Assessing Bumble Bee Communities on the Fred's and Power Fires of the Eldorado National Forest: Report for the 2015 Field Season

March 15, 2016

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INTRODUCTION

Bumble bees (*Bombus* spp.) provide vital ecosystem services as pollinators of both native plant species and agricultural crops (Kearns and Inouye 1997). However, many species of bumble bees are declining across the Northern Hemisphere due to causes that are often inter-related and include habitat loss and fragmentation (Goulson et al. 2008, Koh et al. 2016), agricultural practices (Carvell 2002, Williams and Osborne 2009), altered fire regimes (Taylor and Catling 2012), and the fungal pathogen *Nosemi bombi,* which is believed to have been transmitted from domesticated bumble bees (Cameron et al. 2011, Koch and Strange 2012). Climate change is another cause of decline (Potts et al. 2010), leading to shifts in the ranges of bumble bees (Kerr et al. 2015) and temporal mismatches between bumble bee life-cycle phenology and the floral resources they require (Miller-Struttmann et al. 2015). Unless widespread declines in bumble bees and other pollinators (Koh et al. 2015) are better understood and addressed (LeBuhn et al. 2013), the functional integrity of natural ecosystems may be compromised (Ollerton et al. 2011) and agricultural crop production could be greatly reduced (Klein et al. 2007). With widespread declines of bumble bees attributed in part to habitat loss (Goulson et al. 2008, Koh et al. 2016), it is essential to understand how habitat characteristics influence bumble bee abundance and diversity, and to use that understanding to guide land management efforts towards improving habitat for bumble bees and other pollinators (Goulson et al. 2011).

During the spring and summer of 2015 we conducted bumble bee (*Bombus* spp.) surveys throughout the area burned by the Power and Fred's fires, using a standardized survey protocol. Bumble bees are often found in montane meadows (Hatfield and LeBuhn 2007), but burned or otherwise disturbed areas also provide habitat when abundant flowering plants and suitable nesting burrows exist (Grundel et al. 2010). Our goal was to determine which post-fire vegetation communities and specific areas within the Power and Fred's fires provide the most important habitat for bumble bee species. Understanding bumble bee habitat associations and temporal use patterns will enable us to identify and recommend post-fire management and restoration strategies that will provide or maintain high quality habitat for bumble bees. Monitoring the effects of forest management actions on bumble bees will enable us to refine our models of habitat selection, and to make further forest management recommendations in an adaptive management context.

METHODS

Site Selection

We surveyed bumble bees within 20-m radius plots located throughout the areas burned by the Fred's and Power fires on Eldorado National Forest (Fig. 1). For efficiency during surveys, most of the plots were clustered in groups of five, with a central plot and 4 additional plots centered 100 m from the mid-point of the central point in each cardinal direction. We determined locations for the 5-plot clusters using a random design stratified by 3 elevation bands (<1372 m, 1373 m – 1676 m, and >1676 m) and 2 treatment categories (within treatment units (e.g., herbicide, grubbing, planting), and outside of treatment units) with the centers of plot clusters located a minimum of 275 m apart. In addition, we deliberately placed additional plots in plant communities that were relatively rare within out study areas (e.g., meadows, riparian

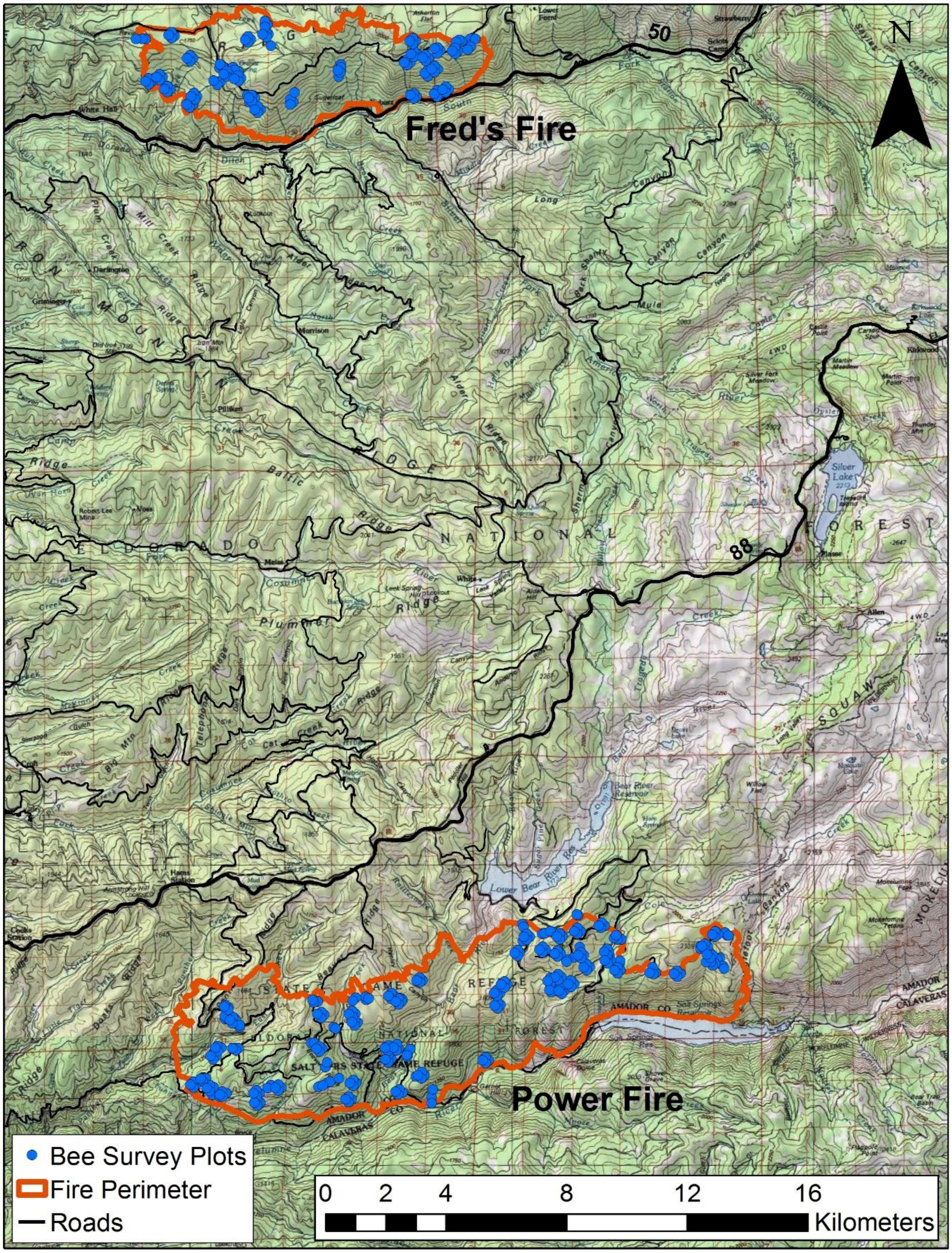

Figure 1. The location of bumble bee plots that were surveyed in 2015 within the Fred's and Power fire perimeters on the Eldorado National Forest.

habitats, unburned areas within the fire perimeter) and not well represented in our random sample, but which we believed might host distinct floral resources and possibly distinct assemblages of bumble bees. In all instances, plot coordinates were selected based on existing geospatial land cover information using ArcMap 10.3 (Environmental Systems Research Institute, Redlands, CA), and then navigated to in the field.

Crew Training and Certification

All data were collected by full-time crew members working or volunteering for The Institute for Bird Populations. At the beginning of the 2015 field season, crew members underwent an intensive 1-week bumble bee training session to ensure surveyors were fully competent and qualified to collect reliable bumble bee and related vegetation data. At the end of the training session all crew members passed a rigorous bumble bee identification exam that tested the skills necessary to survey for and identify bumble bees in the field.

Data Collection

Bumble Bee Surveys

Bumble bee surveys were conducted within 20-m radius plots centered at predetermined survey locations. When survey plots fell within in the center of a road, terrain that was too steep to survey, or areas that were inaccessible they were relocated up to 20 m from the given plot center. Each plot was surveyed for bumble bees over a 16 minute survey period between 0830 and 1900. During that period a single observer would visually scale and walk throughout the plot. When a bumble bee was encountered within the 20-m radius plot the surveyor would capture the bee and suspend the survey until the bumble bee was transferred to a numbered vial and placed in a cooler to chill. They surveyor also recorded the plant species on which the bumble bee was caught (or noted if the bumble bee was caught in flight). Once completed the survey was resumed and the search time continued until another bee was caught. At the end of the 16 minute survey period, or the passing of 1 hour of searching and capturing of bumble bees combined, the survey was ended. All bumble bees caught were photographed from various angles and characteristics used to identify the bumble bee to species (i.e. cheek length, face color, terga color, number of terga, corbicula presence) and caste (queen, worker, male) were recorded after which time the bumble bee was released.

Plots were typically surveyed twice during the field season according to a random firing order within the 3 elevation zones, such that plots in the lower elevation zone were visited earlier in the season than plots in the higher elevation zones to account for earlier bloom and bumble bee emergence cycles at lower elevations. Plots were first surveyed between May 20 and July 26, surveyed a second time between July 9 and August 15, and a very small sample of the plots were also surveyed a third time, between August 11 and August 20, 2015. The timing of the surveys was based on information about the timing of the bumble bee species expected to be found in the survey region (Koch et al. 2012).

Floral Resource and Habitat Assessment

Before beginning each bumble bee survey surveyors collected data on weather conditions (i.e., temperature, cloud cover). Following the survey they identified the five flowering plants with the most inflorescences blooming in the plot and estimated the number of inflorescences blooming at that time on a logarithmic scale. Surveyors also completed a habitat assessment after the initial bumble bee survey at a plot. Within the 20 m-radius survey plot surveyors recorded overstory and mid-layer cover estimates for conifers, hardwoods, and shrubs (by species), relative cover of understory vegetation by type and the relative cover of abiotic ground cover components. Cover was estimated as if one was looking down on the site from above. Using the habitat assessment data we designated plots as 'riparian' if they contained any standing or flowing water or if they had a minimum of 10% cover of riparian shrubs, trees, sedges, and rushes combined; all other plots were designated as 'upland'.

Opportunistic Detections of Hummingbirds, Monarch Butterflies, and Milkweed Plants

During bumble bee surveys the surveyors also recorded any detections of hummingbirds, monarch butterflies, and milkweed plants. If a hummingbird was observed during a survey within a survey plot the number and species (if identified) were recorded. The number of monarch butterflies and milkweed plants present on plots during bee surveys were also recorded.

Data Analysis

Bumble Bee Abundance

To assess bumble bee abundance we calculated the average number of bumble bees captured per plot (all species and castes pooled) by dividing the total number of bees captured per plot by the total number of surveys conducted at the plot. We used a two-sample *t*-test to evaluate the difference between the average number of bumble bees per survey in riparian and upland plots. We used a one-way ANOVA test to evaluate if there was a difference in the average number of bumble bees per survey by burn severity category.

