant traits (e.g. flower number) to increase bee attraction. We hypothesized that recent burns of moderately productive areas would have larger mean values for bee traits (e.g. body size) because larger bees are capable of dispersing further (Warzecha, Diekotter, Wolters, & Jauker, 2016) to forage in open canopy recent burns. Second, we hypothesized that inter-and intra-specific plant trait variation would be greater among higher productivity levels because trait variation increases with productivity (Zhang et al., 2012). We hypothesized that inter- and intra-specific bee functional trait variation would be greater among lower productivity levels because decreased forest canopies, found in lower productivity, open up areas for forb species to establish creating bee forage habitat (Taki et al., 2013). Third, we hypothesized that recent fires would have lower inter- and intra-specific plant functional trait variation because fewer species and individuals have had the opportunity to establish in areas that are in an early successional stage. Therefore, we expected older fires and unburned areas would have higher inter- and intra-specific plant functional trait variation. We

hypothesized that recent fires would allow bees to disperse and establish (Taki et al., 2013), therefore, the inter-specific bee functional trait variation would be higher among recent burns and the intra-specific trait variation would increase over time as more individuals disperse and establish. Fourth, we hypothesized that the inter- and intra-specific functional trait variation of flowering plants and bees would be highest in areas that burned with mixed-severity fires compared to those that burned with high-severity fires, and lowest in unburned areas. The heterogeneous pattern of mixed-severity fires is likely to select for various trait expressions and encourage trait variation.

METHODS

Study Area and Site Selection

This study was conducted in two locations in southwestern Montana USA with similar wildfire histories, different productivity levels (Burkle et al., 2015), and different forest types. A location near Helena (HE) (46°43'N, 111°45'W) was selected to represent low productivity, typically dominated by ponderosa pine (*Pinus ponderosa*) woodlands within an elevational range of 1,210 – 1,674 m. A location in Paradise Valley (PV) (45°16'N, 110°27'W) was selected to represent moderate productivity, dominated by lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga menziesii*) forests within an elevational range of 2,071 – 2,321 m (see Burkle et al. 2015 for details about these locations).

Within each of these two locations, wildfires were selected based on time-since-fire, including both older (22-29 years-since-burn) and recent (6-10 years-since-burn) fires. The wildfires in Helena included the North Hill fire (27,162 acres in 1984) and the Jimtown fire (1,108 acres in 2003). The wildfires in Paradise Valley included the Thompson Creek fire (6,979 acres in 1991) and the Wicked Creek fire (22,195 acres in 2007) (MTBS). Within each wildfire perimeter, fire severities were identified using the Monitoring Trends in Burn Severity (MTBS) program (<http://www.mtbs.gov/>). Mixed-severity areas burned in a heterogeneous pattern, with patches of unburned, low-, moderate-, and high-severity burns. High-severity areas burned in a homogeneous pattern of high severity. Within older burns, high-severity areas were selected. Within recent

burns, both high-severity and mixed-severity areas were selected. Mixed-severity areas were not available within the older fires. Unburned areas were selected where a wildfire was not recorded in the last 60 years prior to the start of the study (i.e. 2013). Two units of 15 hectares were selected in each area of recent-mixed-severity, old-high severity, recent-high severity, and unburned areas for a total of eight units in each location. Nine sites were randomly stratified across each unit using generalized random tessellation stratified (GRTS) techniques (Burkle et al., 2015; Kincaid & Olsen, 2016). Within each mixed-severity unit, three sites were low-severity, three sites were moderate-severity, and three sites were high-severity. We established a 25 m diameter circular plot (491 m²) at each site. There were 36 recent mixed-severity sites (18 in PV and 18 in HE), 34 unburned sites (18 in PV and 16 in HE; two HE sites were previously burned and excluded), 36 high-severity sites from the more recent wildfires (18 in PV and 18 in HE), and 36 high-severity sites from the older wildfires (18 in PV and 18 in HE). In total, we sampled 70 sites in Helena and 72 sites in Paradise Valley.

Plant Functional Trait Measurement Collection

Plant Species Selection

Based on previous observations of plant species (Burkle et al., 2015) and their interactions with bees at these sites (unpublished data), we selected a subset of these plant species for functional trait measurement. We selected flowering plant species with an observed interaction with at least one bee species in our collection where (1) the plant species was present at both locations (HE and PV) in order to compare trait variation

between low and moderately productive areas, or (2) was present in all fire severity types in one or both locations to compare trait variation between fire severities, totaling 84 plant species overall. Due to the nature of our criteria, most of these flowering plant species were common and abundant, but a few occurred in low abundance with only a few individuals in each of the locations and fire severities.

Plant Trait Field Collection

Traits (Table 1) were measured in the field from May to August 2017. Measurements were collected every week alternating location throughout the duration of the growing season. Up to five individuals of each species at each site were selected with random stratification across the plot and measured during the peak flowering period for each selected species.

Plant height was measured from the ground to above the inflorescence (associated with visitor plant recognition; Fornoff et al., 2017). Inflorescence type, a trait associated with bee attractiveness (Coux et al., 2016), was determined visually and confirmed with Lesica (2012) and Harris & Harris (1994). The number of open flowers per randomly selected inflorescence of an individual (Coux et al., 2016) was recorded as a measure of plant attractiveness to pollinators (Conner & Rush, 1996). Flowering head symmetry (i.e., radial, bilateral, dissymmetry, and asymmetry) (Hileman, 2014), a metric of flower adaptation to pollinators (Fornoff et al., 2017), was determined visually. Flowering head dimensions (i.e., length, width, and depth), an estimate of flowering plant species attractiveness and visitation rates (Stang, Klinkhamer, & Van Der Meijden, 2006), were measured in mm using digital calipers. In order to determine the specific leaf area (SLA:

leaf surface area/dry leaf mass), a measure of potential relative growth rate (Cornelissen et al., 2003), a leaf from each individual was collected and pressed. Once dry, each leaf was weighed (mg) and photographed. ImageJ (Schneider, Rasband, & Eliceiri 2012) was used to determine the surface area (mm^2) of each leaf from the photograph to complete the SLA calculation.

Bee Collection and Functional Trait Measurements

Throughout four growing seasons (2013-2016), each site was observed for bee pollinators during sunny, calm weather and individuals contacting the reproductive parts of flowers were hand-netted, frozen, pinned, and identified to species. An average of 8.9 hours was spent observing each site from 2013 to 2016, with 1263 total hours of observation (see Appendix for sampling efforts).

Bee Species Selection for Trait Analysis

Bee species were selected for functional trait measurement (Table 2) if individuals of that bee species were captured while visiting a flower of a plant species being considered (above). Queen bumblebees were not collected and, thus, were not included in trait measurements. Individuals of 293 bee species qualified for trait measurements with 106 of those species observed in both Helena and Paradise Valley (i.e. common species).

Bee Laboratory Trait Measurements

The intertegular distance (IT distance) of each individual was measured as the width between the wing bases on the dorsal side of the thorax (Cariveau et al. 2016). IT distance is highly correlated with the tongue length, body mass, and foraging distance of an individual (Cane, 1987; Greenleaf, Williams, Winfree, & Kremen, 2007). The IT distance of each individual was measured in ocular units under a Leica S6E microscope using a reticle ruler (10 mm with 200 divisions; supplier: Microscope World) installed in the eyepiece. The IT distances (in mm) were determined from these ocular units standardized by the reticle ruler calibration term (previously determined with a stage micrometer). Bee nesting behavior and sociality were determined through a literature review for each species measured.

Statistical Analysis

To test for the main effects of productivity, fire severity, and time-since-burn on the measured functional trait values for each numeric trait (i.e. plant height, flower number, flower volume, SLA, and IT), a linear mixed effects model was used with species included as a random effect to account for species-to-species variation. Trait measurements were log-transformed to meet the normality assumption when needed. To test for the main effects of productivity, fire severity, and time-since-burn on the measured functional trait values for each categorical trait (i.e. inflorescence type, flowering head symmetry, nesting behavior, and sociality), a multinomial log-linear model was used with species included as a random effect to account for species-to-

species variation. Least-squares means were calculated along with a compact letter display with a Tukey p-value adjustment to understand the variation of mean trait values across the various productivity levels, time-since-burn, and fire severities.

To understand the inter- and intra-specific variation of functional traits involved in plant-bee interactions among various productivity levels, time-since-burn, and fire severities. First, we standardized numeric functional traits (i.e. plant height, number of flowers, flower volume, specific leaf area, and intertegular distance) using Z-scores (mean=0 and standard deviation=1) to control for variance and differences in the units of measurement collected among traits. An inter-specific trait variation value was calculated for each standardized numeric trait for each species at each site using Equation 1 and Equation 2 (Table 3) (Lepš, de Bello, Lavorel, & Berman, 2006), where trait values are weighted by the proportion of that species at the site. An intra-specific trait variation value was calculated for each standardized numeric trait of each species with a minimum of five individuals sampled at each site (Siefert et al., 2015) using Equation 3 (Table 3) (Lepš et al., 2006), where the trait variance of a species is weighted by the proportion of that species at the site. These values were calculated for all plant and bee species individuals measured and for plant and bee species individuals measured in both Helena and Paradise Valley (i.e. common species) to compare community composition variation (i.e. all species) to species identity variation (i.e. common species) among time-since-burn and fire severity controlling for location. The inter- and intra-specific trait variation values were log-transformed prior to analyses to satisfy the assumptions of normality.

Separate two-way MANCOVA tests were conducted for all and common plant and bee species to test for the main and interactive effects of productivity (i.e. location), fire severity, and time-since-burn on multiple functional traits inter- and intra-specific trait variation. Significant MANCOVAs ($p < 0.05$) were followed by separate two-way ANOVA tests to examine the main and interactive effects of productivity, fire severity, and time-since-burn on the inter- and intra-specific trait variation of each species at each site for each trait. Significant ANOVAs ($p < 0.05$) were followed by a least-squares means calculation and compact letter display with a Tukey p-value adjustment to compare and understand the inter- and intra-specific trait variation of each trait between site combinations of productivity, fire severity, and time-since-burn.

All analyses were performed in the statistical software, 'R' (v.3.4.1: Single Candle) (R Development Core Team, 2017). Linear mixed-effects models were performed using the nlme package (Pinheiro et al., 2017), multinomial log-linear models were conducted using the nnet package (Venables & Ripley, 2002), and least square means and compact letter displays were calculated using the lsmeans package (Russell Lenth, 2016). Figures were created with the ggplot2 (Hadley Wickham, 2009) and gridExtra (Baptiste Auguie, 2016) packages.

Table 1: Plant Functional Traits. Plant functional traits selected plant traits measured, the methods used to measure the traits, whether an intra-specific analysis and/or inter-specific trait variation analysis was conducted, main factors that contribute to each trait, and literature supporting trait importance in plant-bee interactions.

Plant Trait	Measurement Methods	Intra- and/or Inter-specific	Variable Type	Trait Driver	Literature
Plant Height	Top of the inflorescence in cm	Inter-specific Intra-specific	Numeric	Reproduction	(Cornelissen et al., 2003; Fornoff et al., 2017; Lavorel et al., 2011; Vieira, Cianciaruso, & Almeida-Neto, 2013)
Inflorescence Type	Visual estimation & confirmed by literature	Inter-specific	Categorical	Reproduction	(Chamberlain et al., 2014; Coux et al., 2016; Fornoff et al., 2017)
Flower Number	Count the number of flowers for a randomly selected individual/inflorescence	Inter-specific Intra-specific	Numeric	Reproduction	(Coux et al., 2016)
Flower Symmetry	Visual estimation & confirmed by literature	Inter-specific	Categorical	Reproduction	(Chamberlain et al., 2014; Coux et al., 2016; Fornoff et al., 2017)
Flower Volume	Measure length, width, and depth with calipers in mm (LxWxD)	Inter-specific Intra-specific	Numeric	Reproduction	(Stang et al., 2006)
Specific Leaf Area (SLA)	Collect a leaf from the base of each individual measured; press; weigh in mg to obtain dry mass; photograph and run through ImageJ to obtain surface area SLA = leaf surface area/dry leaf mass	Inter-specific Intra-specific	Numeric	Energy Use	(Cornelissen et al., 2003; Fornoff et al., 2017; Vieira et al., 2013)

Table 2: Bee Functional Traits. Selected bee traits measured, the methods used to measure the traits, whether an intra-specific analysis and/or inter-specific trait variation analysis was conducted, main factors that contribute to each trait, and literature supporting trait importance in plant-bee interactions.

Bee Trait	Measurement Methods	Intra- and/or Inter-specific	Variable Type	Trait Driver	Literature
Intertegular Distance (IT)	Measure the IT distance in mm under a microscope using a reticle ruler	Inter-specific Intra-specific	Numeric	Dispersal/Diet/ Reproduction	(Cariveau et al., 2016; Chamberlain et al., 2014)
Tongue Length	IT & Tongue Length are correlated	Inter-specific Intra-specific	Numeric	Diet	(Cariveau et al., 2016)
Body Mass	IT & Body Mass are correlated	Inter-specific Intra-specific	Numeric	Dispersal/ Reproduction	(Cariveau et al., 2016; Chamberlain et al., 2014; Coux et al., 2016)
Foraging Distance	IT & Foraging Distance are correlated	Inter-specific Intra-specific	Numeric	Dispersal/Diet	(Cariveau et al., 2016)
Nesting Behavior	Literature review of species measured	Inter-specific	Categorical	Reproduction	(Chamberlain et al., 2014)
Sociality	Literature review of species measured	Inter-specific	Categorical	Reproduction	(Bommarco et al., 2010)

Table 3: Variation Equations. Inter- and intra-specific trait variation equations (Lepš et al., 2006)

Equation 1	Inter-specific trait variation calculation (Lepš et al., 2006) where p_i is the proportion of i^{th} species at a site, x_i is the mean functional trait value of i^{th} species at a site, and \bar{x} is the grand mean at a site, calculated with Equation 2.	$\sum_i p_i + (x_i - \bar{x})^2$
Equation 2	The grand mean (i.e. \bar{x}) calculation used in Equation 1 (i.e. Inter-specific trait variation calculation) where p_i is the proportion of i^{th} species at a site, x_i is the mean functional trait value of i^{th} species at a site (Lepš et al., 2006)	$\bar{x} = \sum_i p_i + x_i$
Equation 3	Intra-specific trait variation calculation (Lepš et al., 2006) where p_i is the proportion of i^{th} species at a site and s_i^2 is the within-species variance of a particular trait at a site.	$\sum_i p_i s_i^2$

RESULTS

Plant Functional Traits

In total, 5306 individuals from 84 flowering plant species (i.e. all species) (Table 4) ranging from one to 69 individuals per species' traits (Table 1) were measured (see Appendix A for species and abundance lists). There were 17 plant species common to Helena and Paradise Valley that were observed and measured (i.e. common species), with 1857 total individuals measured. Common species measurements ranged from two to 69 individuals per species measured.

Functional Trait Mean Comparison

Location (i.e. productivity), time-since-burn, wildfire severity, and sampling date affected the mean plant height for all (Table 5) and common (Table 6) species. Mean plant height across all and common species was 5-8% greater in Helena than in Paradise Valley (Figure 1A-1D), 4% greater across all species in recent burns than in older burns (Figure 1A), and 2% greater across common species in older burns than in recent burns (Figure 1C). Mean plant height of all and common species in unburned areas were 17-20% greater than in older burns and 16-19% greater than in recent burns (Figure 1A & 1C). All and common species in mixed-severity burns were 3-9% taller than in high-severity burns (Figure 1B & 1D). Mean plant height of all and common species in unburned areas was 12-15% greater than in high-severity burns and 11-13% greater than in mixed-severity burns (Figure 1B & 1D).