Bumble Bee Species Richness Patterns

As survey methods rarely detect all individuals or all species present in a given sampling area, it is critical when analyzing community patterns to account for potentially missed species (Gotelli and Colwell 2001). We capitalized on temporally replicated surveys for bumble bees at the same plots within a single season to build a community occupancy model (Dorazio and Royle 2005, Dorazio et al. 2006, Iknayan et al. 2014) within a hierarchical Bayesian framework. Such models have previously demonstrated the robust capacity to estimate the effects of environmental variables (Ruiz-Gutiérrez et al. 2010), management treatments (Zipkin et al. 2010), and temporal turnover (Tingley and Beissinger 2013) on species assemblages while accounting for the biases of imperfect detection.

Community occupancy models have 2 major assumptions relevant to this study. First, in order to calculate the probability of detection for each species, the models assume that individual plots are 'closed' to immigration or emigration across replicate surveys (MacKenzie et al. 2002). This assumption can be slightly relaxed by interpreting models as predicting 'usage' rather than occupancy (MacKenzie 2005), and closure violations can, in some instances, be subsumed into variance explained by temporally dynamic covariates of detection (Rota et al. 2009). In our case, while closure would be violated for individual bees, because bumble bee colonies are both active and fixed in space throughout a single season, we feel that the closure assumption is valid for species within our plots. Second, community occupancy models are hierarchical in that they assume that species-level parameters are drawn from hyper-distributions governed by community-level parameters. For this model assumption to be valid, species-level traits must be adequately approximated by a chosen probability distribution – typically, the normal distribution. Although the cases when such an assumption could be invalid are poorly explored in the ecological literature (but see Pacifici et al. 2014), given that all species in our system are congeneric, we feel this hierarchical assumption to be appropriate. Additionally we designed our study duration to overlap with estimated peak periods in colony size for all *Bombus* species expected within the project area (Koch et al. 2012, Williams et al. 2014).

We developed a Bayesian hierarchical model, where $y_{i,j,k}$ is a binomial random variable that indicates if species *i* was detected ($y_{i,j,k} = 1$) or not detected ($y_{i,j,k} = 0$) at sampling point *j* during survey visit *k*. We used a mixture model specification to describe the data-generating process in terms of probability distributions, such that $y_{i,j,k} \sim \text{Bernoulli}(p_{i,j,k} \cdot z_{i,j})$, where $z_{i,j}$ is a latent variable (i.e, imperfectly observed) used to indicate true occurrence of species *i* at point *j*, modeled as $z_{i,j} \sim \text{Bernoulli}(\psi_{i,j})$. The probability of detecting species *i* at point *j* during sampling visit *k* is defined as $p_{i,j,k}$. We assume that a detection ($y_{i,j,k} = 1$) represents a true occurrence ($z_{i,j} = 1$) but that a non-detection ($y_{i,j,k} = 0$) could be the outcome of either a true absence ($z_{i,j} = 0$ with probability $1 - \psi_{i,j}$) or a true presence ($z_{i,j} = 1$ with probability $1 - p_{i,j,k}$).

We modeled detectability as a function of 3 covariates:

$$\text{logit}(p_{i,j,k}) = \alpha 0_i + \alpha 1_i \text{day}_{j,k} + \alpha 2_i \text{time}_{j,k} + \alpha 3_i \text{time}^2_{j,k}$$

where $day_{j,k}$ is the Julian day of the year, and $time_{j,k}$ is the time of day at which the survey started. We included a quadratic effect on time of day as surveys were conducted throughout daylight hours and we expected bees to be most active in the middle of the day.

We modeled the occurrence probability for each species at each plot, $\psi_{i,j}$, using the logit link function and *a priori* covariates such that:

$$\begin{aligned}\text{logit}(\psi_{i,j}) = {} & \beta 0_i + \beta 1_i \text{upland}_j + \beta 2_i \text{elev}_j + \beta 3_i \text{shrub}_j + \beta 4_i \text{overstory}_j + \beta 5_i \text{herb}_j \\ & + \beta 6_i \text{whitethorn}_j + \beta 7_i \text{bearclover}_j\end{aligned}$$

where $\beta 0_i$ is the intercept, and $\beta 1_i$ – $\beta 7_i$ are the effects of environmental covariates on species *i*: whether the plot was upland (versus riparian), the elevation, and the percent cover of shrubs (all species pooled), total overstory, all herbaceous plant categories pooled, and species-specific cover for mountain whitethorn and bearclover. Percent cover of mountain whitethorn and bearclover were included as distinct variables because they were by far the two most abundant chaparral species in our study area, and anecdotal observations indicated substantial disparity in the presence of foraging bumble bees on the two species. All continuous occupancy and detectability covariates were standardized to a mean of 0 and a standard deviation of 1.

For the community-level component, we defined each species-level covariate parameter ($\beta 0_i$- $\beta 7_i$ and $\alpha 0_i$- $\alpha 3_i$,) following the form:

$$\beta 0_i \sim \text{Normal}(\mu_{\beta 0}, \sigma_{\beta 0})$$

where $\mu_{\beta 0}$ and $\sigma_{\beta 0}$ are hyper-parameters representing the community-level mean and standard deviation for each of *i* species-level parameters for $\beta 0$. Hyper-parameters were given vague (i.e. locally flat) priors (μ: normal priors with $\mu = 0$ and $\sigma = 100$; τ: gamma priors with shape and rate parameters of 0.01).

We fit the data to the model using JAGS (JAGS version 4.0.0, http://mcmc-jags.sourceforge.net, accessed 1 Jan 2016) via R (R version 3.2.1, www.r-project.org, accessed 10 Dec 2015). We ran 3 chains of 60,000 iterations with a burn-in of 1,000 followed by a posterior draw of 15,000 thinned by 100, yielding a posterior sample of 450 across all chains.

Convergence was assumed when the Gelman-Rubin statistic of all monitored parameters calculated across both chains was less than 1.1 (Gelman et al. 2004). Inference from the fitted model was based on evaluation of 95% Bayesian credible intervals (BCI) of community hyper-parameters (e.g., $\mu_{\beta0}$), species-specific parameters (e.g., $\beta7_i$), and posterior estimates of true plot-specific species richness derived from the $z_{i,j}$ matrix.

Foraging Use versus Availability of Blooming Plant Species

We evaluated foraging use versus availability for each plant species following the method of Neu (Neu et al. 1974, Alldredge and Ratti 1986, Alldredge and Ratti 1992). This method was chosen as we did not track plant usage by individual bumble bees nor did we have exhaustive inventories of all plant species within each plot. The method described by Neu et al. (1974) relies on a Chi-squared goodness-of-fit test of the distribution of available habitats versus used habitats, where available is a stand-in for expected frequency (i.e., the null hypothesis is that bees will forage on plants at rates proportional to their frequency on the landscape). Following a significant chi-squared test, a Bonferroni Z-statistic (Alldredge and Ratti 1992) is used to test for specific habitats that are used significantly more or less frequently.

Key to such an analysis are the definitions used for "use" and "availability" (Hall et al. 1997). We defined usage as the proportion of all bee captures that occurred on a given plant species (Alldredge and Ratti 1992). We defined availability as the proportion of times that each plant species was identified as one of the 5 flowering plant species with the most inflorescences blooming in a plot on the day of a survey across all plots and surveys. We limited our analysis to only those plant species that had at least one bee capture, thus differentiating between high use and low use within the community of plants that are actually foraged on by bees in our study area (Johnson 1980). Consequently, our analysis revealed plant species that were preferentially used by bees, species that were avoided by bees, and species that were used in proportion to their availability. For the two most frequently used plant species, we plotted availability and frequency of use against date to examine changing patterns in availability and use by bumble bees during the study period.

RESULTS

Bumble Bee Abundance

We captured and identified 676 bumble bees of 12 species during 966 surveys on 495 plots (413 upland plots and 82 riparian plots; Table 1). *Bombus vosnesenskii* (479 captures, 71% of all bees captured) and *B. vandykei* (109 captures, 16% of all bees captured) were by far the most frequently encountered species. The remaining species encountered, in decreasing order of captures were *B. mixtus*, *B. californicus*, *B. insularis*, *B. flavifrons*, *B. melanopygus*, *B. rufocinctus*, *B. fernaldae*, *B. appositus*, *B. sylvicola*, and *B. bifarius* (Table 1).

Figure 2. The average number of bumble bees per plot by plot type. Lines above bars represent one standard deviation.

Table 1. The number of individual bumble bees (*Bombus*) of each species and caste detected, and the number and percent of riparian and upland plots with detections.

	No. of individuals detected			No. (percent) of plots with detections	
Species	Workers	Drones	Queens	Riparian	Upland
B. appositus	1	0	1	2 (2)	0 (0)
B. bifarius	1	0	0	0 (0)	1 (1)
B. californicus	7	4	5	5 (6)	9 (2)
*B. fernaldae**	N/A	3	0	2 (2)	1 (1)
B. flavifrons	7	6	2	7 (9)	7 (2)
*B. insularis**	N/A	15	1	9 (11)	5 (1)
B. melanopygus	1	9	1	3 (4)	7 (2)
B. mixtus	17	0	1	3 (4)	5 (1)
B. rufocinctus	1	2	1	0 (0)	3 (1)
B. sylvicola	2	0	0	1 (1)	0 (0)
B. vandykei	60	39	10	12 (15)	46 (11)
B. vosnesenskii	315	159	5	31 (38)	144 (35)

*Cuckoo species having only drones and queens

The average number of bumble bees captured per plot visit was not significantly different (t_{109} = 1.11, $P = 0.27$) between riparian plots (0.84 ± 1.36 bumble bees/plot visit) and upland plots (0.66 ± 1.23 bumble bees/plot; Fig. 2). Ten bumble bee species were detected on riparian plots and ten species were detected on upland plots, but only eight species were detected on both plot types; *B. appositus* and *B. sylvicola* were unique to riparian plots and *B. bifarius* and *B. rufocinctus* were unique to upland plots. However only a small number of individuals of these four species were captured, precluding determination that any species was strictly associated with riparian or upland habitats.

In terms of bumble bee community composition by fire footprint, 6 of the bumble bee species were found on both fires: *B. californicus, B. fernaldae. B. flavifrons, B. insularis, B. vandykei. B. vosnesenskii.* Three bumble bee species were found only on the Fred's fire: *B. appositus, B. rufocinctus, B. appositus,* and *B. sylvicola*, and three bumble bee species were found only on the Power fire: *B. bifarius*, *B. melanopygus*, and *B. mixtus* (Table 2). The average number of bumble bees caught per survey was 0.78 ± 1.37 on the Fred's fire (Fig. 3), and 0.65 ± 1.20 on the Power fire (Fig. 4).

Table 2. The total number of bumble bees (*Bombus* spp.) caught by species and fire.

Species	Fred's	Power
B. appositus	2	0
B. bifarius	0	1
B. californicus	6	10
*B. fernaldae**	1	2
B. flavifrons	12	2
*B. insularis**	4	12
B. melanopygus	0	11
B. mixtus	0	19
B. rufocinctus	4	0
B. sylvicola	2	0
B. vandykei	70	39
B. vosnesenskii	166	313
Total	267	409

*Cuckoo (parasitic) species

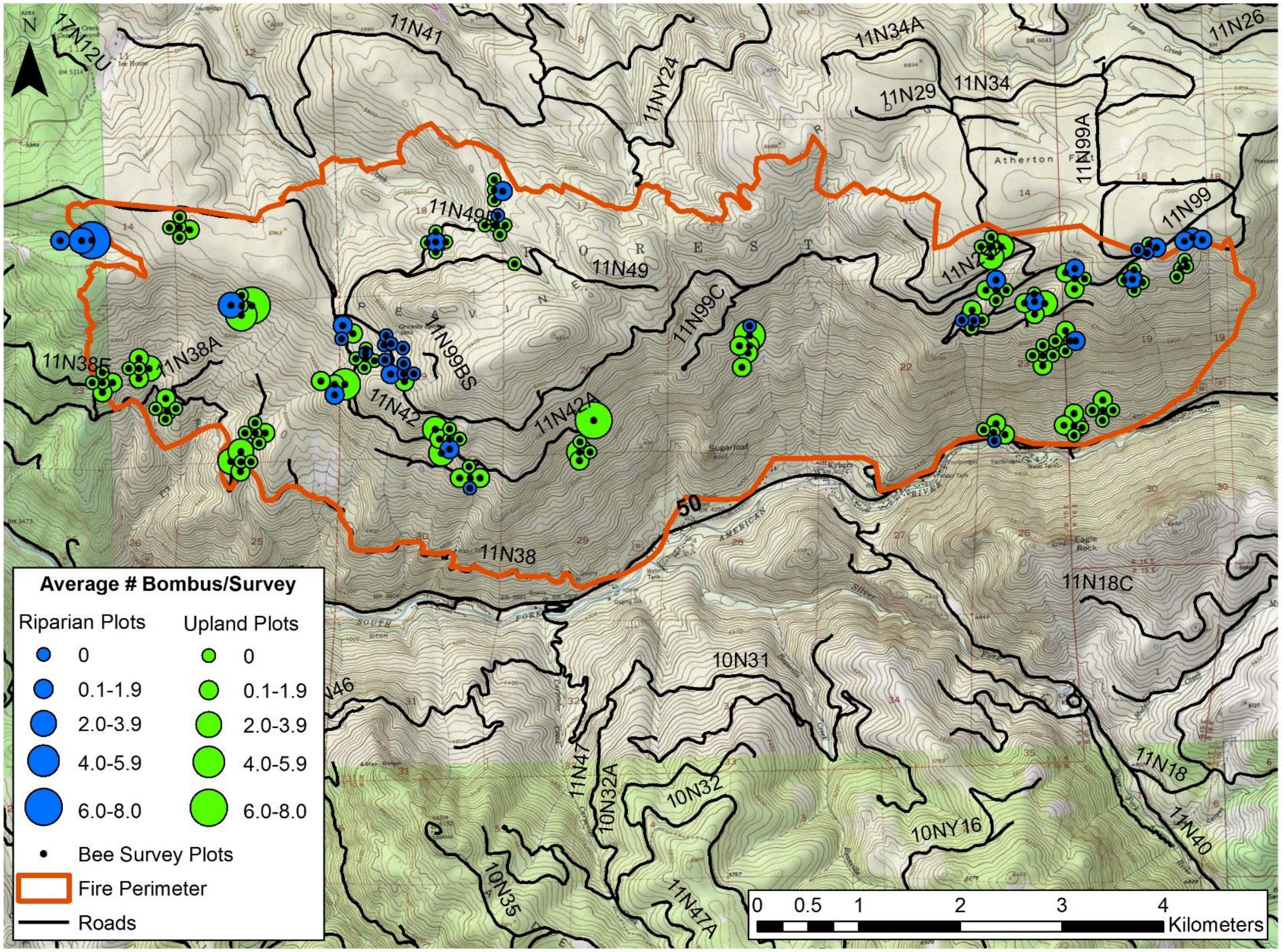

Figure 3. The average number of bumble bees (*Bombus* spp.) caught per survey by plot on the Fred's fire in 2015.

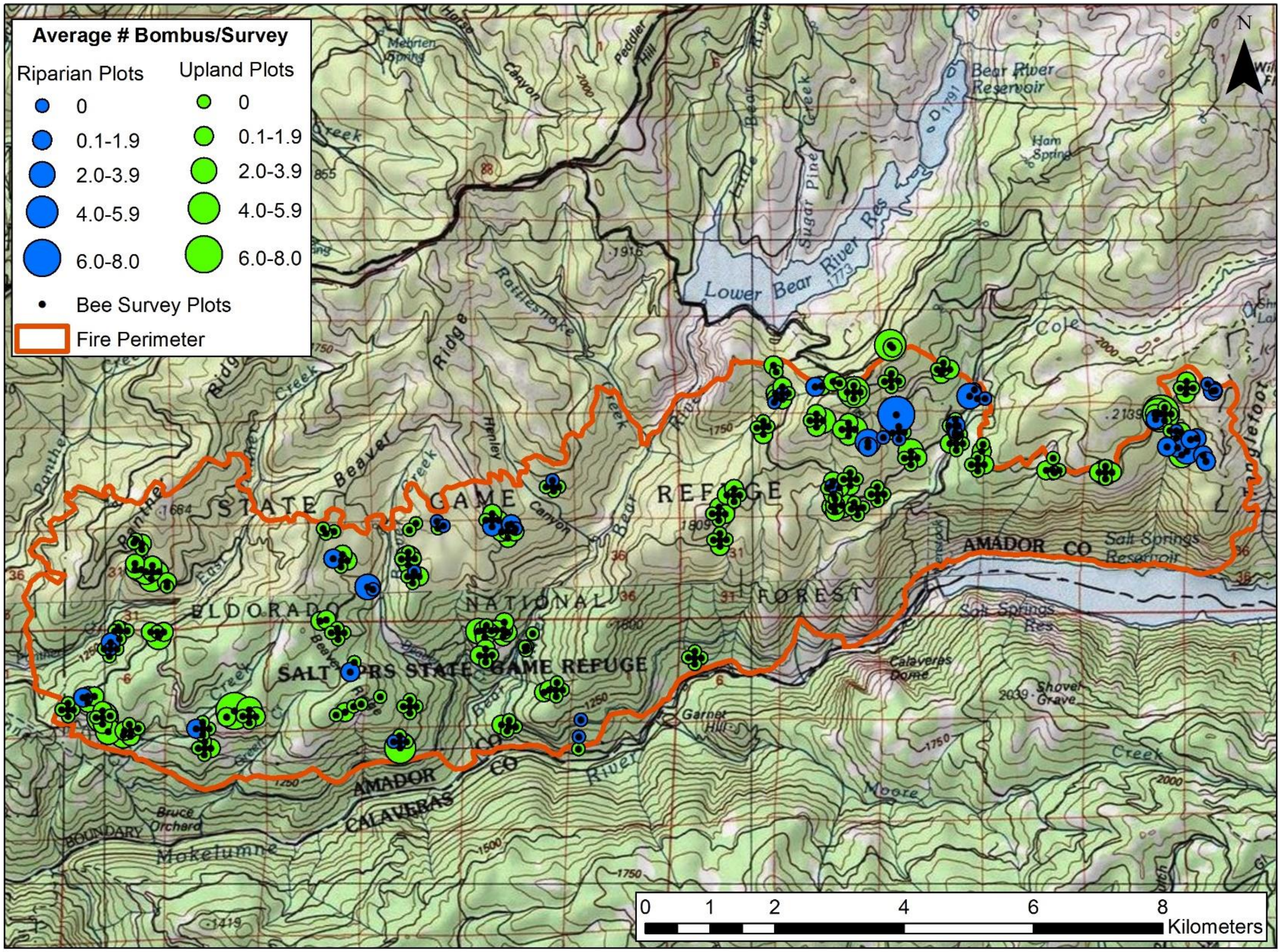

Figure 4. The average number of bumble bees (*Bombus* spp.) caught per survey by plot on the Power fire in 2015.

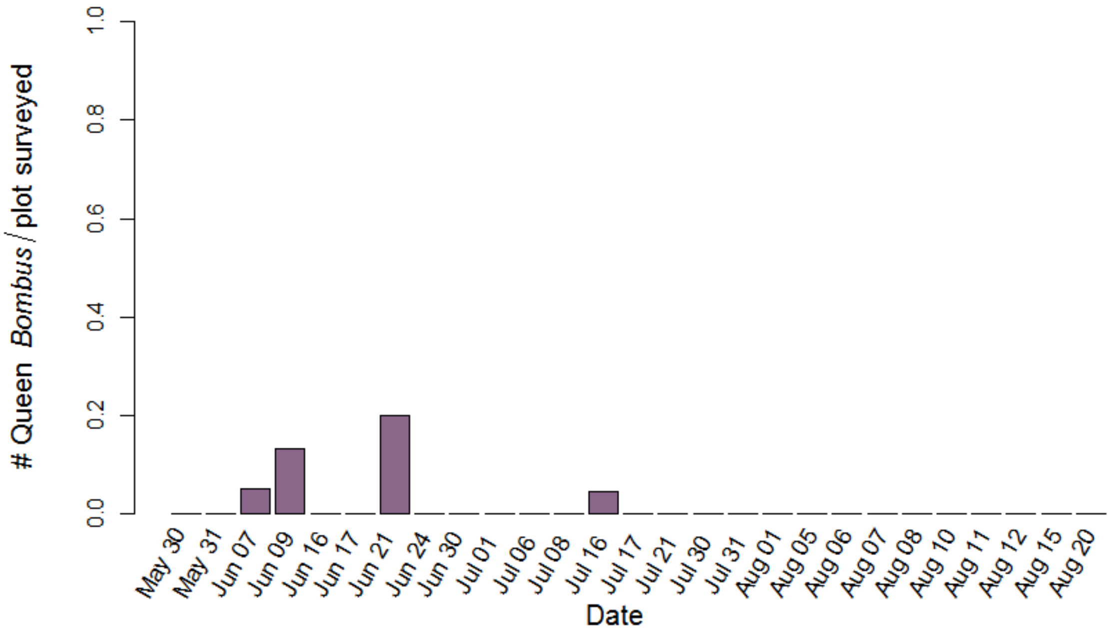

Figure 5. The number of queen bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Fred's fire.