Location (i.e. productivity) had the greatest effect ($p < 0.0002$) on inflorescence type presence when all observed species were considered (Table 5). Round umbel and verticillaster were only observed in Helena, and vines were only observed in Paradise Valley. Helena plants were primarily capitulum, corymb, and solitary, while Paradise Valley plants were primarily cyme, raceme, panicle, and spike (Figure 2A). Round umbel, vine, solitary, and cyme were the most prevalent inflorescence types in unburned areas (Figure 2B). Older burns were dominated by panicle and recent burns consisted of spike, verticillaster, corymb, raceme, and capitulum inflorescence types (Figure 2B). High-severity burns were dominated by panicle, corymb, verticillaster, and capitulum types, while solitary, spike, and corymb were more prevalent in mixed-severity burns (Figure 2C). Inflorescence types across all species varied with 26.8% raceme, 25.3% corymb, 17.0% capitulum, 11.5% cyme, 9.4% panicle, 6.6% solitary, 2.4% spike, 0.5% round umbel, 0.3% vine, and 0.2% verticillaster.

Location ($p = 0.0078$) and time-since-burn ($p = 0.0026$) affected inflorescence type presence for common species (Table 6). Helena plants were primarily spike, capitulum, and corymb, while Paradise Valley plants were primarily solitary, cyme, panicle, and raceme (Figure 2D). Cyme was the most prevalent inflorescence type in unburned areas (Figure 2E). Older burns were dominated by solitary, panicle, and corymb, while recent burns consisted of spike, raceme, and capitulum inflorescence types (Figure 2E). High-severity burns were dominated by spike, panicle, capitulum, corymb, and solitary types, while cyme and raceme were more prevalent in mixed-severity burns (Figure 2F). Inflorescence types across common species varied with 32.1% raceme,

23.5% corymb, 24.7% capitulum, 13.7% cyme, 0.2% panicle, 5.7% solitary, and 0.1% spike.

Location, time-since-burn, fire severity, and sampling date affected the mean flower number across all (Table 5) and common species (Table 6). The mean number of flowers per inflorescence across all and common species was 34-41% greater in Helena than Paradise Valley (Figure 1E-1H). The mean flower number across all species in recent burns was 18% greater compared to older burns and 37% greater than species in unburned areas (Figure 1E). The mean flower number across common species in older burns was 2% greater compared to recent burns and 40% greater than species in unburned areas (Figure 1G). Across all species, older burns had 19% more flowers per inflorescence than unburned areas (Figure 1E), while, common species in recent burns had 39% more flowers per inflorescence than in unburned areas (Figure 1G). All and common species in high-severity burns had 19-21% more flowers per inflorescence compared to those in mixed-severity burns and 34-36% more than those in unburned areas (Figure 1F & 1 H). All and common species in mixed-severity burns had 13-17% more flowers per inflorescence compared to unburned areas (Figure 1F & 1H).

Time-since-burn ($p = 0.0085$) and fire severity ($p = 0.0186$) had the greatest effect on flower symmetry across all species (Table 5). Helena flowers were primarily radially symmetric, while flowers in Paradise Valley were mostly di-symmetric (i.e. symmetric across 2 planes) and bilaterally symmetric (Figure 3A). Di-symmetric flowers dominated older (Figure 3B) and high-severity burns (Figure 3C). Bilateral flowers were prevalent among recent (Figure 3B) and mixed-severity burns (Figure 3C), while radially symmetric

flowers were ubiquitous in unburned areas (Figure 3B). Flower symmetry across all species varied with 78% radial, 15% bilateral, and 7% di-symmetry.

Location ($p = 0.0005$), time-since-burn ($p < 0.0001$), and fire severity ($p < 0.0001$) had the greatest effect on flower symmetry across common species (Table 6). Helena flowers were primarily radially symmetric, while flowers in Paradise Valley were mostly bilaterally symmetric (Figure 3D). Bilateral flowers were prevalent among recent (Figure 3E) and high-severity burns (Figure 3F), while radially symmetric flowers were ubiquitous among older burns and unburned areas (Figure 3E). The flowers among mixed-severity burns were equally radially and bilaterally symmetric (Figure 3F). The flower symmetry across common species varied with 82% radial and 18% bilateral.

Location, time-since-burn, and fire severity affected mean flower volume across all species, while location did not affect mean flower volume across common species (Tables 5 & 6). Specifically, mean flower volume across all species was 19% greater in Paradise Valley than in Helena (Figure 1I & 1J). There was a marginal difference in mean flower volume across common species between Helena and Paradise Valley ($p = 0.0669$; Figure 1K & 1L). The mean flower volume across all species in recent burns was 10% greater compared to older burns (Figure 1I), with no mean difference across common species ($p = 0.9276$; Figure 1K). Mean flower volume across all and common species among unburned areas was 12-17% greater than older burns and 7-14% greater than recent burns (Figure 1I & 1K). Mean flower volume of all species across high-severity burns were 5% greater than mixed-severity burns (Figure 1J), while mean flower volume across all and common species among unburned areas was 7-12% greater than

mixed-severity fires (Figure 1J & 1L). There were no differences in mean flower volume across all species ($p = 0.6982$; Figure 1J) and common species ($p = 0.2328$; Figure 1L) between high-severity burns and unburned areas, or across common species ($p = 0.3047$; Figure 1L) between high-severity fires and mixed-severity fires.

Location, time-since-burn, and fire severity had the greatest effect on mean SLA across all (Table 5) and common (Table 6) species. The mean SLA across all and common species was 23-25% greater in Paradise Valley compared to Helena (Figure 1M-1P). Mean SLA of all and common species in unburned areas was 24-30% greater than in older burns and 25-27% greater than in recent burns (Figure 1M & 1O). Mean SLA across all species in recent burns was 4% greater than in older burns (Figure 1M), while there was no mean difference of SLA across common species ($p = 0.8183$; Figure 1O) between recent and older burns. Across all species in mixed-severity burns the estimated mean SLA was 3% greater than in high-severity burns (Figure 1N), with no difference across common species ($p = 0.8013$, Figure 1P). SLA means across all and common species in unburned areas was 20-21% greater than in high-severity and 17-20% greater than in mixed-severity burns (Figure 1N & 1P).

Inter- and Intra-specific Functional Trait Variation for All and Common Species

Across all and common species, the inter- and intra-specific variation of numeric plant functional traits was affected by the main and interactive effects of location, time-since-burn, and fire severity (Table 7). For plant height, increased productivity had higher inter- and intra-specific variation among all species and higher intra-specific variation among common species (Figure 4). As time-since-burn increased, the inter- and intra-

specific variation of plant height was higher for all and common species (Figure 4A, 4C, 4E, 4G). Among fire severities, unburned areas had greater inter- and intra-specific plant height variation for all and common species (Figure 4B, 4D, 4F, 4H). For the number of flowers, low productivity had higher increased inter-specific variation among all and common species, while intra-specific among all and common species (Figure 5) was higher among moderately productive environments. As time-since-burn increased, the inter- and intra-specific variation of flower number was greater for all and common species (Figure 5A, 5C, 5E, 5G). High-severity fires had higher inter-specific flower number variation among all and common species, while unburned areas had the greatest intra-specific flower number variation among all and common species (Figure 5B, 5D, 5F, 5H). For flower volume, low productivity had higher inter-specific variation among all species, while the inter-specific variation of common species and the intra-specific variation among all and common species (Figure 6) was higher among moderately productive environments. As time-since-burn increased the inter- and intra-specific variation of flower volume was higher for all and common species (Figure 6A, 6C, 6E, 6G). For fire severities, unburned areas had the greatest inter- and intra-specific flower volume variation among all and common species (Figure 6B, 6D, 6F, 6H). For SLA, the inter- and intra-specific variation among all and common species (Figure 7) was higher among moderately productive environments. As time-since-burn increased the inter- and intra-specific variation of SLA was higher for all and common species (Figure 7A, 7C, 7E, 7G). For fire severities, unburned areas had the greatest inter- and intra-specific SLA variation among all and common species (Figure 7B, 7D, 7F, 7H).

Bee Functional Traits

In total, 6374 individuals from 293 bee species (Table 9) traits (Table 2) were measured (see Appendix for species and abundance lists). All species pertains to individuals measured in the study ranging from one to 87 individuals per species. Among Helena and Paradise Valley there were 106 species that were observed and measured (i.e. common species) with 4388 total bee individual measurements. Common species measurements ranged from one to 87 individuals per species measured.

Functional Trait Mean Comparison

Across all and common species, there were no differences in mean IT distance between location, time-since-burn, and severity (Tables 5 & 6; Figure 8). Mean IT distance was observed to be larger in female than male bees and slightly increased throughout the growing season (Tables 5 & 6).

Location and sex had the greatest effect on nesting behavior presence across all (Table 5) and common (Table 6) species measured. Across all (Figure 9A) and common (Figure 9D) species, bees in Helena were dominantly ground and cavity nesters, while in Paradise Valley bees were mostly generalist nesters and above ground nesters. Across all and common species, recent burns consisted of primarily above ground nesters, unburned areas consisted of cavity nesters (Figure 9B & 9E), and older burns were dominated by ground nesters across all species (Figure 9B). Across common species, generalist nesters dominated older burns (Figure 9E). High-severity fires were dominated by above ground nesting behavior for all and common species (Figure 9C & 9F), while mixed-severity

fires consisted of cavity nesting bees across all species (Figure 9C) and generalist nesting bees across common species (Figure 9F). Nesting behavior across all and common species varied with about 57-60% cavity nesters, 20-25% ground nesters, 11-14% above ground nesters, and 6-7% generalists.

Location, time-since-burn, and fire severity had no effect on bee sociality presence across all (Table 5) and common (Table 6) species measured. Each type of sociality listed here was present among all locations, time-since-burn, and fire severities. Helena bee sociality was primarily solitary and social across all species (Figure 10A) with more eusocial than social bees across common species (Figure 10D). Across all (Figure 10A) and common species (Figure 10D), Paradise Valley was dominated by eusocial and social bees. Across all and common species, recent burns mostly had eusocial bees, solitary bees were prevalent in unburned areas (Figure 10B & 10E), and older burns were dominated by social bees across all species (Figure 10B) and solitary bees across common species (Figure 10E). Across all species, high-severity fires were dominated by social bees, while mixed-severity fires mostly had eusocial bees (Figure 10C). Across common species, high-severity fires were dominated by solitary bees, while mixed-severity fires mostly had social bees (Figure 10F). The sociality across all and common species varied with about 45-54% solitary, 32-42% eusocial, and 13-14% social.

Inter- and Intra-specific Trait Variation for All and Common Species

Increased productivity had higher the inter- and intra-specific IT distance variation among all and common species (Figure 11). As time-since-burn increased the inter- and intra-specific variation of IT was higher for all and common species (Figure

11A, 11C, 11E, 11G). For fire severities, unburned areas had the greatest inter- and intra-specific IT variation among all and common species (Figure 11B, 11D, 11F, 11H).

Table 4: Number of Plant Species and Individuals Collected. The number of plant species and individuals measured in Helena, Paradise Valley, and for species observed in both Helena and Paradise Valley (i.e. common) across time-since-burn and fire severities.

Overall plant species and individuals measured				
Location			# of Individuals	# of Species
Helena	All observed species		2737	57
Paradise Valley	All observed species		2427	44
Helena & Paradise Valley	Commonly observed species		1857	17
Plant species and individuals measured among various time-since-burn & severity				
Location	Time-Since-Burn	Severity	# of Individuals	# of Species
Helena	-	Unburned	467	29
Helena	New	Mixed	841	47
Helena	New	High	875	38
Helena	Old	High	554	21
Paradise Valley	-	Unburned	241	13
Paradise Valley	New	Mixed	792	29
Paradise Valley	New	High	763	35
Paradise Valley	Old	High	631	28

Table 5: Plant and Bee Model Results for All Species. The linear mixed-effects model (numeric traits) and multinomial log-linear model (categorical traits) ANOVA results of functional trait values for all plant and bee species observed and measured. Bolded p-values indicate significant effects at $\alpha < 0.05$.

Trait	Variable	X²	p-value	df
<i>Plant Height</i>	Location	6.939	0.0084	1
	Time-Since-Burn	142.7890	<0.0001	2
	Severity	92.742	<0.0001	2
	Sampling date	43.502	<0.0001	1
<i>Inflorescence Type</i>	Location	32.2	0.0002	9
	Time-Since-Burn	25.3	0.1177	18
	Severity	20.0	0.3316	18
<i>Flower Number</i>	Location	56.363	<0.0001	1
	Time-Since-Burn	102.891	<0.0001	2
	Severity	115.665	<0.0001	2
	Sampling Date	17.726	<0.0001	1
<i>Flower Symmetry</i>	Location	4.2	0.1248	2
	Time-Since-Burn	13.6	0.0085	4
	Severity	11.8	0.0186	4
<i>Flower Volume</i>	Location	20.121	<0.0001	1
	Time-Since-Burn	40.855	<0.0001	2
	Severity	12.5691	0.0019	2
	Sampling Date	75.297	<0.0001	1
<i>Specific Leaf Area</i>	Location	188.48	<0.0001	1
	Time-Since-Burn	399.37	<0.0001	2
	Severity	185.4128	<0.0001	2
	Sampling Date	4.5235	0.0334	1
<i>Intertegular Distance</i>	Location	1.2191	0.2695	1
	Time-Since-Burn	4.5103	0.1049	2
	Severity	1.1850	0.5529	2
	Sampling Date	15.6882	<0.0001	1
	Sex	738.6526	<0.0001	1
<i>Nesting Behavior</i>	Location	164.0	<0.0001	3
	Time-Since-Burn	10.7	0.09762	6
	Severity	4.6	0.59453	6
	Sex	347.3	<0.0001	3
<i>Sociality</i>	Location	0	1.0000	2
	Time-Since-Burn	0	1.0000	4
	Severity	0	1.0000	4
	Sex	0	1.0000	2

Table 6: Plant and Bee Model Results for Common Species. The linear mixed effects model (numeric traits) and multinomial log-linear model (categorical traits) ANOVA results of functional trait values for plant and bee species observed and measured in both Helena and Paradise Valley (i.e. common species). Bolded p-values indicate significant effects at $\alpha < 0.05$.

Trait	Variable	X²	p-value	df
<i>Plant Height</i>	Location	12.341	0.0004	1
	Time-Since-Burn	49.3196	<0.0001	2
	Severity	63.645	<0.0001	2
	Sampling Date	36.306	<0.0001	1
<i>Inflorescence Type</i>	Location	17.4	0.0078	6
	Time-Since-Burn	30.2	0.0026	12
	Severity	7.1	0.8534	12
<i>Flower Number</i>	Location	30.944	<0.0001	1
	Time-Since-Burn	46.841	<0.0001	2
	Severity	43.100	<0.0001	2
	Sampling Date	35.375	<0.0001	1
<i>Flower Symmetry</i>	Location	12.09	0.0005	1
	Time-Since-Burn	32.39	<0.0001	2
	Severity	28.65	<0.0001	2
<i>Flower Volume</i>	Location	3.3649	0.0666	1
	Time-Since-Burn	8.1404	0.0171	2
	Severity	7.4078	0.0246	2
	Sampling Date	9.0617	0.0026	1
<i>Specific Leaf Area</i>	Location	101.8152	<0.0001	1
	Time-Since-Burn	106.2133	<0.0001	2
	Severity	89.051	<0.0001	2
	Sampling Date	1.5355	0.2153	1
<i>Intertegular Distance</i>	Location	0.8345	0.3610	1
	Time-Since-Burn	0.8765	0.6452	2
	Severity	2.1766	0.3368	2
	Sampling Date	3.6291	0.05678	1
	Sex	536.8503	<0.0001	1
<i>Nesting Behavior</i>	Location	157.3	<0.0001	3
	Time-Since-Burn	2.6	0.8525	6
	Severity	4.5	0.6122	6
	Sex	304.2	<0.0001	3
<i>Sociality</i>	Location	0	1.0000	2
	Time-Since-Burn	0	1.0000	4
	Severity	0	1.0000	4
	Sex	0	1.0000	2

Table 7: Plant Trait Variation Results. The MANCOVA results of the main and interactive effects of location, time-since-burn, and fire severity for all and common plant species. Bolded p-values indicate significant effects at $\alpha < 0.05$.