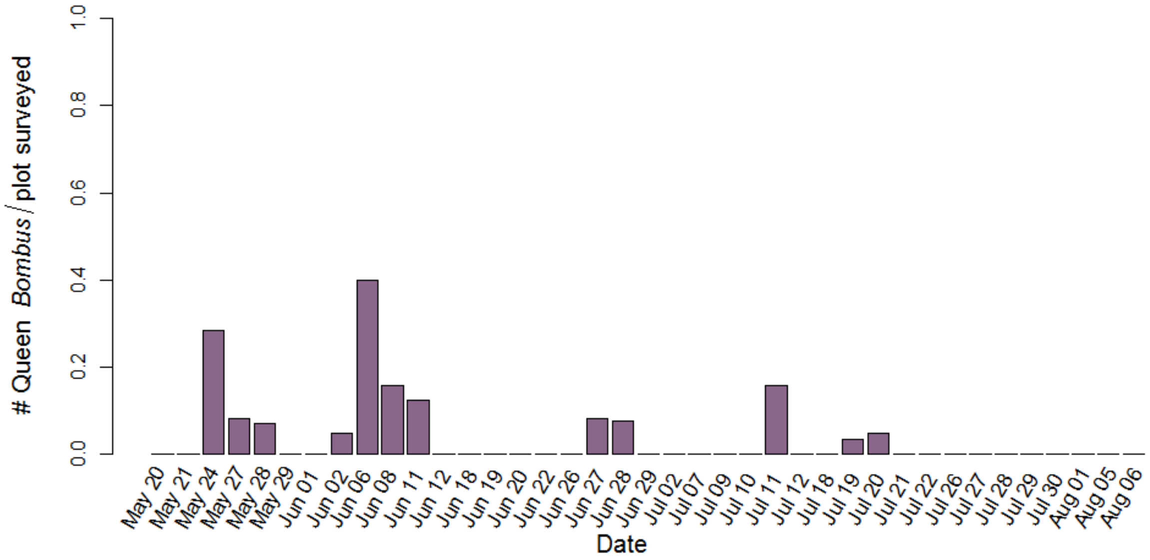

Figure 6. The number of queen bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Power fire.

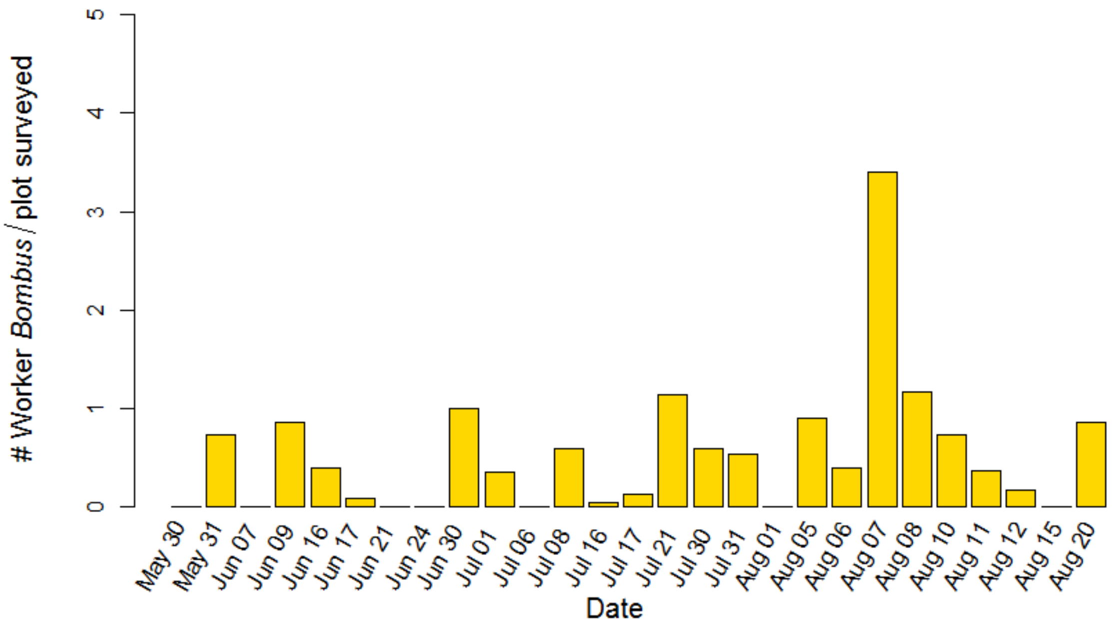

Figure 7. The number of worker bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Fred's fire.

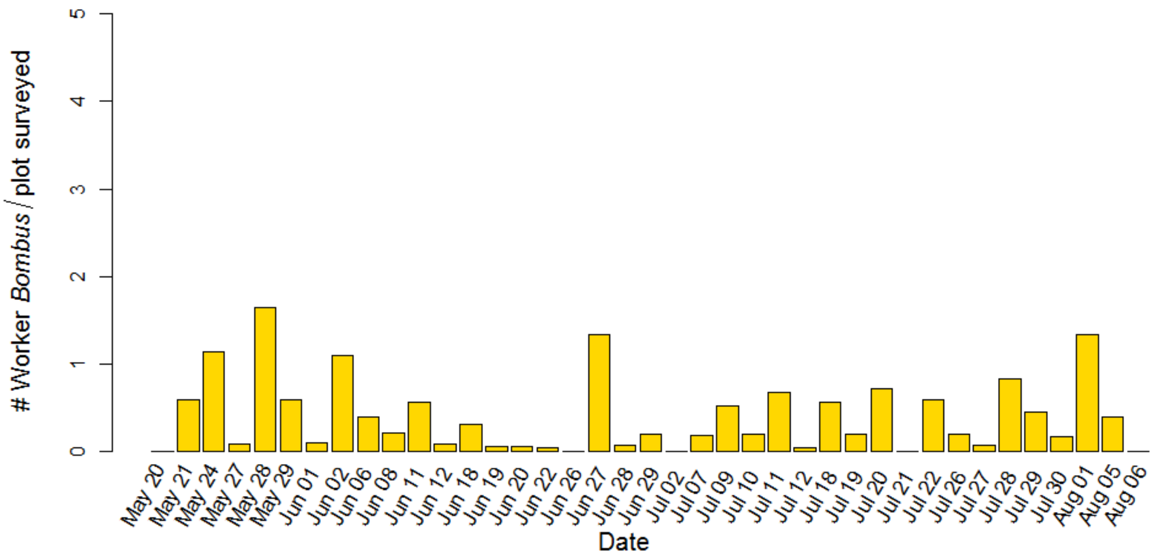

Figure 8. The number of worker bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Power fire.

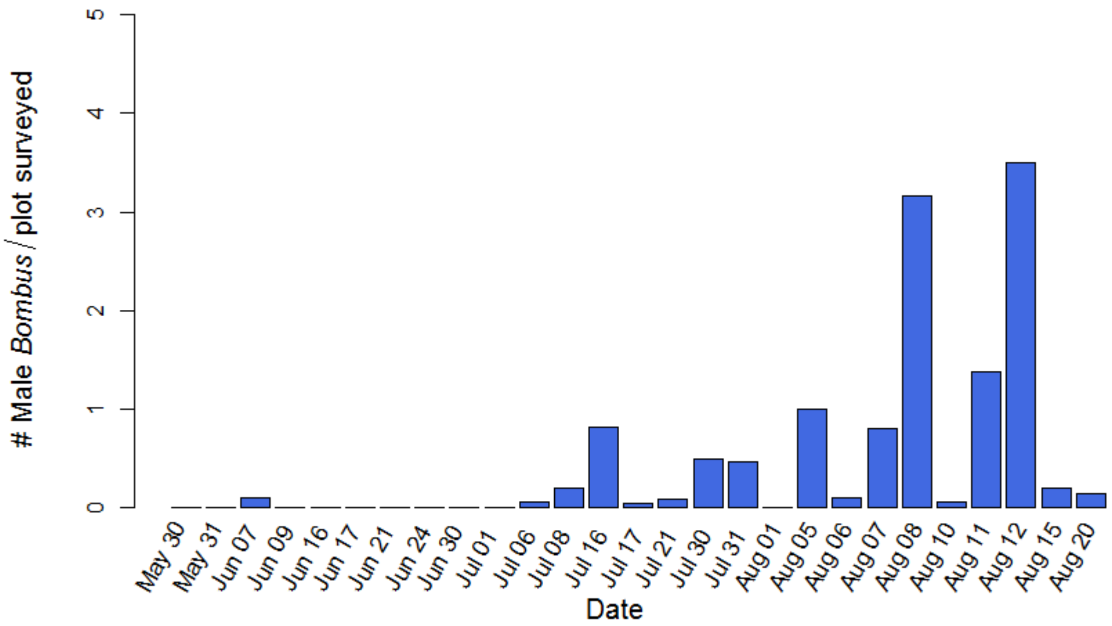

Figure 9. The number of male bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Fred's fire.

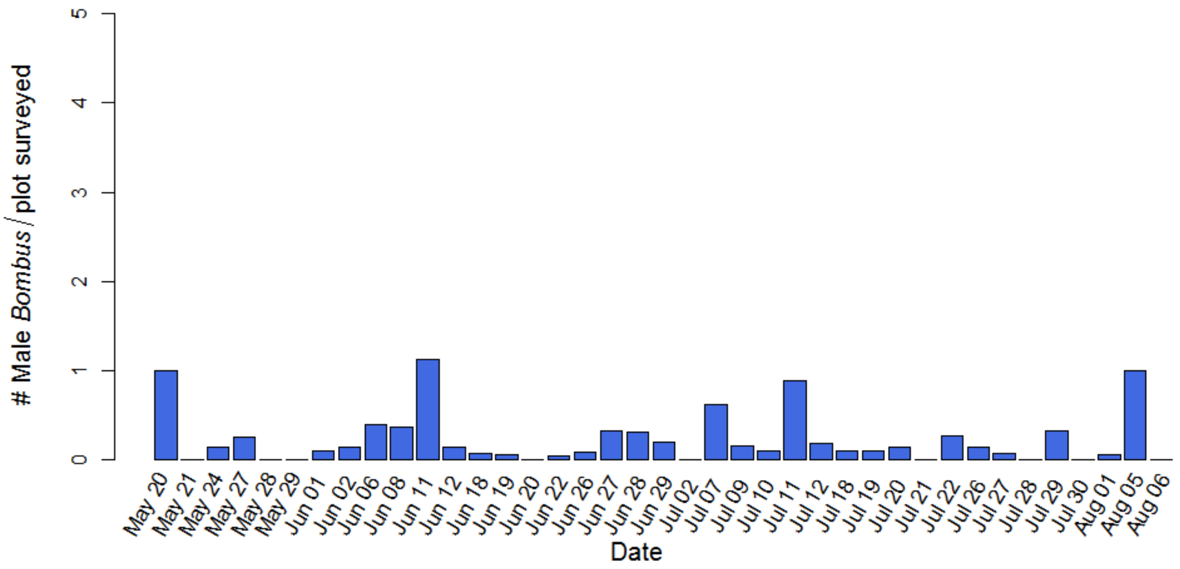

Figure 10. The number of male bumble bees (*Bombus* spp.) caught per plot surveyed by date in 2015 on the Power fire.

Pooling captures across all species, 61% (*n* = 412) of the captured bees were workers, 35% (*n* = 237) were drones, and 4% (*n* = 27) were queens. The timing of queen bumble bees (Fig. 5, Fig. 6), worker bumble bees (Fig. 7., Fig 8) and male bumble bees (Fig. 9, Fig. 10) was similar to what would be expected based on the bumble bee life cycle with queen bumble bees emerging first, followed by workers and then males later in the season (Williams et al. 2014). The timing of when different bumble bee species were caught also varied across the season; timing results by species are summarized in Appendix A.

Table 3. The number of plots surveyed for bumble bees by burn severity category (and plot type.

Burn Severity	Upland	Riparian	Total
Unchanged	54	15	69
Low	86	14	100
Moderate	126	22	148
High	147	31	178
Total	413	82	495

Bumble bee survey plots were located across a range of burn severities based on RdNBR (Relative differenced Normalized Burn Ratio; Miller and Thode 2007, Miller et al. 2009) with the highest number of plots located in high burn severity and moderate burn severity plots (Table 3). The average number of bumble bees per survey was not significantly different by burn severity category for either riparian ($F_{3,78}$ = 1.16, P = 0.33) or upland survey plots ($F_{3,409}$ = 0.96, P = 0.41; Fig. 11).

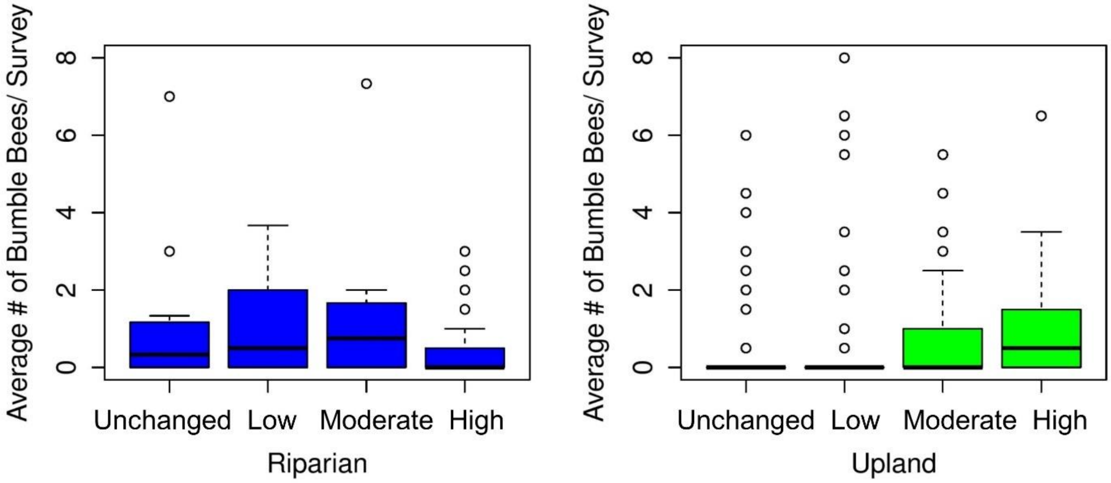

Figure 11. The average number of bumble bees per survey by burn severity based on RdNBR (Relative differenced Normalized Burn Ratio; Unchanged, Low severity, Moderate severity, and High severity), and plot type.

Species Richness Patterns

The average bumble bee species richness per plot was 0.61 ± 0.84 across both fires, 0.72 ± 0.96 on the Fred's fire (Fig. 12), and 0.56 ± 0.77 species on the Power fire (Fig. 13)**.** Our hierarchical community model of bumble bee species richness identified multiple important covariates of occupancy and detectability across the entire bumble bee community. Detectability of bumble bees was marginally affected by time of day, with the greatest detectability in the middle of the day (95% BCI on μ_{a2} = -0.18 – 0.47, μ_{a3} = -0.35 – 0.03). Day of year did not have a strong effect (95% BCI on μ_{a1} = -0.24 – 0.33). For occupancy parameters (Fig. 14), overstory

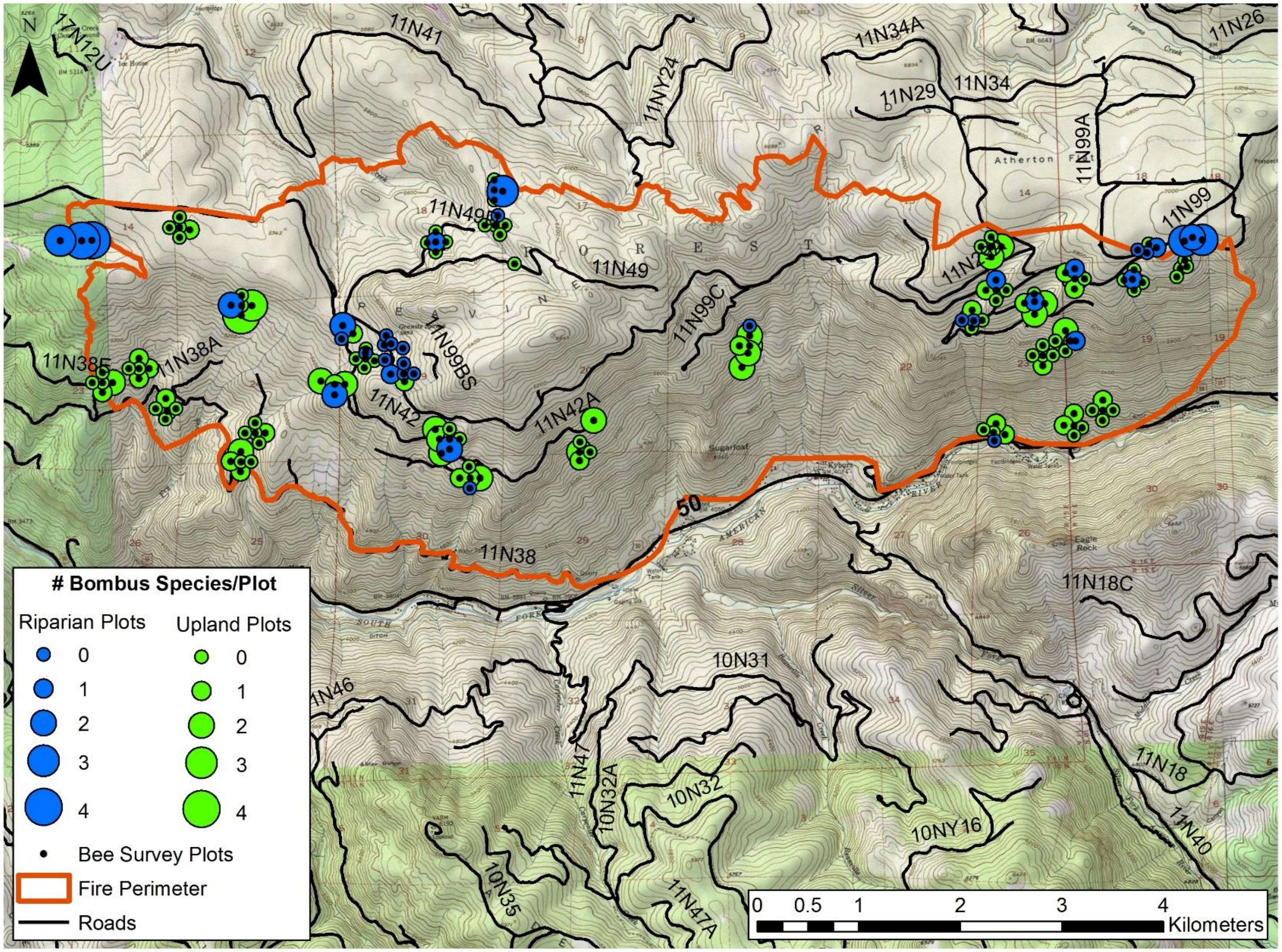

Figure 12. The total number of bumble bee (*Bombus*) species caught per plot on the Fred's fire in 2015.