Source	F	df	P
<i>All species : Inter-specific</i>			
Whole Model	4361.6	4,1106	< 0.0001
Location	29.1	4,1106	< 0.0001
Time-Since-Burn	33.8	8,2214	< 0.0001
Fire Severity	5.5	4,1106	0.0002
Time-Since-Burn x Location	8.8	8,2214	< 0.0001
Fire Severity x Location	17.0	4,1106	< 0.0001
<i>All species : Intra-specific</i>			
Whole Model	11111.2	4,832	< 0.0001
Location	91.4	4,832	< 0.0001
Time-Since-Burn	16.9	8,1666	< 0.0001
Fire Severity	5.7	4,832	0.0001
Time-Since-Burn x Location	4.0	8,1666	< 0.0001
Fire Severity x Location	1.6	4,832	0.1613
<i>Common species : Inter-specific</i>			
Whole Model	1783.58	4,393	< 0.0001
Location	21.49	4,393	< 0.0001
Time-Since-Burn	9.64	8,788	< 0.0001
Fire Severity	1.14	4,393	0.3361
Time-Since-Burn x Location	6.60	8,788	< 0.0001
Fire Severity x Location	5.69	4,393	0.0002
<i>Common species : Intra-specific</i>			
Whole Model	3509.3	4,287	< 0.0001
Location	1.7	4,287	0.1611
Time-Since-Burn	3.9	8,576	0.0002
Fire Severity	0.7	4,287	0.6263
Time-Since-Burn x Location	3.0	8,576	0.0025
Fire Severity x Location	0.7	4,287	0.5713

Table 8: Plant Trait Variation Results: Univariate Analysis. The univariate two-way ANOVA results testing the main and interactive effects of location, time-since-burn, and fire severity on the inter- and intra-specific trait variation for each plant numeric functional trait. Bolded p-values indicate significant effects at $\alpha < 0.05$.

Source	Plant Height			Flower Number			Flower Volume			Specific Leaf Area		
	F	df	P	F	df	P	F	df	P	F	df	P
<i>All species: Inter-specific</i>												
Location	7.24	1,1109	0.0072	14.20	1,1109	0.0002	27.77	1,1109	<0.0001	27.08	1,1109	<0.0001
Time-Since-Burn	26.59	2,1109	<0.0001	15.02	2,1109	<0.0001	27.30	2,1109	<0.0001	65.78	2,1109	<0.0001
Fire Severity	0.88	1,1109	0.3484	2.70	1,1109	0.1008	0.79	1,1109	0.375	11.70	1,1109	0.0006
Time-Since-Burn x Location	4.34	2,1109	0.0132	2.26	2,1109	0.1054	13.68	2,1109	<0.0001	27.92	2,1109	<0.0001
Fire Severity x Location	20.15	1,1109	<0.0001	23.21	1,1109	<0.0001	1.65	1,1109	0.199	3.75	1,1109	0.0530
<i>All species: Intra-specific</i>												
Location	108.5	1,849	<0.0001	52.74	1,930	<0.0001	18.31	1,849	<0.0001	96.26	1,840	<0.0001
Time-Since-Burn	9.52	2,849	<0.0001	9.95	2,930	<0.0001	37.16	2,849	<0.0001	46.31	2,840	<0.0001
Fire Severity	1.12	1,849	0.2910	0.71	1,930	0.3984	9.62	1,849	0.0020	2.26	1,840	0.1330
Time-Since-Burn x Location	13.30	2,849	<0.0001	4.65	2,930	0.0098	6.81	2,849	0.0012	10.31	2,840	<0.0001
Fire Severity x Location	0.69	1,849	0.4050	0.05	1,930	0.8274	0.40	1,849	0.5277	1.06	1,840	0.3040
<i>Common species: Inter-specific</i>												
Location	54.55	1,396	<0.0001	74.55	1,396	<0.0001	4.81	1,396	0.0289	8.67	1,396	0.0034
Time-Since-Burn	10.56	2,396	<0.0001	6.73	2,396	0.0013	10.13	2,396	<0.0001	14.35	2,396	<0.0001
Fire Severity	1.15	1,396	0.2834	0.75	1,396	0.3884	0.11	1,396	0.7377	1.40	1,396	0.2375
Time-Since-Burn x Location	4.23	2,396	0.0153	6.23	2,396	0.0022	10.31	2,396	<0.0001	12.63	2,396	<0.0001
Fire Severity x Location	0.006	1,396	0.9407	15.01	1,396	0.0001	0.07	1,396	0.7978	2.15	1,396	0.1435
<i>Common species: Intra-specific</i>												
Location	14.84	1,386	0.0001	6.74	1,386	0.0098	11.82	1,387	0.0007	5.65	1,290	0.0182
Time-Since-Burn	0.32	2,386	0.7231	0.07	2,386	0.9361	2.24	2,387	0.1083	7.96	2,290	0.0004
Fire Severity	0.40	1,386	0.5258	1.82	1,386	0.1787	0.84	1,387	0.3593	0.54	1,290	0.4636
Time-Since-Burn x Location	0.53	2,386	0.5915	2.26	2,386	0.1063	0.001	2,387	0.9993	9.50	2,290	0.0001
Fire Severity x Location	0.34	1,386	0.5619	0.38	1,386	0.5401	0.30	1,387	0.5865	0.48	1,290	0.4896

Table 9: Number of Bee Species and Individuals Measured. The number of bee species and individuals measured in Helena, Paradise Valley, and for species observed in both Helena and Paradise Valley (i.e. common) across time-since-burn and fire severities.

Overall bee species and individuals measured				
Location			# of Individuals	# of Species
Helena	All observed species		4476	257
Paradise Valley	All observed species		1898	142
Helena & Paradise Valley	Commonly observed species		4388	106
Bee species and individuals measured among various time-since-burn & severity				
Location	Time-Since-Burn	Severity	# of Individuals	# of Species
Helena	-	Unburned	590	106
Helena	New	Mixed	1414	185
Helena	New	High	1696	167
Helena	Old	High	776	105
Paradise Valley	-	Unburned	47	20
Paradise Valley	New	Mixed	680	100
Paradise Valley	New	High	678	86
Paradise Valley	Old	High	493	86

Table 10: Bee Trait Variation Results. The univariate two-way ANOVA results testing the main and interactive effects of location, time-since-burn, and fire severity on the inter- and intra-specific functional trait variation of bee intertegular distance. Bolded p-values indicate significant effects at $\alpha < 0.05$.

Source	Intertegular Distance		
	F	df	P
<i>All species : Inter-specific</i>			
Location	19.69	1,2818	<0.0001
Time-Since-Burn	75.14	2,2818	<0.0001
Fire Severity	7.36	1,2818	0.0067
Time-Since-Burn x Location	6.12	2,2818	0.0022
Fire Severity x Location	0.49	1,2818	0.4843
<i>All species : Intra-specific</i>			
Location	10.08	1,2789	0.0015
Time-Since-Burn	1.36	2,2789	0.2570
Fire Severity	1.18	1,2789	0.2776
Time-Since-Burn x Location	0.75	2,2789	0.4704
Fire Severity x Location	0.67	1,2789	0.4117
<i>Common species : Inter-specific</i>			
Location	33.20	1,1952	<0.0001
Time-Since-Burn	12.74	2,1952	<0.0001
Fire Severity	1.72	1,1952	0.1890
Time-Since-Burn x Location	3.21	2,1952	0.404
Fire Severity x Location	0.03	1,1952	0.8577
<i>Common species : Intra-specific</i>			
Location	17.75	1,157	<0.0001
Time-Since-Burn	3.26	2,157	0.0411
Fire Severity	0.01	1,157	0.9066
Time-Since-Burn x Location	1.71	1,157	0.1934
Fire Severity x Location	1.10	1,157	0.2952

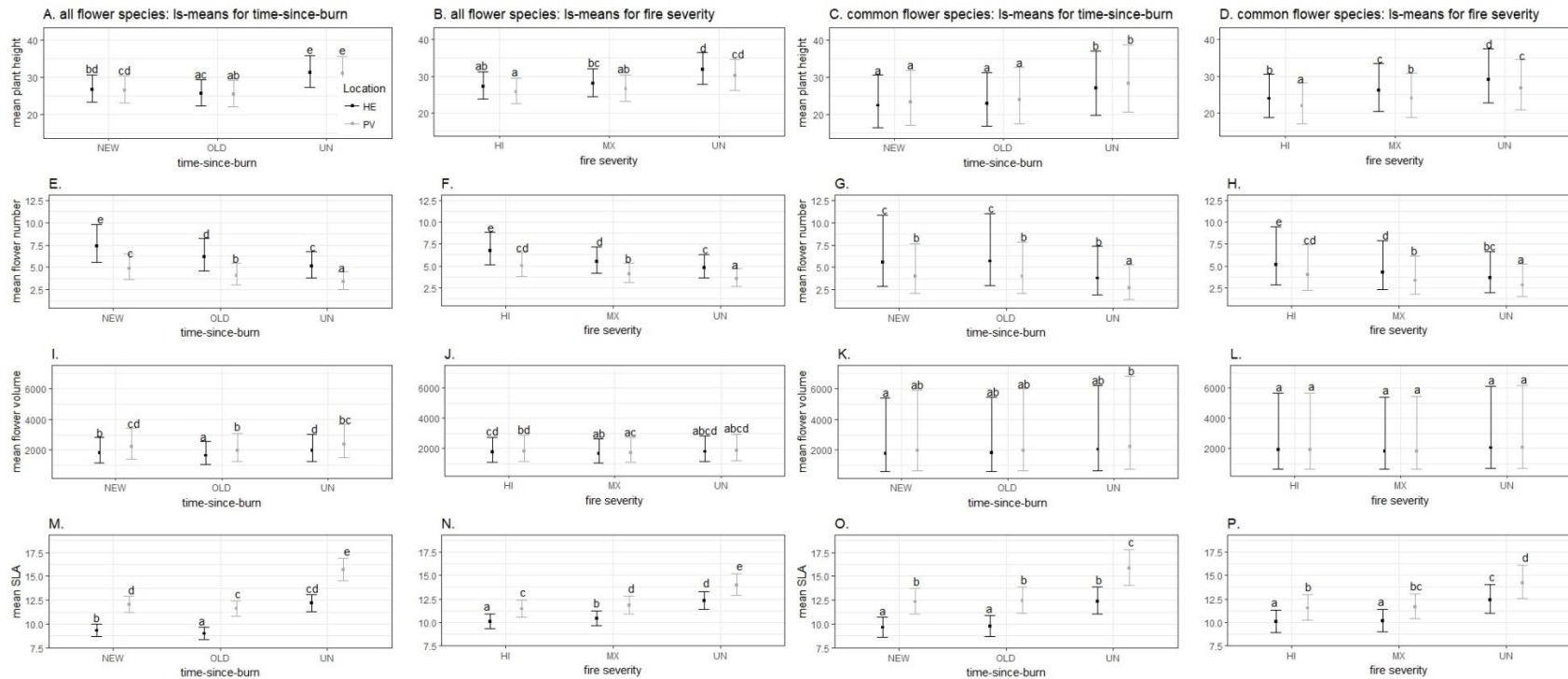


Figure 1: Mean Plant Trait Values. The linear mixed-effects ls-means results of mean trait values among all and common plant species across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for plant height (A-D), flower number (E-H), flower volume (I-L), and specific leaf area (M-P). The linear mixed-effects model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

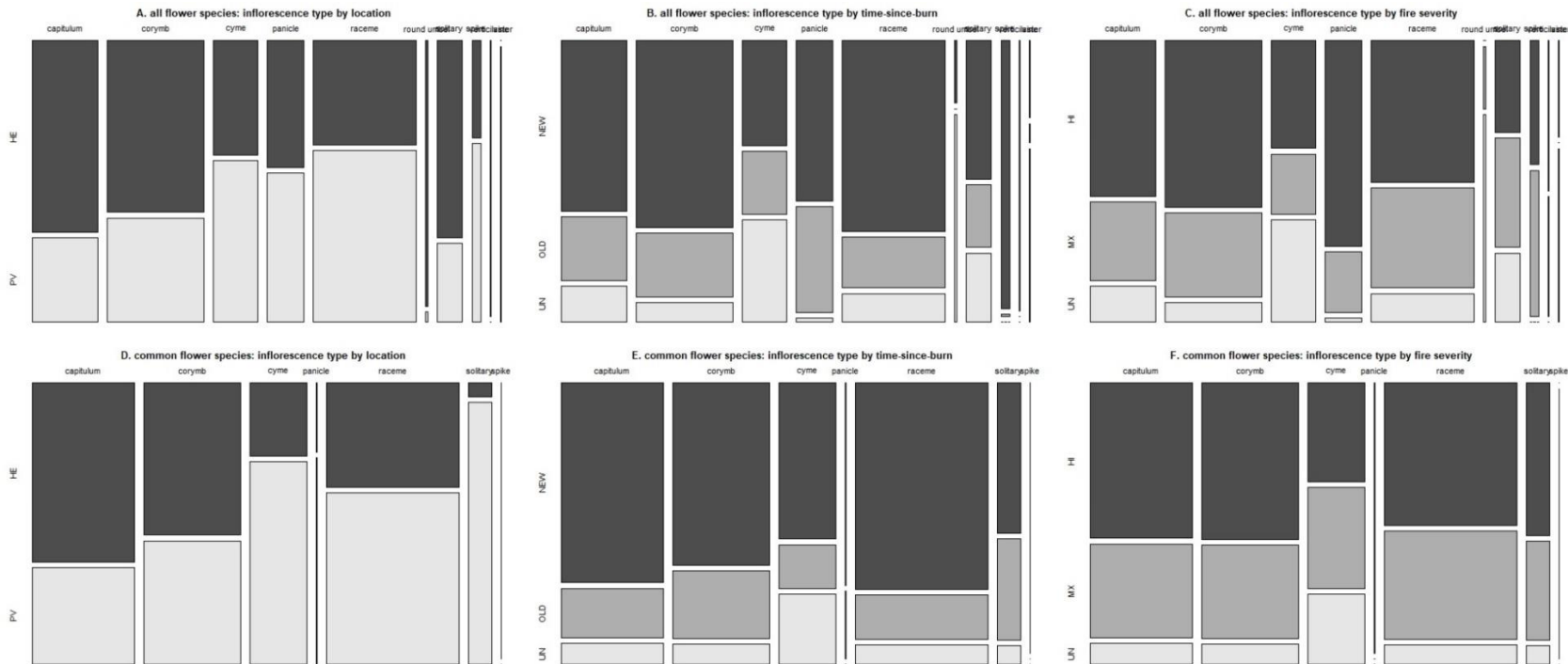


Figure 2: Inflorescence Type Distribution. The inflorescence type distribution among all and common plant species across location (i.e. Helena and Paradise Valley: A & D), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un): B & E), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un): C & F). The width of the blocks in this mosaic plot represent the proportion of each inflorescence type among each location, time-since-burn, and fire severity. The multinomial log-linear model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

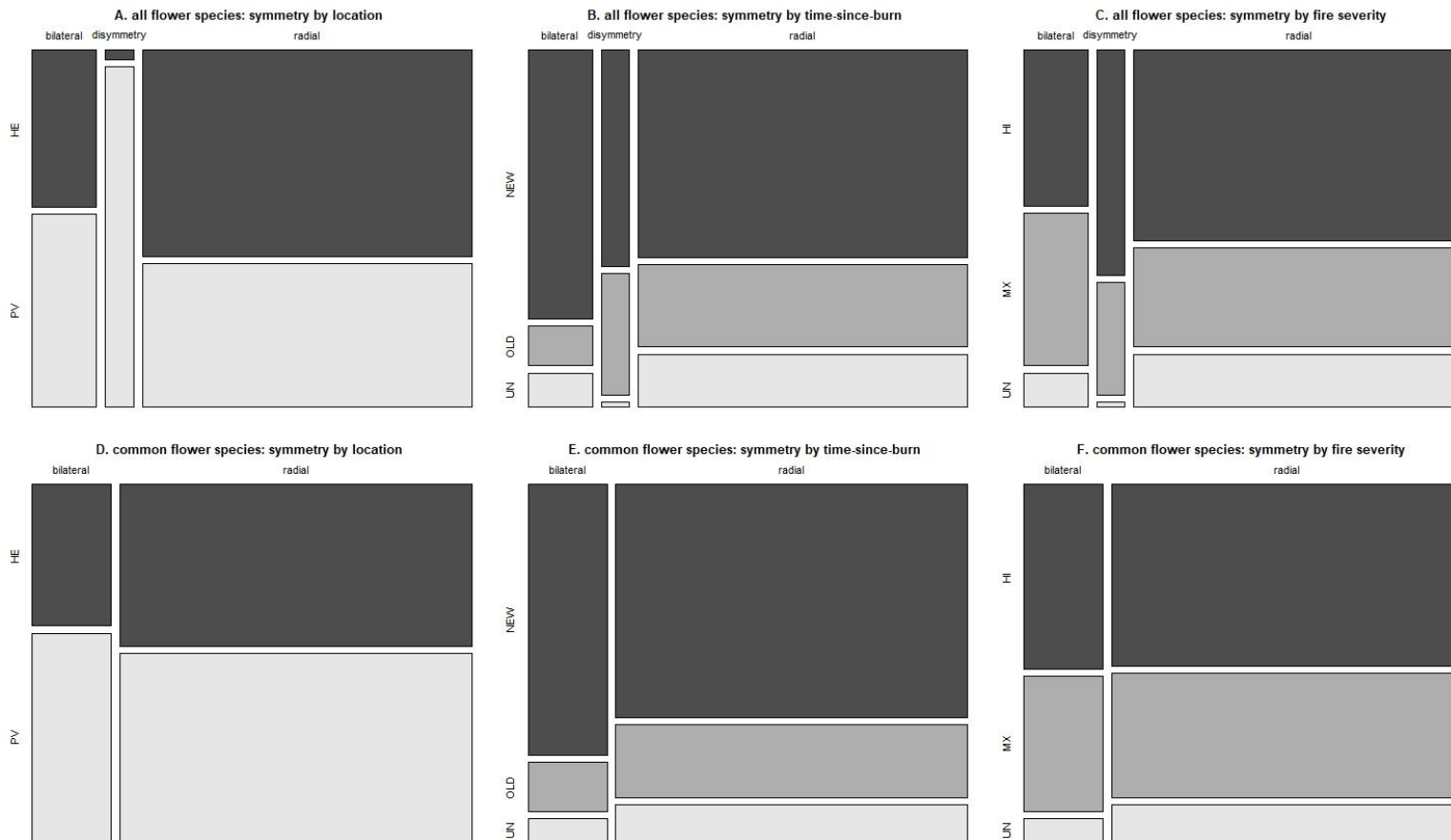


Figure 3: Flower Symmetry Distribution. The flower symmetry distribution among all and common plant species across location (i.e. Helena and Paradise Valley: A & D), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un): B & E), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un): C & F). The width of the blocks in this mosaic plot represent the proportion of each type of flower symmetry among each location, time-since-burn, and fire severity. The multinomial log-linear model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

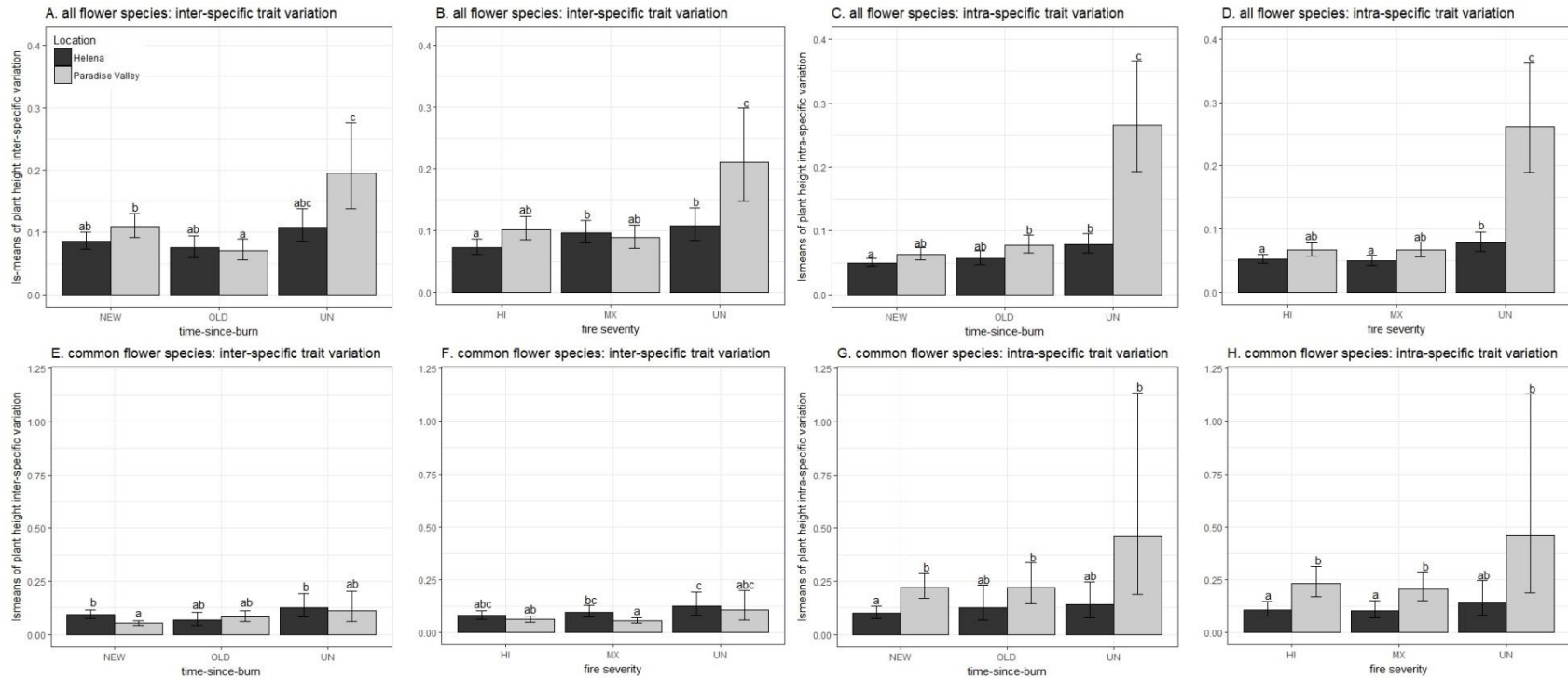


Figure 4: Plant Height Variation. The two-way ANOVA is-means results of plant height variation across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for the (A) inter-specific variation across all species among time-since burn, (B) inter-specific variation across all species among fire severity, (C) intra-specific variation across all species among time-since burn, (D) intra-specific variation across all species among fire severity, (E) inter-specific variation across common species among time-since burn, (F) inter-specific variation across common species among fire severity, (G) intra-specific variation across common species among time-since burn, and (H) intra-specific variation across common species among fire severity. The trait variation ANOVA results for all and common plant species can be found in Table 8.

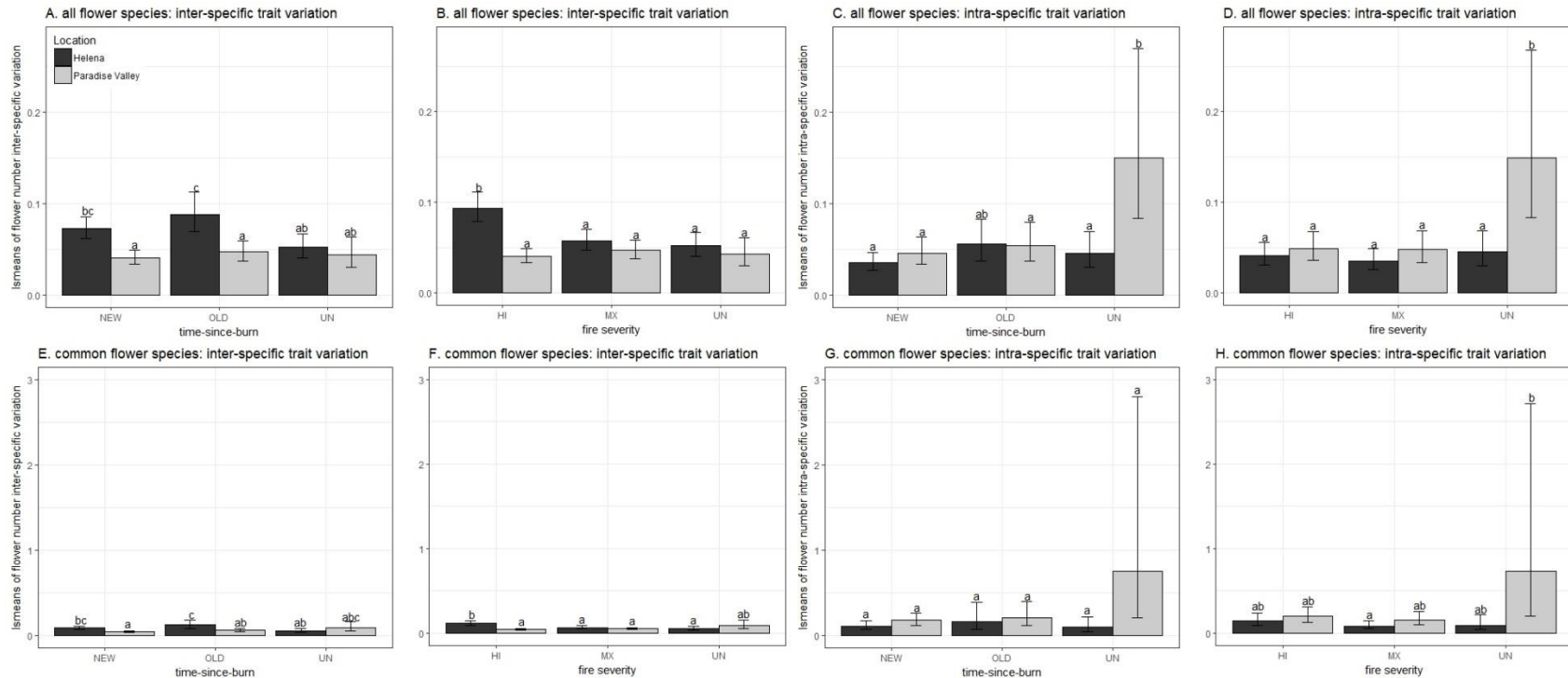


Figure 5: Flower Number Variation. The two-way ANOVA is-means results of flower number variation across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for the (A) inter-specific variation across all species among time-since burn, (B) inter-specific variation across all species among fire severity, (C) intra-specific variation across all species among time-since burn, (D) intra-specific variation across all species among fire severity, (E) inter-specific variation across common species among time-since burn, (F) inter-specific variation across common species among fire severity, (G) intra-specific variation across common species among time-since burn, and (H) intra-specific variation across common species among fire severity. The trait variation ANOVA results for all and common plant species can be found in Table 8.

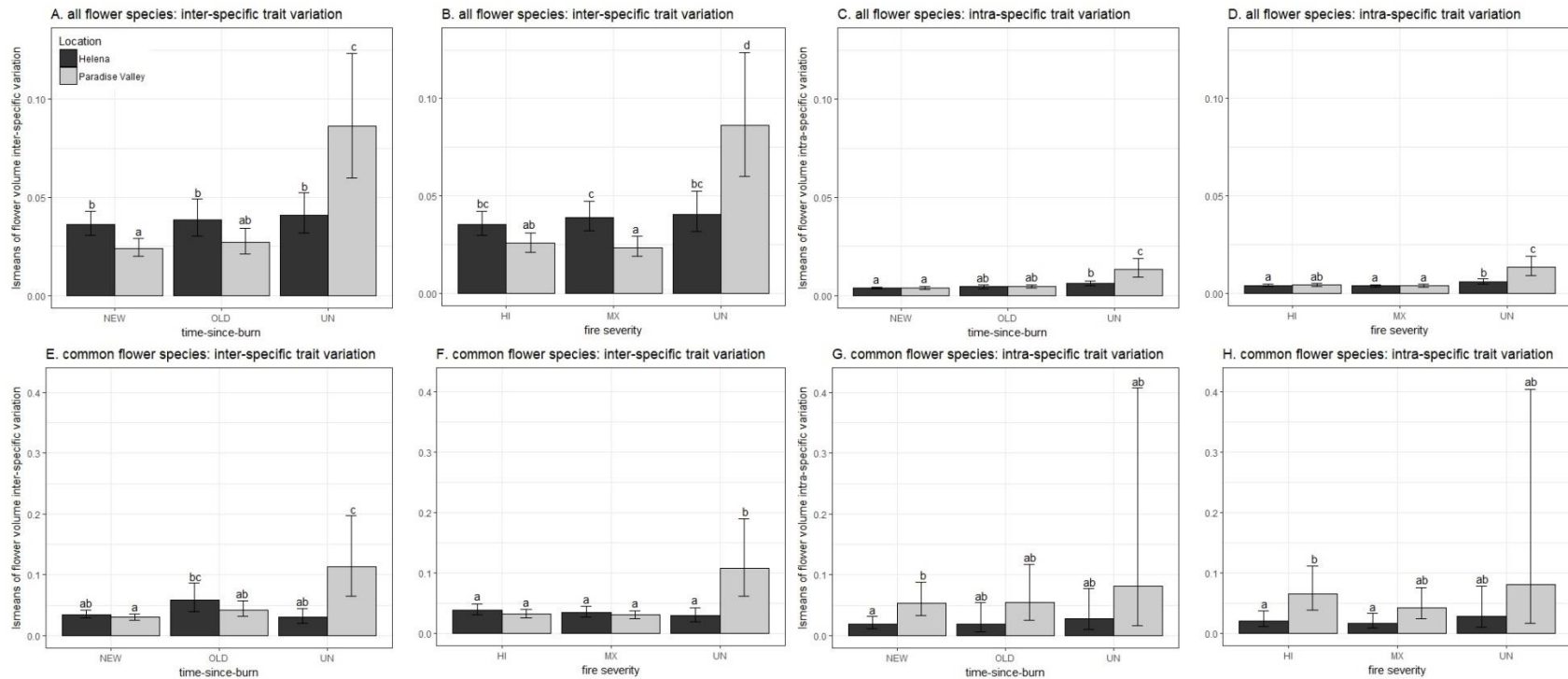


Figure 6: Flower Volume Variation. The two-way ANOVA Is-means results of flower volume variation across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for the (A) inter-specific variation across all species among time-since burn, (B) inter-specific variation across all species among fire severity, (C) intra-specific variation across all species among time-since burn, (D) intra-specific variation across all species among fire severity, (E) inter-specific variation across common species among time-since burn, (F) inter-specific variation across common species among fire severity, (G) intra-specific variation across common species among time-since burn, and (H) intra-specific variation across common species among fire severity. The trait variation ANOVA results for all and common plant species can be found in Table 8.