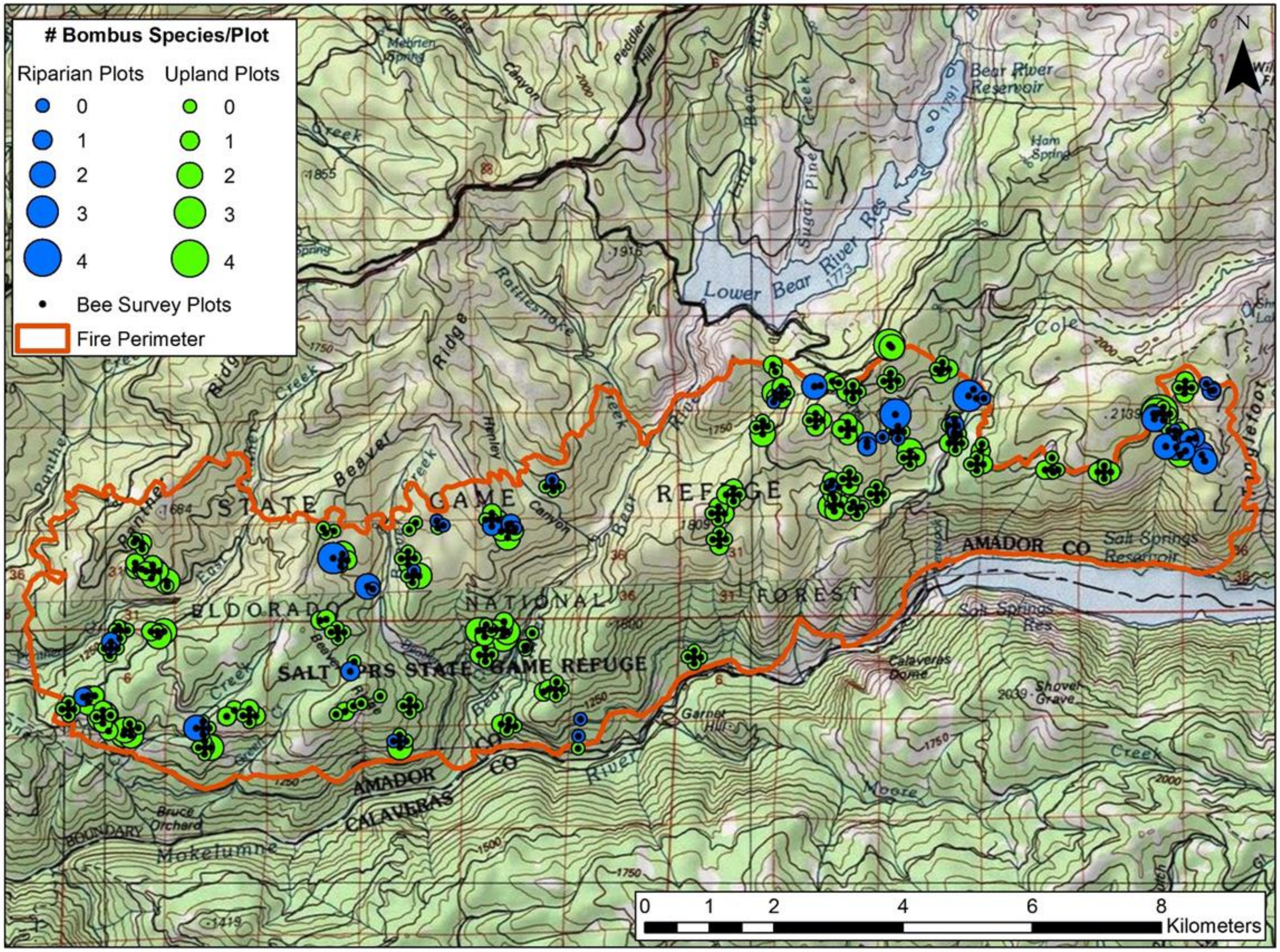

Figure 13. The total number of bumble bee (*Bombus*) species caught per plot on the Power fire in 2015.

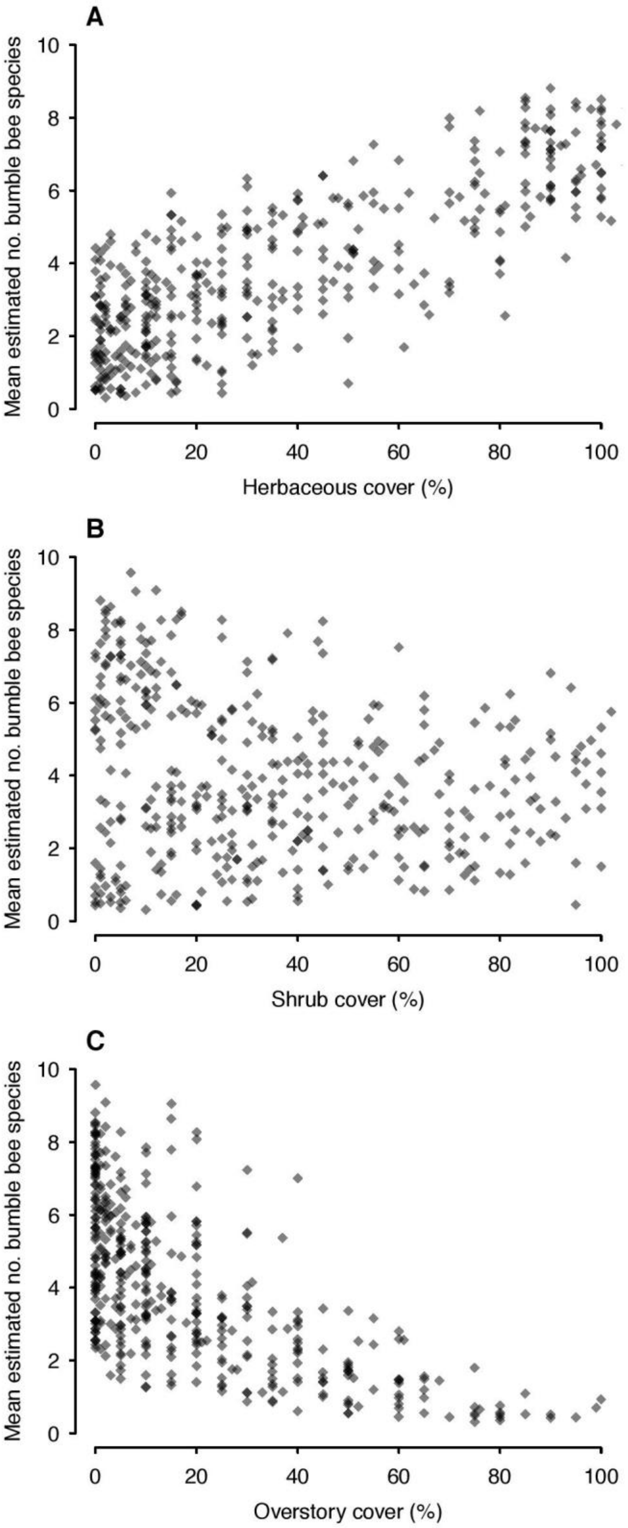

Figure 14. Mean estimated number of bumble bee species by the (A) herbaceous cover, (B) shrub cover, and (C) overstory cover.

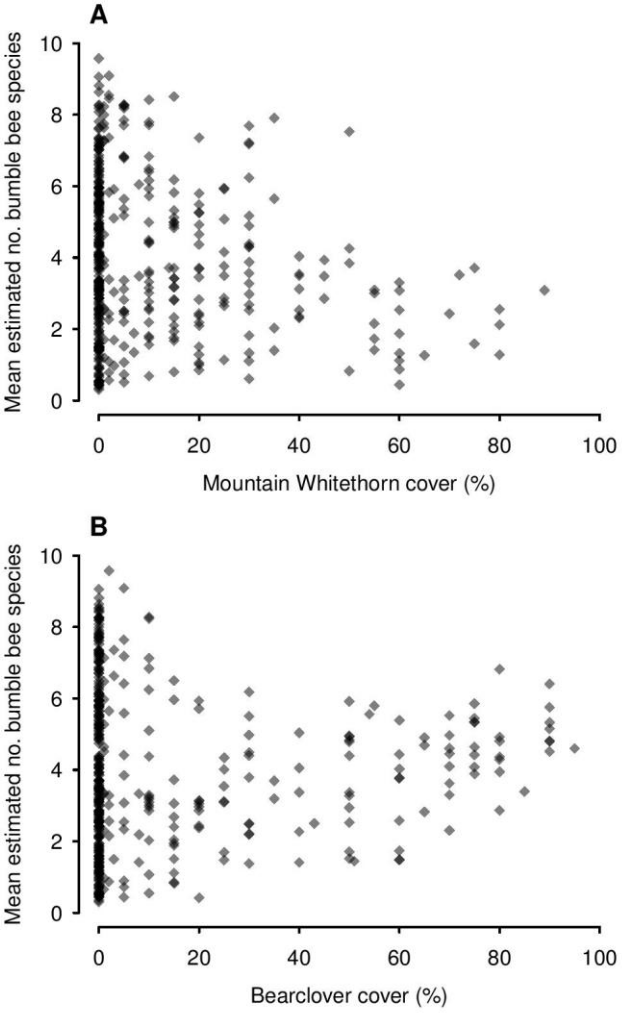

Figure 15. Mean estimated number of bumble bee species by the (A) mountain whitethorn (*Ceanothus cordulatus*) cover, and (B) bearclover (*Chamaebatia foliolosa*) cover.

cover had a significant negative effect on estimated bumble bee species richness (95% BCI on μ_{b4} = -3.06 – -0.41), herbaceous cover had a significant positive effect (95% BCI on μ_{b5} = 0.71 – 7.68), and total shrub cover had no significant effect (95% BCI on μ_{b3} = -2.34 – 0.56). For the two *a priori* selected chaparral plant species (Fig. 15), the amount of mountain whitethorn cover within a plot did not affect estimated bumble bee species richness (95% BCI on μ_{b6} = -1.11 – 1.34), while the amount of bearclover cover within a plot had a marginal positive effect (95% BCI on μ_{b7} = -0.71 – 4.87). Upland plots had significantly fewer bee species than riparian plots (95% BCI on μ_{b1} = -11.13 – 0.99) but there was no independent effect of elevation (95% BCI on μ_{b2} = -2.30 – 6.67). In terms of burn severity, within riparian plots there was no significant difference in bumble bee species richness by burn severity; however, within upland plots bumble bee species richness was significantly greater with higher burn severity (Fig. 16).

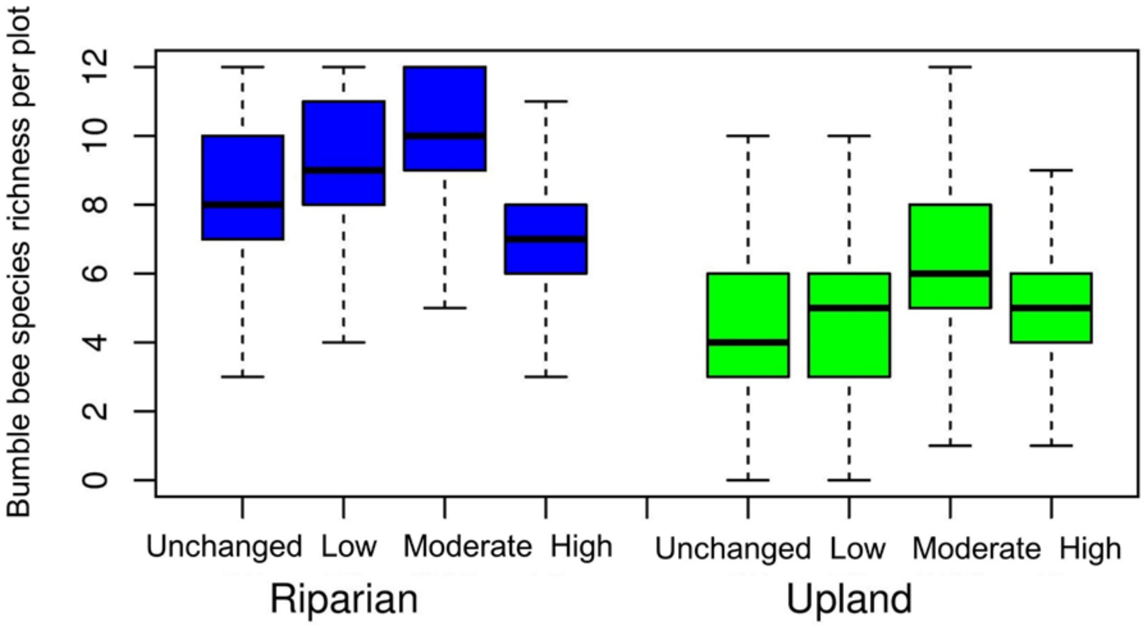

Figure 16. Bumble bee species richness per plot by burn severity based on RdNBR (Relative differenced Normalized Burn Ratio; Unchanged, Low severity, Moderate severity, and High severity), and plot type.