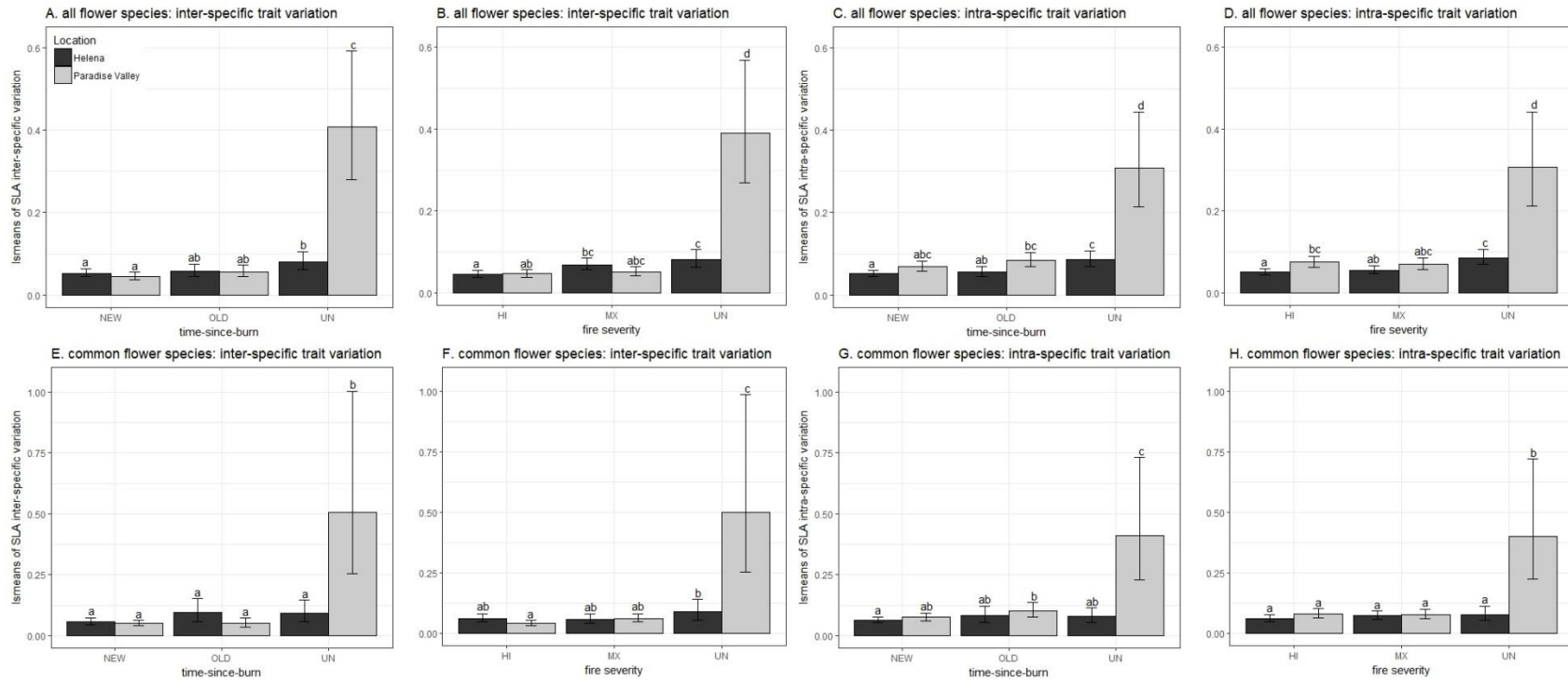


Figure 7: Specific Leaf Area Variation. The two-way ANOVA Is-means results of specific leaf area variation across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for the (A) inter-specific variation across all species among time-since burn, (B) inter-specific variation across all species among fire severity, (C) intra-specific variation across all species among time-since burn, (D) intra-specific variation across all species among fire severity, (E) inter-specific variation across common species among time-since burn, (F) inter-specific variation across common species among fire severity, (G) intra-specific variation across common species among time-since burn, and (H) intra-specific variation across common species among fire severity. The trait variation ANOVA results for all and common plant species can be found in Table 8.

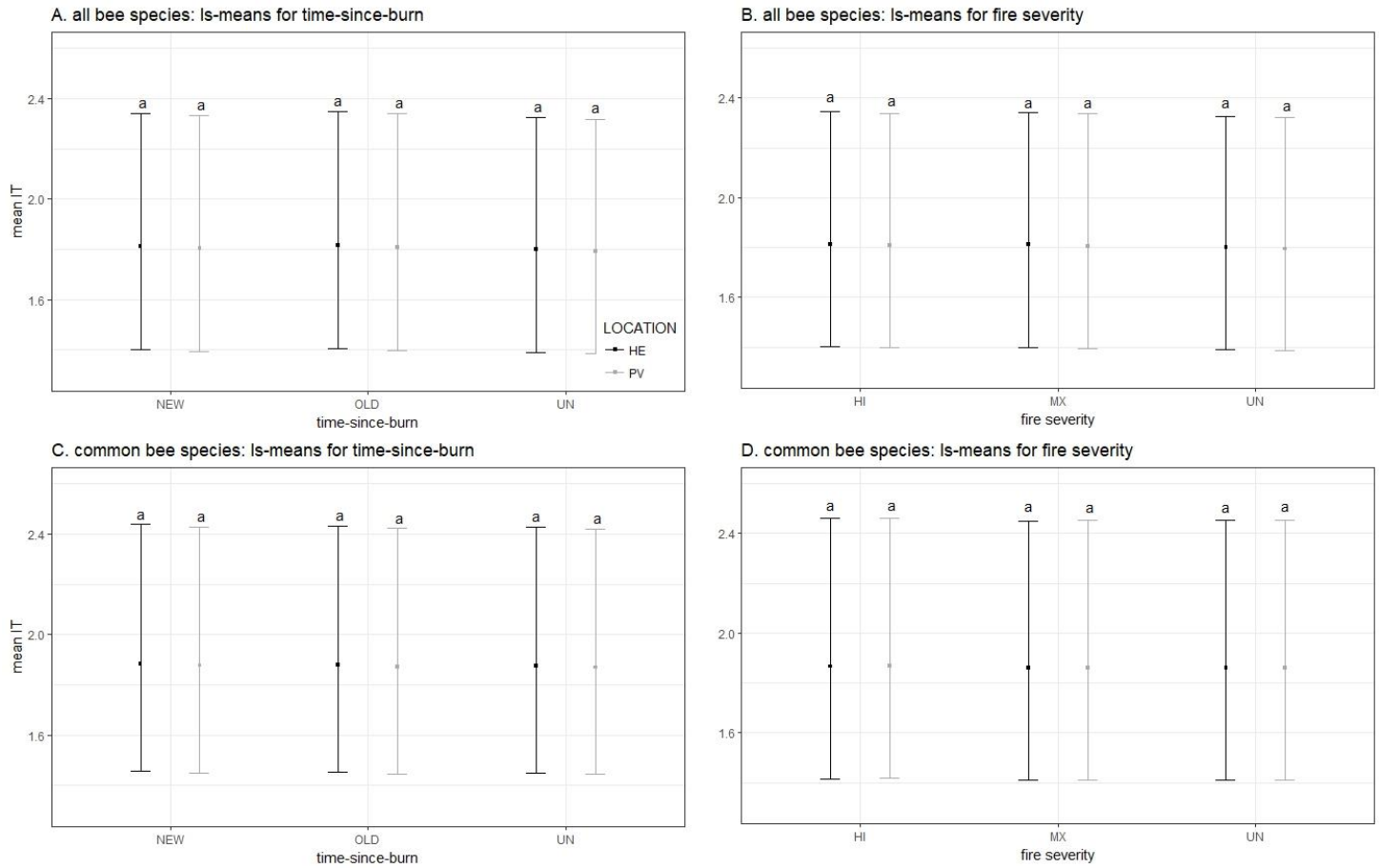


Figure 8: Mean Bee Trait Values. The linear mixed-effects ls-means results of mean intertegular distance across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for (A) all species among location and time-since-burn, (B) all species among location and fire severity, (C) common species among location and time-since-burn, and (D) common species among location and fire-severity. The linear mixed-effects model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

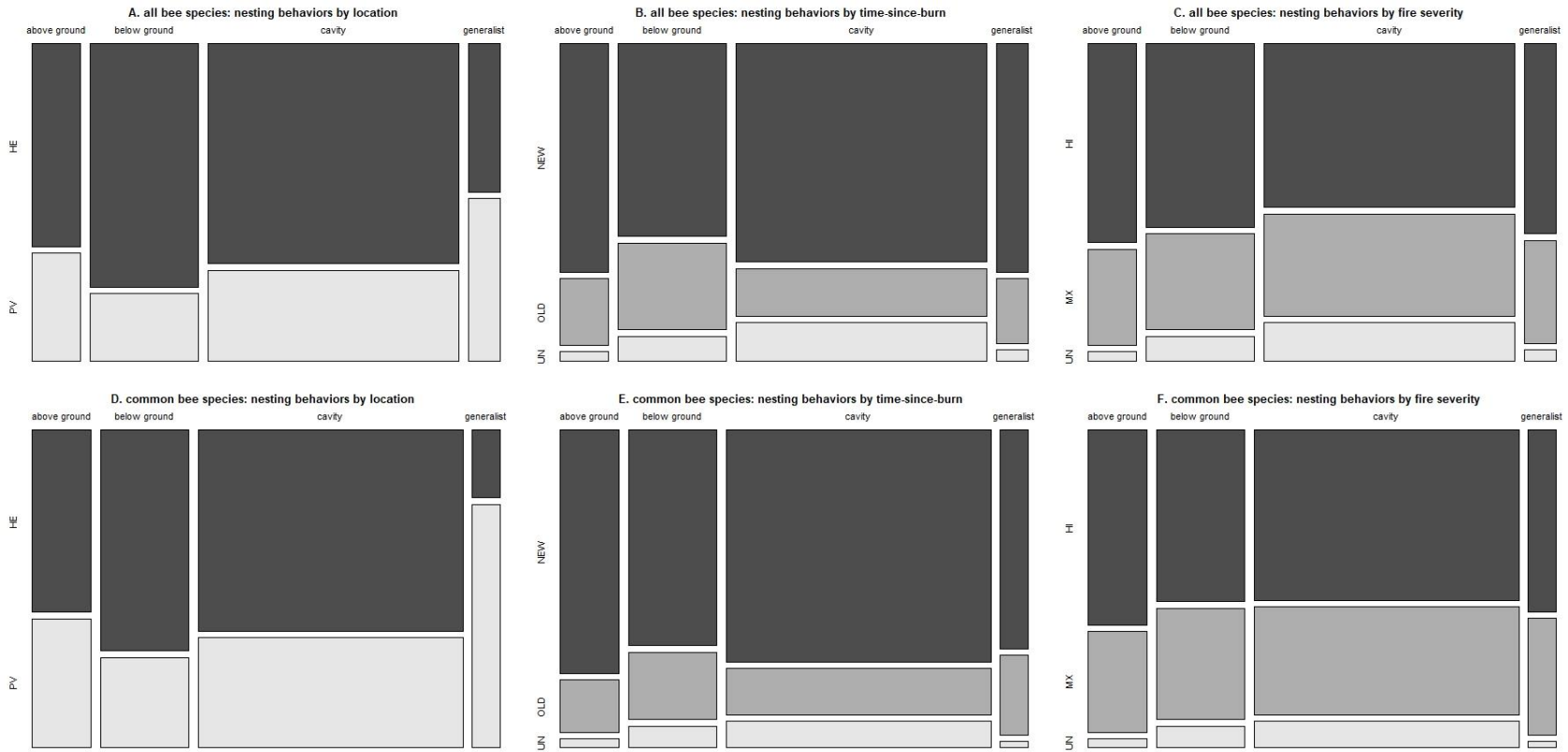


Figure 9: Nesting Behavior Distribution. The nesting behavior distribution among all and common species across location (i.e. Helena and Paradise Valley: A & D), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un): B & E), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un): C & F). The width of the blocks in this mosaic plot represent the proportion of each type of bee nesting behavior among each location, time-since-burn, and fire severity. The multinomial log-linear model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

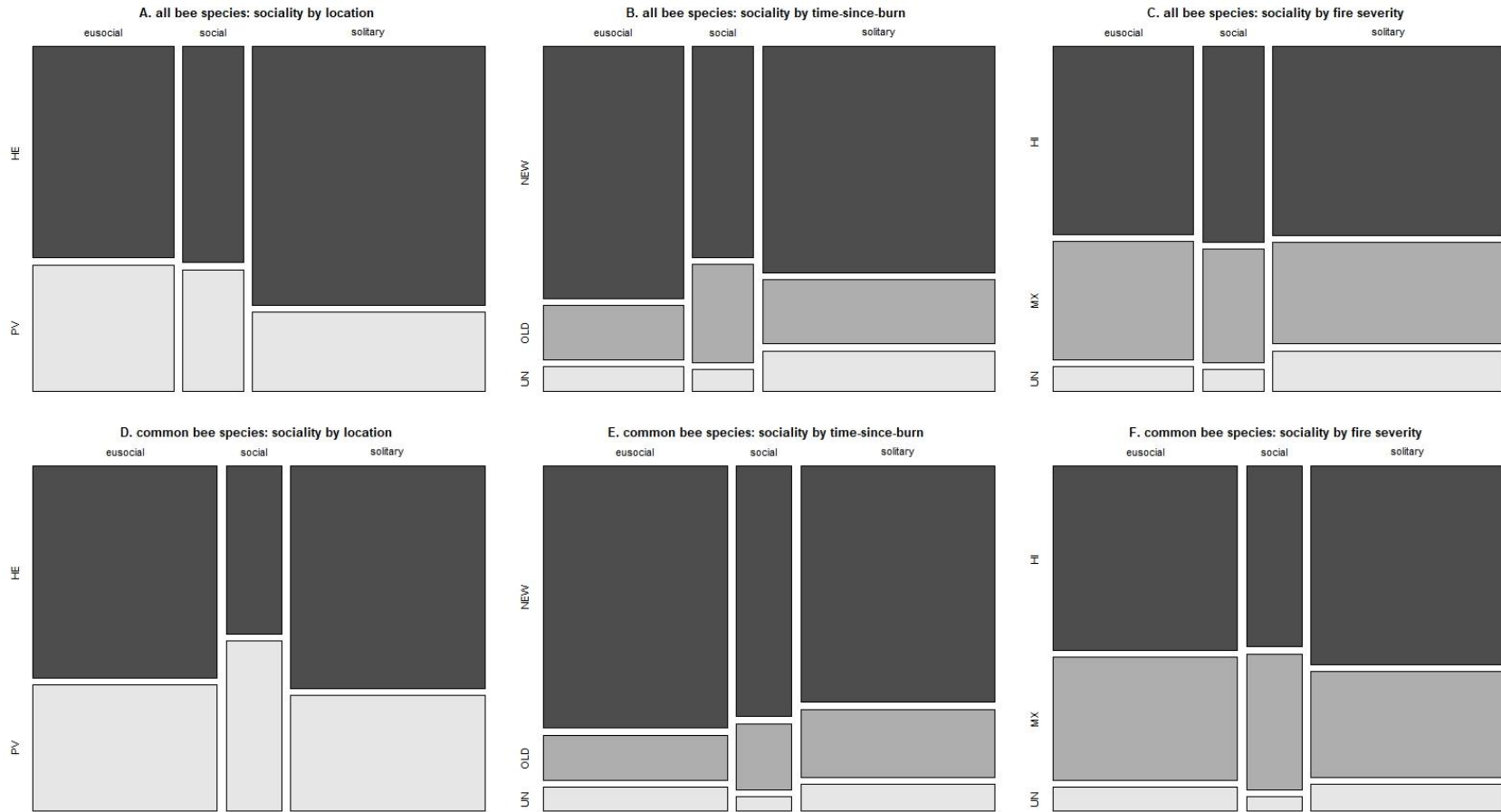


Figure 10: Sociality Distribution. The sociality distribution among all and common species across location (i.e. Helena and Paradise Valley: A & D), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un): B & E), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un): C & F). The width of the blocks in this mosaic plot represent the proportion of each type of bee sociality among each location, time-since-burn, and fire severity. The multinomial log-linear model ANOVA results for all species can be found in Table 5 and the results common species can be found in Table 6.

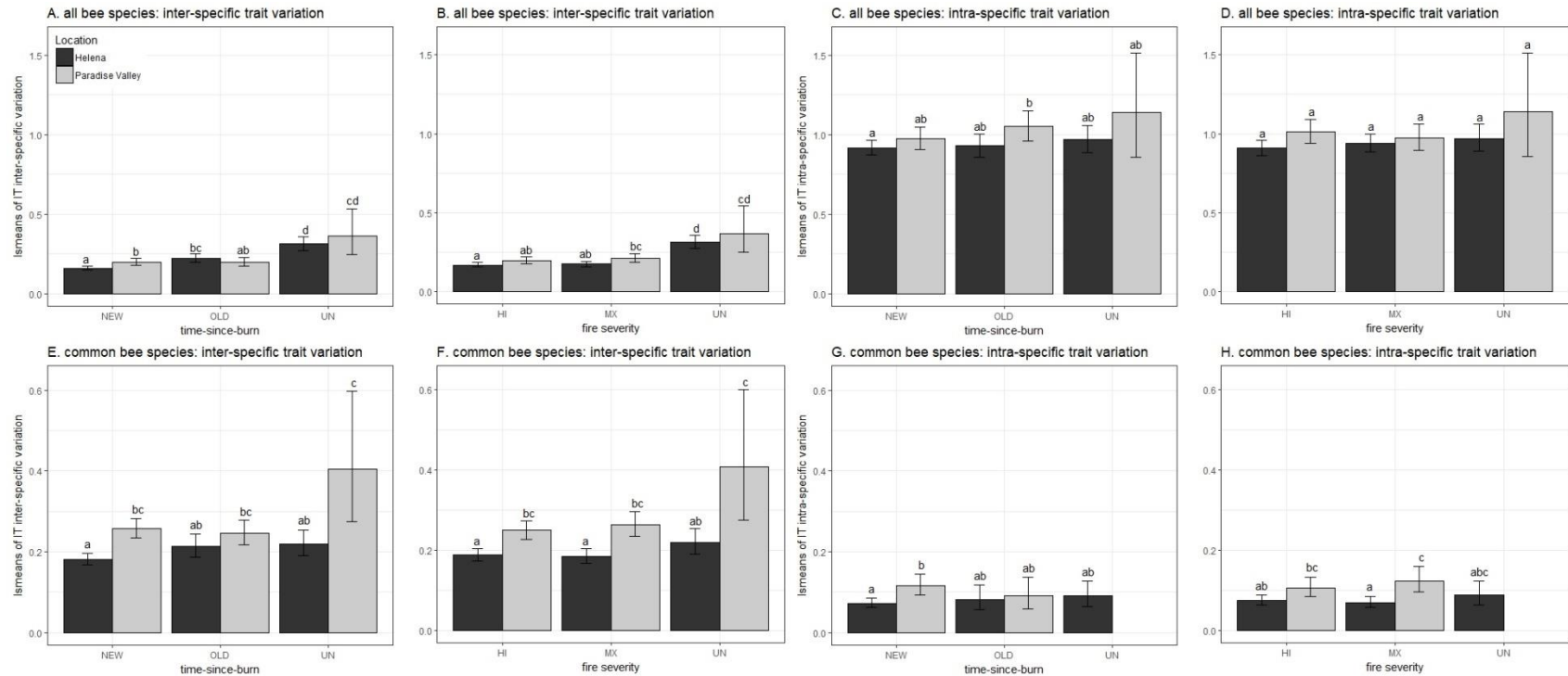


Figure 11: Intertegular Distance Variation. The two-way ANOVA ls-means results of intertegular distance variation across location (i.e. Helena and Paradise Valley), time-since-burn (i.e. recent burns (new), older burns (old), and unburned areas (un)), and fire severity (i.e. high-severity (hi), mixed-severity (mx), and unburned areas (un)) for the (A) inter-specific variation across all species among time-since burn, (B) inter-specific variation across all species among fire severity, (C) intra-specific variation across all species among time-since burn, (D) intra-specific variation across all species among fire severity, (E) inter-specific variation across common species among time-since burn, (F) inter-specific variation across common species among fire severity, (G) intra-specific variation across common species among time-since burn, and (H) intra-specific variation across common species among fire severity. The trait variation ANOVA results for all and common bee species can be found in Table 10.

DISCUSSION

The aim of this study was to understand how productivity, time-since-burn, and fire severity affected the mean functional trait values and the inter- and intra-specific functional variation of plant and bee traits involved in plant-bee interactions. Our results show that productivity and time-since-burn affected the mean trait values of flowering plant more than the mean trait values of bees, with fire severity having little effect on mean trait values on either plants or bees. In addition, older burns, unburned areas, and moderately productive environments had higher functional trait variation of flowering plants and bees, while high-severity fires had decreased variation relative to mixed-severity fires. Generally, unburned areas in moderately productive environments had the greatest functional trait variation and mean trait values compared to all other areas investigated.

Our results supported our hypothesis that the mean values of some plant traits (i.e., plant height and SLA) would be higher in unburned areas, while the mean values of other plant traits (i.e., flower number and flower volume) would be higher in recent burns, indicating that areas affected by fire or not affected select certain phenotypic trait expressions (i.e. more flowers in recent burns and larger leaves in unburned areas) better suited for the environmental conditions (Bond & Keeley, 2005). For example, unburned areas had higher specific leaf areas to capture light maximizing photosynthetic rates (Cornelissen et al., 2003) among unburned areas that had dense canopy cover and greater vegetation crowding. The mean trait value trends of increased mean trait values in unburned areas was similar across plant traits with the exception of mean flower number,

suggesting that for plant height, flower volume, and specific leaf area higher mean values are selected for in unburned areas. This could be the result of plants expending energy to grow to capture light to photosynthesize and increased water retention found among unburned areas with more canopy cover. Productivity, time-since-burn, and fire severity did not affect the mean trait values of bees, suggesting that the dispersal abilities of bees allow them to ward off the habitat filtering effects of wildfires (Weiher & Keddy, 2004). These patterns suggest that mean trait values may potentially affect plant-bee interactions because wildfire appears to affect plant trait means more than bee trait means creating a disconnect between the two trophic levels.

There was support for our hypothesis that the inter- and intra-specific functional trait variation of plants would be higher in moderately productive environments, suggesting that trait variation is higher as productivity increases (Zhang et al., 2012) suggesting phylogenetic overdispersion patterns among areas of greater productivity resulting from interspecific competition or the co-occurrence of distantly related plant species among these areas (Ndiribe, Salamin, & Guisan, 2013). The results of our study do support our hypothesis that the inter- and intra-specific functional trait variation of plants would be greater among older burns and unburned areas and that older burns would have increased intra-specific variation among bees, suggesting trait variation is higher as time-since-burn increases (Mouillot et al., 2013). However, there was no support that recent fire would have a greater inter-specific bee trait variation (Taki et al., 2013), but was observed to be greatest among unburned areas. Contrary to our expectations, we found that inter- and intra-specific functional trait variation of plants

and bees was greatest among unburned areas. These results indicate that time-since-burn had the greatest effect of habitat filtering on the functional trait variations of plants and bees with patterns of phylogenetic clustering among recently burned areas and phylogenetic overdispersion among unburned areas (Ndiribe et al., 2013). Overall, productivity (i.e. location) played a role in what combination of traits associated with a species occur spatially, while the habitat filtering effects of fire severity were marginal on trait variation. Nevertheless, the habitat filtering effects of time-since-burn were superior to productivity and fire severity, thereby altering phylogenetic structuring and selecting for various traits suitable for post-wildfire conditions.

Plant Functional Traits

Productivity affected mean plant height, inflorescence type, the number of flowers, flower volume, and SLA across all species, indicating that productivity affects species sorting with the loss or addition of functional traits (D. Tilman, 1997) potentially affecting ecosystem processes. Time-since burn affected the mean trait values for all plant functional traits except inflorescence type among all species, indicating succession affects the mean functional trait values of observed numeric traits and the distribution of flower symmetry, but not the distribution of inflorescence type. Fire severity impacted the mean trait values of plant height, number of flowers, symmetry, flower volume and SLA, suggesting fire severity has the ability to limit trait presence and mean variation.

Overall, productivity (i.e. location) and time-since-burn increased the inter- and intra-specific variation of plant functional traits, with moderately productive unburned

areas having the greatest variation, indicating that productive areas where fire is absent may contribute to the functional diversity and stability of these fire-prone landscapes (Gross et al., 2017). Fire severity influenced the inter-specific SLA variation and intra-specific flower volume variation across all species, suggesting that fire severity filters plant traits associated with a plants ability to capture light and pollinator attractiveness. However, fire severity is a marginally influential habitat filter of functional trait variation with productivity and time-since-burn the most influential habitat filters among the communities observed.

Plant Height

For all species, the inter- and intra-specific variation of plant height was greatest in moderately productive unburned areas. Among common species, inter-specific variation of plant height was greatest among unburned areas in low and moderately productive environments, and intra-specific variation greatest among unburned areas in moderate productivity. These results suggest that unburned areas support and foster plant height variation between and within flowering plant species.

Plant height is a trait associated with competitive ability, fecundity, and environmental productivity (Cornelissen et al., 2003; Vieira et al., 2013). In addition, plant height is influenced by abiotic and land use changes (Lavorel et al., 2011). For all plant species observed in this analysis, the inter- and intra-specific variation of plant height was greatest in moderately productive unburned areas. Among common species, inter-specific variation of plant height was greatest among unburned areas in low and moderately productive environments, and intra-specific variation greatest among

unburned areas in moderate productivity. These results suggest that unburned areas support and foster plant height variation between and within flowering plant species. Increased plant height variation among fire-prone areas allows various plant species to withstand environmental change because some plant heights are selected for and some are selected against by wildfire. Plant species with selected for plant heights persist after fire along with their other associated traits and strategies affecting the outcome of ecosystem components, such as productivity. It has been observed that increased intra-specific plant height diversity enhances light capture (Lavorel et al., 2011; Lepš et al., 2006). Our results support previously observed trends, suggesting plant height variation among unburned areas allows flowering plants to maximize light capture, thereby increasing plant fecundity and productivity. In addition, plant height is a long-distance attractant for bees. Fornoff et. al. (2017) found that plant height, independent of total flower abundance, was associated with pollinator richness and visitation frequency contributing to functional diversity. Their results imply that increased plant height variation found among unburned areas may increase pollinator richness and visitation rates, therefore, increasing plant fecundity.

Inflorescence Type

Inflorescence type influences the attractiveness of a plant to bees (Coux et al., 2016). Given that inflorescence types varied with location and time-since-burn, then these two factors are selecting for inflorescence type presence potentially influencing plant-pollinator interactions among these environments. In addition, inflorescence type is an important trait involved in explaining species interaction network structure

(Chamberlain et al., 2014). Our results suggest that location and time-since-burn may affect species interactions network structure through its effect on inflorescence type.

Number of Flowers

Greater variation in flower number among species within a community leads to increased floral availability and bee attraction (Coux et al., 2016; Klinkhamer & Jong, 2016), thereby potentially explaining visiting pollinator species variation (Stang et al., 2006). When all species are considered, inter-specific variation in flower number was greater in older-high-severity burns in the low productivity environment (i.e. Helena), suggesting differences in post-fire plant species recruitment between burned and unburned areas and low and moderately productive environments. This is supported by previous finding of species richness patterns among these same sites (Burkle et al., 2015). Intra-specific variation in flower number was greater in unburned areas of moderately productive environments, indicating possibly phenotypic plasticity (Schlichting, 1986) of flowering plant species in unburned areas and the morphological adaptation of the number of flowers a plant with reproduce to attract bees among these areas. There were similar trends across common species. The number of flowers per inflorescence was the only plant species trait measured the had higher variation among older-high-severity burns in the low productivity environment, suggesting that wildfire acts as a habitat filter selecting for a variety of plant species with various flower number morphologies.

Flower Symmetry

Time-since-burn and fire severity had the greatest effect on flower symmetry presence across all species, while location, time-since-burn, and fire severity had the largest effect on flower symmetry presence across common species. The evolution of different types of flower symmetry are thought to be adaptations that select for visitation by attractiveness to suites of pollinators with specific tongue lengths (Fornoff et al., 2017). Thus, the presence of more types of flower symmetry across species may result in increased variation in tongue lengths of visiting pollinators. Our results indicate that higher variation in floral symmetry of plant species in recent burns (including mixed- and high-severity in moderately productive environments) may, in turn, attract bee species and bee individuals with higher variation in tongue lengths compared to unburned areas. However, our results for bee IT distance variation, where IT distance is correlated to tongue length, contradict this hypothesis with higher IT distance in unburned areas, suggesting a mismatch between flower symmetry type presence and bee tongue length variation. There could be additional unmeasured factors influencing the relationship between flower symmetry and bee tongue length. Additionally, flower symmetry is important in defining species interaction network structures (Chamberlain et al., 2014). According to our results, productivity (i.e. location), time-since-burn, and fire severity influenced flower symmetry, potentially affecting species interaction network structure.

Flower Volume

Inter-specific and intra-specific variation in flower volume was consistently greater across all species in unburned areas of the moderately productive location. This

suggests that increased water retention found among unburned areas with more canopy cover may lead to greater floral volumes, thereby flower volume variation is higher among unburned areas. Increased water retention leading to higher flower volume variation potentially explains why the water stressed environments found in Helena had lower flower volume variation. Flower volume can limit which pollinator individuals and species can access the floral rewards within a flower due to tongue length variation (Cariveau et al., 2016), thereby influencing patterns in pollinator visitation (Stang et al., 2006). Therefore, the unburned areas in the moderately productive environments potentially have a wider array of pollinators visiting each species in these areas.

Specific Leaf Area

Inter- and intra-specific variation in SLA was consistently greater in unburned areas of the moderately productive environment (i.e. Paradise Valley). This is consistent with observations between the moderate and the low productivity environment (i.e. Helena), with increased canopy cover among the Paradise Valley sites with plants responding by increasing SLA to maximize light capture (Lepš et al., 2006) thereby maximizing photosynthetic rates (Cornelissen et al., 2003). Our results suggest that SLA variation is higher among unburned areas due to the heterogeneity of light dispersal characteristic of unburned areas.

Bee Functional Traits

Interestingly, we did not observe any relationships between productivity, time-since-burn, and fire severity and mean IT distance values, contrary to our expectations.

This suggests there is no effect of productivity or wildfire on the mean IT distance of bees, but this could be the result of not accounting for species abundance in the mean trait value models. Upon further investigation, about 30% of the bees measured belong to the *Bombus* genus, which are inherently larger bodied bees with larger IT distances. Further analysis accounting for the abundances of bee genus and species is needed to determine if the trends we found for mean IT distance values are correct. In addition, we found that for most species, the mean IT distance of female bees were larger than male bees, which is consistent with existing literature (Osorio-Canadas et al., 2016). Productivity affected the presence of particular nesting behaviors, suggesting a relationship between biomass production and available nesting habitat. Taki et al. (2013) found increased nesting resources for above and below ground cavity nesters among mature forests containing more biomass, further supporting our results. Productivity, time-since-burn, fire severity, and sex had no effect on sociality presence. The sociality of a bee is directly correlated to the bee's genus and species, indicating that the distributions of sociality across the landscape are more consistent with species richness analyses than trait variation analyses.

Overall, increased productivity (i.e. location) and time-since-burn exhibited greater inter- and intra-specific variation of IT distance across all and common species, indicating that productive areas where fire is absent have increased phenotypic variation contributing to the functional diversity and stability of these unburned communities (Gross et al., 2017). Fire severity only affected the inter-specific IT distance variation across all bee species, suggesting fire severity affects species sorting pressures. Further, fire severity and species sorting pressures only affected the between species functional

trait variation with no effect on individual bees of a single species contributing to intra-specific variation. This indicates that fire severity has an impact on various bee species presence and no impact on the individual bees of a species. This warrants further investigation to understand the selective pressures of wildfire severity on bee IT distance.

Intertegular Distance

Intra-specific IT distance variation across all species was highest in unburned areas in moderately productive unburned areas, contradicting our hypothesis that variation in IT distance would be greatest in mixed-severity burns, suggesting that the effects of wildfire as a habitat filter lowering IT distance variation. Across common bee species, the inter-specific IT distance variation was higher in unburned areas in the moderately productive environment, indicating the effects of wildfire as a habitat filter lower IT distance variation. Across common bee species, the intra-specific IT distance variation was higher in recent-mixed-severity burns in the moderately productive environment, indicating the heterogeneity of mixed-severity burns promotes IT distance variation among a species. As previously discussed, IT distance is directly correlated to tongue length, body size, and foraging distance (Cariveau et al., 2016). Therefore, our results for mean IT distance and IT distance variation translate to tongue length, body size, and foraging distance results.