In addition to community-level inference, we found that several environmental covariates significantly affected likelihood of occurrence for particular bumble bee species (Table 4). Likelihood of occurrence increased significantly with elevation for 2 species, *B. flavifrons* and *B. mixtus* (Fig. 17A). In general *B. fernaldae, B. californicus,* and *B. vandykei* were located at the lowest elevations while *B. bifarius, B. appositus,* and *B. sylvicola* were located at the highest elevations (Fig. 18). While no bumble bee species had a significant relationship to total shrub (Fig. 17B) or mountain whitethorn cover (Fig. 17C), 3 species (*B. fernaldae*, *B. insularis*, and *B. vosnesenskii*) showed significant positive relationships to the amount of bearclover cover within a plot (Fig. 17D). The occupancy of one of those species, *B. vosnesenskii*, was also strongly and positively affected by herbaceous cover, although the effect size for bearclover (posterior mean = 1.72) was higher than for herbaceous cover (posterior mean = 0.98). In addition to *B. vosnesenskii*, occupancy of 6 other species (*B. californicus*, *B. flavifrons*, *B. insularis*, *B. mixtus*, *B. rufocinctus*, and *B. vandykei*) was also significantly and positively affected by the amount of herbaceous cover on a plot (Fig. 17E). The occupancy of 3 species (*B. californicus*, *B. vandykei*, and *B. vosnesenskii*) was negatively affected by overstory cover (Fig. 17F). Seven of the bumble bee species detected (*B. appositus*, *B. californicus*, *B. fernaldae*, *B. flavifrons*, *B. fernaldae*, *B. insularis*, *B. mixtus*, *B. sylvicola*) had higher occupancy in riparian plots than upland plots (Fig. 17G).

Table 4. The posterior mean parameter values for each covariate by bumble bee (*Bombus*) species. The sign of the value indicates whether there was a positive or negative relationship with the covariate. The covariates are upland plot type (Up), elevation (Elev), shrub cover (Shrub), mountain whitethorn (*Ceanothus cordulatus*) cover (Wthrn), bearclover (*Chamaebatia foliolosa*) cover (Bclov), herbaceous cover (Herb), and overstory cover (Over). Asterisks represent significance based on the 95% Bayesian credible interval.

Species	Up	Elev	Shrub	Wthrn	Bclov	Herb	Over
B. appositus	-5.20*	2.93	-0.60	-0.17	1.50	1.51	-1.28
B. bifarius	-3.61	2.96	-0.90	-0.23	1.47	1.74	-1.34
B. californicus	-3.78*	-1.06	-0.63	0.17	1.43	2.18*	-2.17*
B. fernaldae	-4.45*	-0.52	-0.53	-0.25	2.06*	1.32	-1.59
B. flavifrons	-4.27*	5.00*	-1.09	-0.37	1.08	2.04*	-0.79
B. insularis	-4.94*	0.76	-0.57	-0.43	1.78*	2.37*	-1.22
B. melanopygus	-3.46	2.53	-0.30	-0.08	1.23	0.91	-1.47
B. mixtus	-4.78*	4.10*	-0.74	0.20	1.15	1.77*	-1.56
B. rufocinctus	-3.36	1.00	-0.96	-0.28	1.46	2.47*	-1.67
B. sylvicola	-4.77*	1.94	-0.83	-0.10	1.48	1.47	-1.34
B. vandykei	-2.97	-0.54	-0.85	0.07	1.12	2.11*	-1.39*
B. vosnesenskii	-1.27	0.53	-0.49	-0.08	2.32*	1.09*	-1.46*

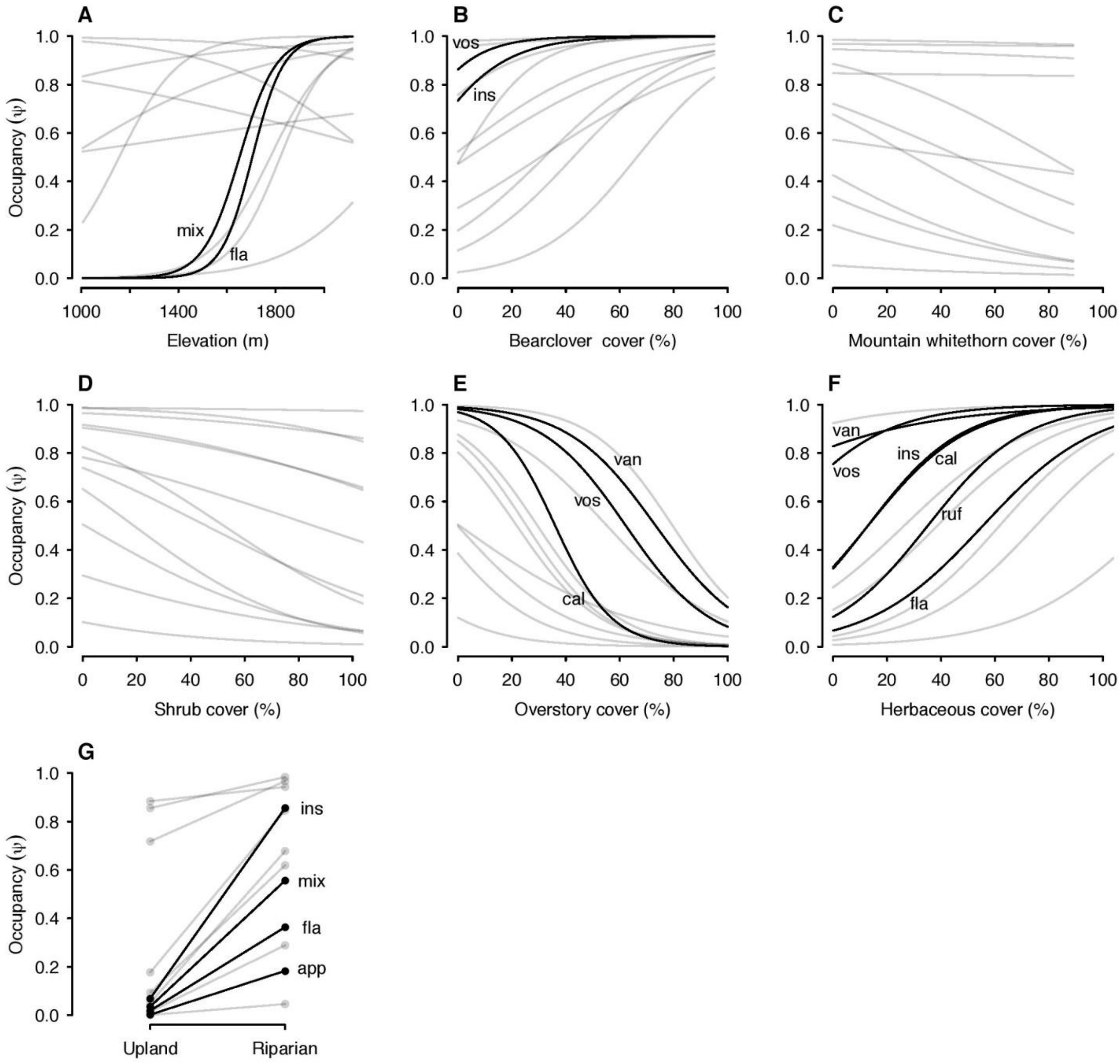

Figure 17. Modeled occupancy for each of the 12 bumble bee species detected in relationship to (A) elevation, (B) bearclover (*Chamaebatia foliolosa*) cover, (C) mountain whitethorn (*Ceanothus cordulatus*) cover, (D) shrub cover, (E) overstory cover, (F) herbaceous cover, and (G) plot type (upland or riparian). Lines represent the relationship for each bumble bee species and are black and labeled for significant relationships: *Bombus appositus* (app), *B. californicus* (cal), *B. flavifrons* (fla), *B. insularis* (ins), *B. mixtus* (mix), *B. rufocinctus* (ruf), *B. vandykei* (van), *B. vosnesenskii* (vos); lines in gray represent non-significant relationships. Note that cover estimates exceed 100% when multiple species of a vegetation group were overlapping.

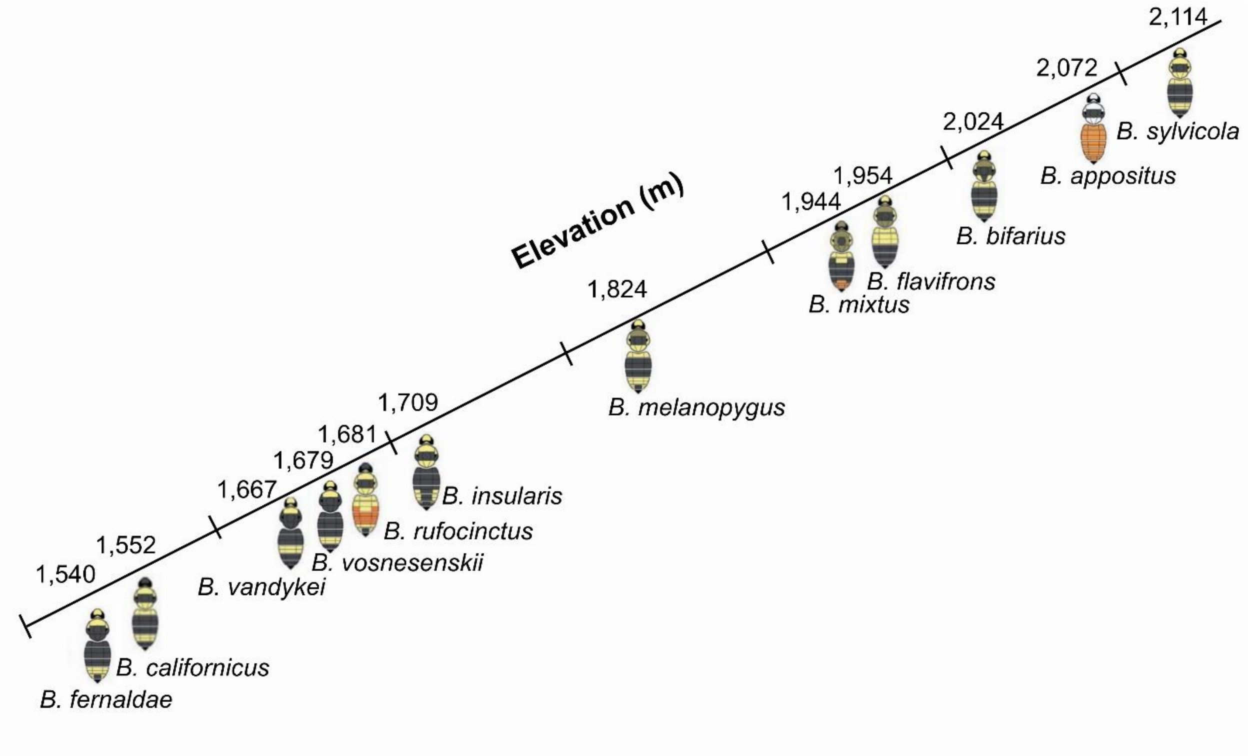

Figure 18. The average elevation where each bumble bee species was captured in 2015.