Bee tongue lengths are a mutually evolved trait with flowering plants (Morales, Arbetman, Cameron, & Aizen, 2013), thus an important functional trait to analyze. Bees with longer tongues that are associated with deep perennial flowering plant species are typically rare and have an increased risk of decline from environmental changes

(Goulson, Lye, & Darvill, 2008). A previous study found that recent fires select for bees with short tongues – with a positive correlation between time-since-burn and tongue length (Ricotta & Moretti, 2011). Our results are consistent with this previous study that, across all species observed, unburned areas had greater tongue length variation (i.e. IT distance variation) than high- and mixed-severity burns, suggesting that flowering plant species associated with longer tongued bees haven't been selected against by fire. We found that the intra-specific variation of tongue length across common species was highest among recent-mixed-severity fires, indicating the heterogeneity of mixed-severity burns promotes tongue length variation among a species.

Body size is an important functional trait related to the potential foraging range of bees, which can, in turn, affect plant population structure and pollination function (Greenleaf et al., 2007). Increased foraging range increases the potential for pollen transport between plant populations (Osborne et al., 2008). Larger bees have longer foraging ranges (Greenleaf et al., 2007). Therefore, larger bees may be able to overcome the spatial separation of floral and nesting habitats that wildfires generate (Wray, Neame, & Elle, 2014). For example, larger bees can travel greater distances to acquire floral and resources (Cresswell, Osborne, & Goulson, 2000), while smaller bees are restricted in their capabilities to forage far distance and must remain closer to their nest site (Wray et al., 2014). The IT distance is a proxy for foraging distance and dispersal abilities (Greenleaf et al., 2007; Warzecha, Diekötter, Wolters, & Jauker, 2016). Previous studies have found that fire affects traits associated with dispersal and foraging, such as body size, with larger bodies bees found in recently burned areas (Moretti & Legg, 2009). Our

results are consistent with previous findings that across all species observed, unburned areas have increased variation in body size and foraging distance (i.e. IT distance variation) because smaller bodied bees are not selected against in unburned areas like they are in recently burned areas. In addition, the smaller bodied bees have had more time to disperse and establish in unburned areas. The presence of larger bodied bees is important for ecosystem function because they're a functionally efficient species, but prone to local extirpation (Larsen, Williams, & Kremen, 2005).

Nesting Behavior

Productivity (i.e. location) had the greatest impact on nesting behavior presence across all and common species measured. To persist across the landscape, bees require access to floral resources and nesting habitats, thus, the floral community composition (Potts, Vulliamy, Dafni, Ne'eman, & Willmer, 2003) and available nesting resources (Taki et al., 2013) may organize the bee communities present (Potts et al., 2003) and their associated traits. Our results are consistent with previous findings, that productivity is associated with various nesting behaviors because each productivity type had distinctly different floral communities and nesting resources present thereby influencing the bee community. However, other studies have documented an effect of time-since-burn on nesting behavior (Williams et al., 2010) and a marginal effect of severity on nesting behavior (Moretti et al., 2009) which we did not observe. This discrepancy suggests that because nesting behavior is associated with the bee species – species found in the different productivity levels may be influencing the patterns we observed with productivity affecting species sorting thereby influencing nesting behavior presence.

Sociality

Productivity, time-since-burn, and fire severity were not associated with bee sociality presence across all and common species. Our results are contradictory to previous studies of the effects of wildfire and habitat loss on bee sociality (Bommarco et al., 2010; Moretti et al., 2009; Ricotta & Moretti, 2011; Williams et al., 2010). Our findings suggest that because sociality is associated with the bee species – the bee species themselves are influencing the patterns we observed.

Functional Trait Means and Variation among Wildfire

It has been documented that plant and animal distributions exhibit similar patterns in response to wildfires, often selecting trait expressions that relate to the persistence, resilience, and mobility of populations in post-wildfire conditions (Moretti & Legg, 2009). This parallel pattern of plant and bee trait selection is the result of fire acting as an environmental filter selecting for convergent traits that are more suitable in post-wildfire conditions (Moretti & Legg, 2009). Within this study, unburned areas in moderately productive environments had the greatest between and within species functional trait variation, indicating that the absence of wildfire disturbances increases trait diversity and promotes ecosystem function and stability. However, these results may be an artifact of the analyses conducted since a small number of flowering plant and bee individuals were observed and measured among unburned areas compared to other areas of various time-since-burn and fire severity levels. These results support previous findings that altered wildfire regimes at various productivity levels increases species sorting and limits species

trait variation after wildfire but trait variation increases as time-since-burn and productivity increases (Mouillot et al., 2013) for flowering plants and bees.

In our analyses, we found that the productivity of an environment and the time since it last burned affected the functional trait variation between and within flowering plants species more than bee species across all species measured and for commonly occurring species measured in both productivity levels. These results suggest that the dispersal abilities of bees allow them to withstand the effects of fire, while plant species are more prone to productivity and time-since-burn habitat filtering and species sorting due to their limited mobility. Further, wildfire severity affected between species variation of flower volume and within species variation of specific leaf area for commonly occurring species, suggesting fire severity affects plant traits involved in pollinator attraction and photosynthetic abilities (e.g. plants ability to capture light). Our results indicate productivity and time-since-burn are stronger environmental filters than fire severity in selecting flowering plant functional traits that are most suitable for the current environmental conditions. Productivity was the strongest environmental filter of bee functional traits.

Concluding Remarks & Future Directions

This study examines the effects of productivity, time-since-burn, and fire severity on functional trait values and variation involved in plant-bee interactions. This study is the first to investigate the effects of mixed-severity fires on functional traits of plants and bees. We found that plant height, number of flowers, flower volume, specific leaf area,

and intertegular distance values and variation increased as productivity and time-since-burn increased. Additionally, location was associated with the distribution of inflorescence types, flower symmetry, and nesting behavior, while sociality distribution was not affected by productivity, time-since-burn, and fire severity. In conclusion, productivity (i.e. location) and time-since-burn affected the functional trait values and variation of traits linked to plant-bee interactions. This suggests that the amount of plant biomass and the succession of an environment may play a critical role in the functional traits involved in plant-bee trophic level interactions through habitat filtering and species sorting.

I recommend the next step is to see if the patterns of plant-bee interactions previously observed in this area follow the same patterns we have observed for mean trait values and functional trait variation observed in this research. These future analyses will further guide managers in efforts to conserve plant-bee interactions to maintain ecosystem function and stability through pollination services and further our knowledge on the effects wildfire may have on pollination efforts.

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APPENDICES

APPENDIX A

BEE SAMPLING EFFORT & PLANT AND BEE SPECIES
AND ABUNDANCE LISTS

A1: Bee Sampling Effort. Sampling effort for 2013-2016 collecting bees and counting the number of flowers along transect at each site.

Transect	Sampling Effort (minutes)	Sampling Effort (hours)
HEMX1_01	540	9.00
HEMX1_02	600	10.00
HEMX1_03	600	10.00
HEMX1_04	560	9.33
HEMX1_05	540	9.00
HEMX1_06	580	9.67
HEMX1_07	600	10.00
HEMX1_10	600	10.00
HEMX1_12	600	10.00
HEMX2_01	560	9.33
HEMX2_02	580	9.67
HEMX2_04	600	10.00
HEMX2_05	580	9.67
HEMX2_07	580	9.67
HEMX2_08	580	9.67
HEMX2_09	580	9.67
HEMX2_10	580	9.67
HEMX2_11	580	9.67
HENEWHI1_01	580	9.67
HENEWHI1_02	600	10.00
HENEWHI1_03	600	10.00
HENEWHI1_04	600	10.00
HENEWHI1_05	580	9.67
HENEWHI1_06	580	9.67
HENEWHI1_08	620	10.33
HENEWHI1_09	580	9.67
HENEWHI1_11	580	9.67
HENEWHI2_01	600	10.00
HENEWHI2_02	600	10.00
HENEWHI2_03	600	10.00
HENEWHI2_04	600	10.00
HENEWHI2_05	600	10.00
HENEWHI2_06	600	10.00
HENEWHI2_07	600	10.00
HENEWHI2_08	620	10.33
HENEWHI2_09	600	10.00
HEOLDHI1_01	580	9.67

HEOLDHI1_02	600	10.00
HEOLDHI1_03	580	9.67
HEOLDHI1_04	540	9.00
HEOLDHI1_05	580	9.67
HEOLDHI1_06	600	10.00
HEOLDHI1_07	560	9.33
HEOLDHI1_08	520	8.67
HEOLDHI1_09	600	10.00
HEOLDHI2_01	600	10.00
HEOLDHI2_02	580	9.67
HEOLDHI2_03	560	9.33
HEOLDHI2_04	580	9.67
HEOLDHI2_05	580	9.67
HEOLDHI2_06	580	9.67
HEOLDHI2_07	560	9.33
HEOLDHI2_08	580	9.67
HEOLDHI2_09	580	9.67
HEUN1_01	580	9.67
HEUN1_02	540	9.00
HEUN1_03	540	9.00
HEUN1_04	580	9.67
HEUN1_05	560	9.33
HEUN1_06	580	9.67
HEUN1_07	600	10.00
HEUN1_08	580	9.67
HEUN1_09	520	8.67
HEUN3_01	560	9.33
HEUN3_03	600	10.00
HEUN3_04	580	9.67
HEUN3_05	580	9.67
HEUN3_07	540	9.00
HEUN3_08	580	9.67
HEUN3_12	560	9.33
PVMX1_01	520	8.67
PVMX1_02	500	8.33
PVMX1_03	500	8.33
PVMX1_04	520	8.67
PVMX1_05	560	9.33
PVMX1_06	500	8.33
PVMX1_07	500	8.33
PVMX1_08	520	8.67

PVMX1_09	500	8.33
PVMX2_01	520	8.67
PVMX2_02	500	8.33
PVMX2_03	520	8.67
PVMX2_04	520	8.67
PVMX2_05	520	8.67
PVMX2_06	540	9.00
PVMX2_07	540	9.00
PVMX2_08	540	9.00
PVMX2_09	500	8.33
PVNEWHI1_01	500	8.33
PVNEWHI1_02	460	7.67
PVNEWHI1_03	500	8.33
PVNEWHI1_04	500	8.33
PVNEWHI1_05	460	7.67
PVNEWHI1_06	460	7.67
PVNEWHI1_07	480	8.00
PVNEWHI1_08	500	8.33
PVNEWHI1_09	460	7.67
PVNEWHI2_01	460	7.67
PVNEWHI2_02	500	8.33
PVNEWHI2_03	500	8.33
PVNEWHI2_04	460	7.67
PVNEWHI2_05	500	8.33
PVNEWHI2_06	480	8.00
PVNEWHI2_07	500	8.33
PVNEWHI2_08	500	8.33
PVNEWHI2_09	480	8.00
PVOLDHI1_01	500	8.33
PVOLDHI1_02	500	8.33
PVOLDHI1_03	480	8.00
PVOLDHI1_04	500	8.33
PVOLDHI1_05	500	8.33
PVOLDHI1_06	460	7.67
PVOLDHI1_07	500	8.33
PVOLDHI1_08	500	8.33
PVOLDHI1_09	500	8.33
PVOLDHI2_01	500	8.33
PVOLDHI2_02	500	8.33
PVOLDHI2_03	500	8.33
PVOLDHI2_04	500	8.33

PVOLDHI2_05	500	8.33
PVOLDHI2_06	500	8.33
PVOLDHI2_07	500	8.33
PVOLDHI2_08	500	8.33
PVOLDHI2_09	460	7.67
PVUN2_01	440	7.33
PVUN2_02	440	7.33
PVUN2_03	460	7.67
PVUN2_04	460	7.67
PVUN2_05	460	7.67
PVUN2_06	460	7.67
PVUN2_07	480	8.00
PVUN2_08	460	7.67
PVUN2_09	480	8.00
PVUN3_01	440	7.33
PVUN3_02	420	7.00
PVUN3_03	460	7.67
PVUN3_04	460	7.67
PVUN3_05	480	8.00
PVUN3_06	460	7.67
PVUN3_07	460	7.67
PVUN3_08	460	7.67
PVUN3_09	460	7.67
Grand Total	75780	1263.00

A2: Plant Species and Abundances List. All flowering plant species and the number of flowers observed from 2013-2016. Plant species measured in Helena and Paradise Valley (i.e. common species) in 2017 in bolded text.

Plant Genus species	Plant Code	Number of Flowers
<i>Achillea_millefolium</i>	ACHMIL	87439
<i>Agoseris_aurantiaca</i>	AGOAUR	50
<i>Agoseris_glauca</i>	AGOGLA	84
<i>Allium_textile</i>	ALLTEX	704
<i>Anaphalis_margaritacea</i>	ANAMAR	27798
<i>Antennaria_microphylla</i>	ANTMIC	1955
<i>Antennaria_neglecta</i>	ANTNEG	38442
<i>Antennaria_rosea</i>	ANTROS	20008
<i>Apocynum_androsaemifolium</i>	APOAND	10823
<i>Arnica_cordifolia</i>	ARNCOR	2504

<i>Arnica_latifolia</i>	ARNLAT	240
<i>Arnica_sororia</i>	ARNSOR	15
<i>Astragalus_alpinus</i>	ASTALP	627
<i>Astragalus_miser</i>	ASTMIS	14122
<i>Astragalus_missouriensis</i>	ASTMISS	798
<i>Balsamorhiza_sagittata</i>	BALSAG	6582
<i>Campanula_rotundifolia</i>	CAMROT	15586
<i>Carduus_nutans</i>	CARNUT	1225
<i>Castilleja_miniata</i>	CASMIN	2906
<i>Ceanothus_velutinus</i>	CEAVEL	1450
<i>Centaurea_stoebe</i>	CENSTO	7141
<i>Cerastium_arvense</i>	CERARV	3529
<i>Chamerion_angustifolium</i>	CHAANG	59532
<i>Cirsium_arvense</i>	CIRARV	1176
<i>Cirsium_vulgare</i>	CIRVUL	181
<i>Clematis_occidentalis</i>	CLEOCC	465
<i>Collomia_linearis</i>	COLLIN	3652
<i>Collinsia_parviflora</i>	COLPAR	819
<i>Crepis_acuminata</i>	CREACU	831
<i>Crepis_intermedia</i>	CREINT	653
<i>Crepis_tectorum</i>	CRETEC	385
<i>Erigeron_caespitosus</i>	ERICAE	1895
<i>Erigeron_glabellus</i>	ERIGLA	2284
<i>Erigeron_speciosus</i>	ERISPE	4
<i>Eurybia_conspicua</i>	EURCON	2898
<i>Fragaria_virginiana</i>	FRAVIR	7349
<i>Gaillardia_aristata</i>	GAIARI	1604
<i>Galium_boreale</i>	GALBOR	19489
<i>Geranium_richardsonii</i>	GERRIC	945
<i>Geranium_viscosissimum</i>	GERVIS	149
<i>Geum_triflorum</i>	GEUTRI	1242
<i>Grindelia_squarrosa</i>	GRISQU	69
<i>Gutierrezia_sarothrae</i>	GUTSAR	6497
<i>Hedysarum_boreale</i>	HEDBOR	1160
<i>Hedysarum_sulphurescens</i>	HEDSUL	31589
<i>Heterotheca_villosa</i>	HETVIL	32566
<i>Heuchera_cylindrica</i>	HEUCYL	579
<i>Hieracium_albiflorum</i>	HIEALB	4857
<i>Hieracium_scouleri</i>	HIESCO	1
<i>Lactuca_tatarica</i>	LACTAT	89
<i>Liatris_punctata</i>	LIAPUN	2825

<i>Linnaea_borealis</i>	LINBOR	16650
<i>Linaria_dalmatica</i>	LINDAL	38041
<i>Lupinus_argenteus</i>	LUPARG	38346
<i>Mahonia_repens</i>	MAHREP	3858
<i>Medicago_lupulina</i>	MEDLUP	20364
<i>Melilotus_officinalis</i>	MELOFF	51565
<i>Oxytropis_sericea</i>	OXYLAG	575
<i>Oxytropis_splendens</i>	OXYSER	6116
<i>Penstemon_albertinus</i>	PENALB	860
<i>Penstemon_eriantherus</i>	PENERI	164
<i>Phacelia_linearis</i>	PHALIN	2043
<i>Phlox_albomarginata</i>	PHLALB	1602
<i>Phlox_hoodii</i>	PHLHOO	1980
<i>Prunus_virginiana</i>	PRUVIR	75
<i>Ribes_cereum</i>	RIB CER	2147
<i>Ribes_hudsonianum</i>	RIB HUD	2743
<i>Rosa_woodsii</i>	ROSWOO	590
<i>Rubus_idaeus</i>	RUBIDA	307
<i>Rubus_parviflorus</i>	RUBPAR	85
<i>Sedum_lancolatum</i>	SEDLAN	723
<i>Senecio_serra</i>	SENSER	398
<i>Solidago_canadensis</i>	SOLCAN	869
<i>Solidago_missouriensis</i>	SOLMIS	15714
<i>Spirea_betulifolia</i>	SPIBET	11014
<i>Symphotrichum_falcatum</i>	SYMFAL	1113
<i>Taraxacum_officinale</i>	TAROFF	1865
<i>Tragopogon_dubius</i>	TRADUB	376
<i>Trifolium_repens</i>	TRI REP	5283
<i>Verbascum_thapsus</i>	VERTHA	2518
<i>Vicia_americana</i>	VICAME	1180
<i>Zigadenus_venenosus</i>	ZIGVEN	679
	Grand Total	660875

A3: Bee Species and Aundances List. All bee species and the number of bee individuals collected from 2013-2016 and measured in 2017. Bee species individuals collected in Helena and Paradise Valley (i.e. common species) and measured in 2017 in bolded text. Bees were identified to the best of our abilities by Elizabeth Reese. Species identified that may be a different species are indicated with a ‘?’ in the genus species name. These species were included in this study as a different species to optimize functional trait variation.

Bee Genus species	Number of Individuals Measured
<i>Agapostemon_texanus</i>	1
<i>Agapostemon_texanus/angelicus</i>	9
<i>Agapostemon_virescens</i>	26
<i>Andrena_amphibola</i>	22
<i>Andrena_candida</i>	1
<i>Andrena_cleodora</i>	1
<i>Andrena_crataegi</i>	28
<i>Andrena_cupreotincta</i>	2
<i>Andrena_evoluta</i>	1
<i>Andrena_lawrencei</i>	82
<i>Andrena_medionitens</i>	3
<i>Andrena_melanochroa</i>	2
<i>Andrena_milwaukeeensis</i>	6
<i>Andrena_miranda</i>	31
<i>Andrena_nigrocaerulea</i>	3
<i>Andrena_nivalis</i>	21
<i>Andrena_pertristis</i>	1
<i>Andrena_prunorum</i>	16
<i>Andrena_s.str. sp.1</i>	2
<i>Andrena_saccata</i>	8
<i>Andrena_salicifloris</i>	2
<i>Andrena_sigmundi</i>	2
<i>Andrena_sp.</i>	1
<i>Andrena_sp.F12</i>	1
<i>Andrena_sp.F13</i>	1
<i>Andrena_sp.F14</i>	1
<i>Andrena_sp.F15</i>	1
<i>Andrena_sp.F16</i>	2
<i>Andrena_sp.F7</i>	3
<i>Andrena_sp.M11</i>	1
<i>Andrena_sp.M13</i>	1
<i>Andrena_thaspii</i>	11
<i>Andrena_topazana</i>	20

<i>Andrena_transnigra</i>	1
<i>Andrena_trevoris</i>	1
<i>Andrena_vierecki</i>	2
<i>Anthidiellum_notatum</i> <i>robertsoni</i>	2
<i>Anthidium_atrifrons</i>	1
<i>Anthidium_clypeodentatum</i>	11
<i>Anthidium_formosum</i>	5
<i>Anthidium_mormonum</i>	37
<i>Anthidium_placitum</i>	1
<i>Anthidium_tenuiflorae</i>	13
<i>Anthidium_utahense</i>	52
<i>Anthophora_bomboides</i>	5
<i>Anthophora_terminalis</i>	39
<i>Anthophora_urbana</i>	11
<i>Anthophora_ursina</i>	19
<i>Apis_mellifera</i>	62
<i>Ashmeadiella_bucconis</i>	57
<i>Ashmeadiella_cactorum</i>	40
<i>Ashmeadiella_californica</i>	28
<i>Ashmeadiella_meliloti</i>	1
<i>Ashmeadiella_pronitens</i>	4
<i>Ashmeadiella_sp.</i>	12
<i>Bombus_appositus</i>	324
<i>Bombus_bifarius</i>	621
<i>Bombus_borealis</i>	2
<i>Bombus_cent/flavi</i>	18
<i>Bombus_centralis</i>	161
<i>Bombus_fervidus</i>	165
<i>Bombus_flavidus</i>	13
<i>Bombus_flavifrons</i>	101
<i>Bombus_griseocollis</i>	30
<i>Bombus_huntii</i>	117
<i>Bombus_insularis</i>	125
<i>Bombus_melanopygus</i>	11
<i>Bombus_mixtus</i>	68
<i>Bombus_occidentalis</i>	10
<i>Bombus_rufocinctus</i>	160
<i>Bombus_sp.</i>	19
<i>Bombus_vagans</i>	1
<i>Ceratina_nanula</i>	88

<i>Ceratina_neomexicana</i>	70
<i>Ceratina_sp.</i>	2
<i>Coelioxys_alternata</i>	9
<i>Coelioxys_modesta</i>	1
<i>Coelioxys_moesta</i>	4
<i>Coelioxys_porterae</i>	2
<i>Coelioxys_rufitarsis</i>	2
<i>Coelioxys_sodalis</i>	1
<i>Colletes_consors consors</i>	1
<i>Colletes_fulgidus</i>	51
<i>Colletes_hyalinus hyalinus</i>	8
<i>Colletes_kincaidii</i>	28
<i>Colletes_lutzi lutzi</i>	2
<i>Colletes_phaceliae</i>	25
<i>Colletes_sp.</i>	1
<i>Diadasia_diminuta</i>	1
<i>Diadasia_sp.F1</i>	1
<i>Dianthidium_subparvum</i>	24
<i>Dianthidium_ulkei</i>	53
<i>Dioxys_productus</i>	1
<i>Dufourea_maura</i>	17
<i>Dufourea_trochantera</i>	17
<i>Epeolus_sp.</i>	1
<i>Eucera_edwardsii</i>	36
<i>Eucera_frater</i>	25
<i>Eucera_fulvitaris</i>	2
<i>Halictus_confusus</i>	72
<i>Halictus_farinosus</i>	4
<i>Halictus_ligatus</i>	52
<i>Halictus_rubicundus</i>	28
<i>Halictus_sp.</i>	1
<i>Halictus_tripartitus</i>	37
<i>Heriades_carinatus</i>	21
<i>Heriades_cressoni</i>	418
<i>Heriades_sp.</i>	10
<i>Heriades_variolosa</i>	9
<i>Hoplitis_albifrons argentifrons</i>	93
<i>Hoplitis_fulgida</i>	28
<i>Hoplitis_fulgida fulgida</i>	7
<i>Hoplitis_grinnelli</i>	7
<i>Hoplitis_hypocrita</i>	61

<i>Hoplitis_producta</i>	8
<i>Hoplitis_robusta</i>	3
<i>Hoplitis_truncata</i>	34
<i>Hylaeus_annulatus</i>	5
<i>Hylaeus_basalis</i>	24
<i>Hylaeus_coloradensis</i>	18
<i>Hylaeus_episcopalis</i>	4
<i>Hylaeus_leptocephalus</i>	6
<i>Hylaeus_mesillae</i>	2
<i>Hylaeus_mesillae/rudbeckiae</i>	20
<i>Hylaeus_mesillae?</i>	1
<i>Hylaeus_modestus</i>	46
<i>Hylaeus_rudbeckiae</i>	10
<i>Hylaeus_sp.</i>	4
<i>Hylaeus_verticalis</i>	7
<i>Hylaeus_wootoni</i>	28
<i>Lasioglossum_abundipunctum</i>	2
<i>Lasioglossum_aff.caducum</i>	12
<i>Lasioglossum_aff.nevadense</i>	3
<i>Lasioglossum_albipenne</i>	81
<i>Lasioglossum_albipenne?</i>	8
<i>Lasioglossum_anhypops</i>	4
<i>Lasioglossum_brunneiventre</i>	1
<i>Lasioglossum_ebmerellum</i>	77
<i>Lasioglossum_ebmerellum?</i>	15
<i>Lasioglossum_egregium</i>	9
<i>Lasioglossum_ephialtum</i>	1
<i>Lasioglossum_hudsoniellum</i>	1
<i>Lasioglossum_hyalinum?</i>	2
<i>Lasioglossum_leucozonulum</i>	1
<i>Lasioglossum_lusoria</i>	1
<i>Lasioglossum_marinense</i>	46
<i>Lasioglossum_marinense?</i>	15
<i>Lasioglossum_nevadense</i>	12
<i>Lasioglossum_nigroviride</i>	61
<i>Lasioglossum_nigroviride?</i>	15
<i>Lasioglossum_nr.occidentale</i>	2
<i>Lasioglossum_nr.pavoninum</i>	5
<i>Lasioglossum_obnubilum</i>	6
<i>Lasioglossum_obnubilum?</i>	32
<i>Lasioglossum_occidentale</i>	14

<i>Lasioglossum_paraforbesii?</i>	1
<i>Lasioglossum_planatum</i>	2
<i>Lasioglossum_pruinosum</i>	8
<i>Lasioglossum_pruinosum?</i>	1
<i>Lasioglossum_ruidosense</i>	16
<i>Lasioglossum_sedi</i>	21
<i>Lasioglossum_semicaeruleum</i>	5
<i>Lasioglossum_sisymbrii</i>	6
<i>Lasioglossum_sp.</i>	16
<i>Lasioglossum_sp.F1</i>	4
<i>Lasioglossum_sp.F17</i>	2
<i>Lasioglossum_sp.F2</i>	14
<i>Lasioglossum_sp.F27</i>	3
<i>Lasioglossum_sp.F28</i>	5
<i>Lasioglossum_sp.F3</i>	5
<i>Lasioglossum_sp.F5</i>	22
<i>Lasioglossum_sp.F6</i>	2
<i>Lasioglossum_sp.F7</i>	1
<i>Lasioglossum_sp.F8</i>	1
<i>Lasioglossum_sp.F9</i>	1
<i>Lasioglossum_sp.M1</i>	2
<i>Lasioglossum_sp.M2</i>	1
<i>Lasioglossum_sp.M3</i>	4
<i>Lasioglossum_sp.M4</i>	26
<i>Lasioglossum_sp.M5</i>	2
<i>Lasioglossum_sp.M6</i>	3
<i>Lasioglossum_sp.M7</i>	1
<i>Lasioglossum_succinipenne</i>	22
<i>Lasioglossum_succinipenne?</i>	3
<i>Lasioglossum_tenax?</i>	25
<i>Megachile_angelarum</i>	7
<i>Megachile_apicalis</i>	95
<i>Megachile_brevis</i>	7
<i>Megachile_brevis/onobrychidis</i>	6
<i>Megachile_campanulae</i>	3
<i>Megachile_fidelis</i>	16
<i>Megachile_frigida</i>	107
<i>Megachile_frigida?</i>	1
<i>Megachile_gemula</i>	13
<i>Megachile_lapponica</i>	84
<i>Megachile_latimanus</i>	3

<i>Megachile melanophaea</i>	29
<i>Megachile montivaga</i>	7
<i>Megachile onobrychidis</i>	3
<i>Megachile parallela</i>	7
<i>Megachile perihirta</i>	80
<i>Megachile pugnata</i>	119
<i>Megachile relativa</i>	54
<i>Megachile rotundata</i>	2
<i>Megachile subnigra</i>	1
<i>Megachile texana</i>	1
<i>Megachile wheeleri</i>	1
<i>Melecta pacifica fulvida</i>	1
<i>Melecta separata</i>	1
<i>Melissodes confusa</i>	2
<i>Melissodes coreopsis</i>	5
<i>Melissodes hymenoxidis</i>	1
<i>Melissodes microsticta</i>	65
<i>Melissodes rivalis</i>	4
<i>Melissodes_sp.F1</i>	1
<i>Melissodes_sp.F2</i>	1
<i>Melissodes_sp.M1</i>	1
<i>Melissodes_sp.M2</i>	2
<i>Melissodes_sp.M3</i>	1
<i>Melissodes_unk1</i>	1
<i>Melissodes utahensis</i>	1
<i>Nomada edwardsii</i>	6
<i>Nomada_sp.F1</i>	4
<i>Nomada_sp.F2</i>	2
<i>Nomada_sp.F3</i>	7
<i>Nomada_sp.F6</i>	1
<i>Nomada_sp.F7</i>	3
<i>Nomada_sp.M1</i>	6
<i>Nomada_sp.M2</i>	4
<i>Nomada_sp.M3</i>	4
<i>Nomada_sp.M4</i>	1
<i>Nomada_sp.M6</i>	1
<i>Nomada_sp.M7</i>	2
<i>Osmia ?phaceliae</i>	25
<i>Osmia ?proxima</i>	10
<i>Osmia aff.albolateralis</i>	1
<i>Osmia aff.grindeliae</i>	1

<i>Osmia</i> <i>aff.paradisica</i>	7
<i>Osmia</i> <i>aff.pusilla</i>	1
<i>Osmia</i> <i>albolateralis</i>	94
<i>Osmia</i> <i>albolateralis?</i>	1
<i>Osmia</i> <i>atrocyanea</i>	13
<i>Osmia</i> <i>brevis</i>	11
<i>Osmia</i> <i>bruneri</i>	5
<i>Osmia</i> <i>bucephala</i>	18
<i>Osmia</i> <i>californica</i>	76
<i>Osmia</i> <i>coloradensis</i>	44
<i>Osmia</i> <i>densa</i>	17
<i>Osmia</i> <i>ednae</i>	2
<i>Osmia</i> <i>grindeliae</i>	1
<i>Osmia</i> <i>grindeliae?</i>	1
<i>Osmia</i> <i>inermis</i>	6
<i>Osmia</i> <i>iridis</i>	10
<i>Osmia</i> <i>juxta</i>	89
<i>Osmia</i> <i>kincaidii</i>	4
<i>Osmia</i> <i>lignaria propinqua</i>	3
<i>Osmia</i> <i>longula</i>	5
<i>Osmia</i> <i>malina</i>	1
<i>Osmia</i> <i>marginipennis</i>	6
<i>Osmia</i> <i>montana montana</i>	50
<i>Osmia</i> <i>nigrifrons</i>	11
<i>Osmia</i> <i>nigriventris</i>	2
<i>Osmia</i> <i>nr.proxima</i>	1
<i>Osmia</i> <i>odontogaster gr.sp.1</i>	2
<i>Osmia</i> <i>odontogaster gr.sp.2</i>	1
<i>Osmia</i> <i>paradisica</i>	6
<i>Osmia</i> <i>paradisica?</i>	1
<i>Osmia</i> <i>pentstemonis</i>	10
<i>Osmia</i> <i>phaceliae</i>	10
<i>Osmia</i> <i>physariae</i>	1
<i>Osmia</i> <i>pikei</i>	2
<i>Osmia</i> <i>proxima</i>	1
<i>Osmia</i> <i>pusilla</i>	41
<i>Osmia</i> <i>sculleni</i>	1
<i>Osmia</i> <i>simillima</i>	3
<i>Osmia</i> <i>sp.</i>	47
<i>Osmia</i> <i>sp.9</i>	1
<i>Osmia</i> <i>subaustralis</i>	8

<i>Osmia_tersula</i>	5
<i>Osmia_texana</i>	2
<i>Osmia_trevoris</i>	32
<i>Osmia_tristella</i>	19
<i>Panurginus_atriceps</i>	5
<i>Panurginus_sp.F1</i>	1
<i>Panurginus_sp.M1</i>	3
<i>Panurginus_torchioi</i>	4
<i>Protandrena_innuptus</i>	1
<i>Stelis_calliphorina</i>	3
<i>Stelis_carnifex</i>	1
<i>Stelis_montana</i>	11
<i>Stelis_monticola</i>	3
<i>Triepeolus_sp.</i>	3
<i>Triepeolus_spp.</i>	1
Grand Total	6374