Foraging Use versus Availability of Blooming Plant Species

On a community-wide level we observed bumble bees foraging on 70 distinct plant species, all of which were identified on at least one plot as one of the 5 flowering plant species with the most inflorescences blooming during a survey (Appendix B). Bumble bees foraged on 5 plant species significantly more than expected based on their availability, and foraged on 17 species of plants significantly less than expected based on their availability across plots (Table 5). Among shrub species, bearclover was used in proportion to its availability, but because it was the most available blooming plant it was also the second most frequently used plant species, accounting for 14% (*n* = 94) of all bumble bee captures (Fig. 19). Mountain whitethorn was the second most available plant species but was rarely used by bumble bees, accounting for only 0.6% (*n* = 4) of all bumble bee captures. Deerbrush was another abundant shrub that was rarely used by bumble bees, accounting for only 0.4% (*n* = 3) of all bumble bee captures. Among herbaceous species, silverleaf phacelia (*Phacelia hastata*) was very highly preferred by bumble bees for foraging relative to its availability and accounted for 19% (*n* =131) of bumble bee captures (Fig. 5). Canada goldenrod (*Solidago canadensis*), Parish's yampah (*Perideridia parishii*), and hedge nettle (*Stachys albens*) were also used more than expected based on their availability. In addition, an invasive plant species, bull thistle (*Cirsium vulgare*), was used more than expected based on its availability. Herbaceous plants that were used significantly less than expected by bumble bees based on their availability included blue gilia (*Gilia capitata*), and diamond clarkia (*Clarkia rhomboidea*).

The timing of use of the availability of the most frequently used species (bearclover and silverleaf phacelia showed some overlap (Fig. 20A), however, the timing of use of those species showed little overlap (Fig. 20B). The number of captures of bees foraging on bearclover peaked on May 28, 2015 with an average of 1.43 bumble bees captured on bearclover per plot and then began to decrease until use reached close to zero by June 19, 2015. The first capture of a bumble bee foraging on silverleaf phacelia was not recorded until June 11, 2015, after which capture numbers increased to a peak of 3.8 bumble bees captured on silverleaf phacelia per plot on August 7, 2015.

Table 5. Floral species usage and availability for only those species that were used by bumble bees significantly less or significantly more for foraging than expected based on their availability. Usage is defined as the proportion of all bumble bee captures on a given plant species. Availability is defined as the proportion of times that each plant species was identified as one of the 5 flowering plant species with the most inflorescences blooming in a plot on the day of a survey across all plots. Class is used to indicate whether a species was used more than expected (1) or less than expected (-1) based on availability.

Scientific Name	Common Name	Usage	Availability	Class
Cirsium vulgare[a]	Bull thistle	0.077	0.024	1
Perideridia parishii	Parish's yampah	0.049	0.012	1
Phacelia hastata	Silverleaf phacelia	0.206	0.063	1
Solidago canadensis	Canada goldenrod	0.052	0.013	1
Stachys albens	Hedge nettle	0.030	0.006	1
Calystegia occidentalis	Bush morning glory	0.002	0.017	-1
Ceanothus cordulatus[b]	Mountain whitethorn	0.006	0.093	-1
Ceanothus integerrimus[b]	Deerbrush	0.005	0.044	-1
Clarkia rhomboidea	Diamond clarkia	0.017	0.050	-1
Eriogonum nudum	Nude buckwheat	0.019	0.048	-1
Erysimum capitatum	Western wallflower	0.002	0.008	-1
Gilia capitata	Blue gilia	0.028	0.062	-1
Hosackia oblongifolia	Meadow lotus	0.006	0.028	-1
Hypericum perforatum[a]	Klamathweed	0.006	0.024	-1
Iris hartwegii	Rainbow iris	0.002	0.016	-1
Lathyrus nevadensis	Sierra Nevada pea	0.006	0.022	-1
Penstemon laetus	Gay penstemon	0.002	0.014	-1
Pseudognaphalium beneolens	Cudweed	0.002	0.014	-1
Sidalcea glaucescens	Checker bloom	0.003	0.012	-1
Solanum xanti	Purple nightshade	0.003	0.023	-1
Verbascum thapsus[a]	Woolly Mullein	0.002	0.024	-1

[a] Non-native plant species for California

[b] Woody plant species

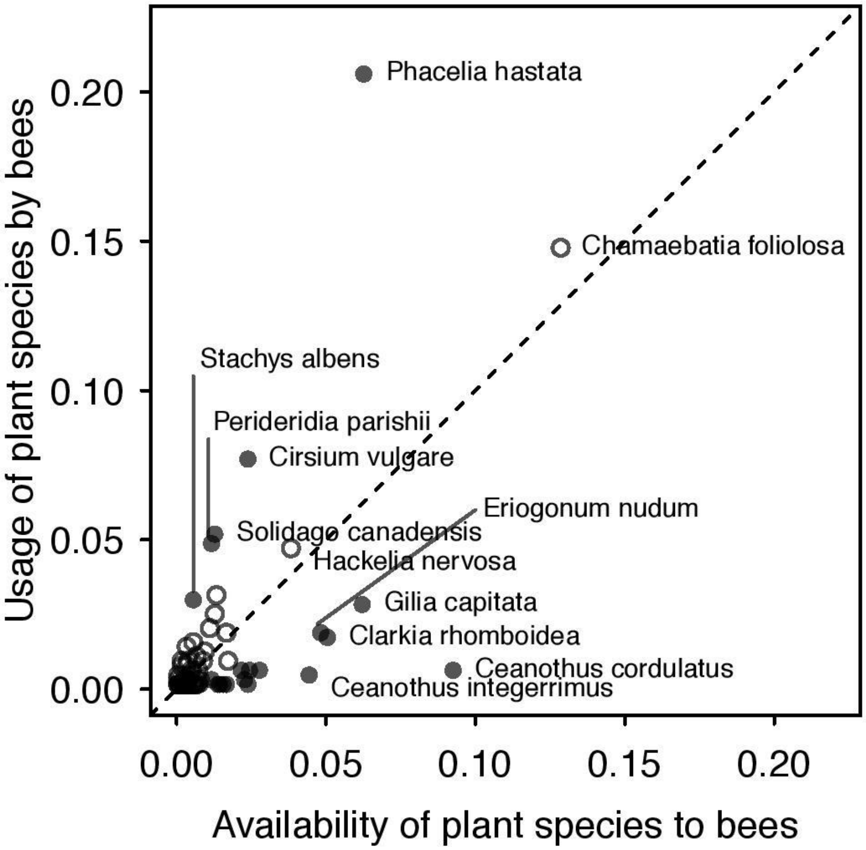

Figure 19. Usage versus availability of 70 plant species that bumble bees were observed foraging on during at least one instance. The dashed line represents a 1:1 line seperating species that were highly used by bumble bees (above the line) as compared to those that were used less than expected based on availability (below the line). Filled dots represent plant species that were used significantly more or less than expected based on bonferonni-corrected tests (Neu et al. 1974, Alldredge and Ratti 1986, Alldredge and Ratti 1992.

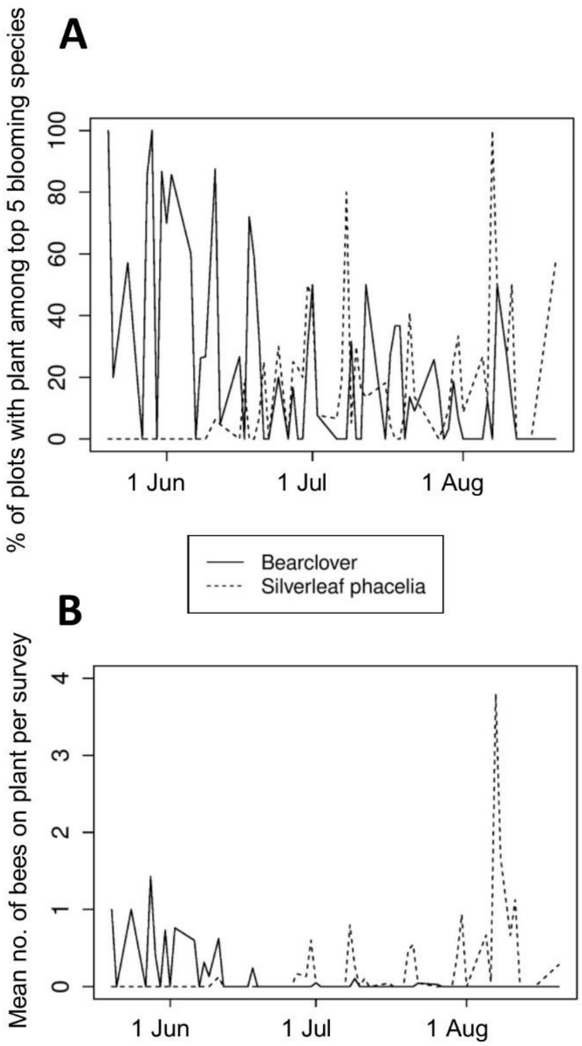

Figure 20. (A) The percent of plots surveyed with bearclover (*Chamaebatia foliolosa*) or silverleaf phacelia (*Phacelia hastata*) among the top 5 blooming plant species by day in 2015, and (B) the mean number of bumble bees captured on bearclover and silverleaf phacelia per survey by day in 2015.

There were also common bumble bee floral associations by bumble bee species that were observed based on which plant species bumble bees were foraging on when they were captured (Table 6). Our most abundant bumble bee species, *B. vosnesenskii*, was observed foraging on bearclover the most followed by silverleaf phacelia, bull thistle, Sierra stickweed (*Hackelia nervosa*) and Parish's yampah (*Perideridia parishii*). Our second most abundant bumble bee species, *B. vandykei*, was observed foraging on silverleaf phacelia the most followed by hedge nettle (*Stachys albens*), bull thistle, and Canada goldenrod (*Solidago canadensis*).

Table 6. The total number of bumble bees captured by species across all plots surveyed in 2015, and the most common floral species associations with the percent of captures of each bumble bee species that occurred on that plant species.

Species	Total Captures	Most Common Floral Species Associations
B. appositus	2	100% - In-flight
B. bifarius	1	100% - *Spiraea splendens* (mountain spiraea)
B. californicus	16	19% - *Cirsium vulgare* (bull thistle), 19% - *Phacelia hastata* (silverleaf phacelia)
B. flavifrons	14	21% - *Phacelia hastata* (silver-leaf phacelia)
B. fernaldae	3	33% - *Cirsium vulgare* (bull thistle), 33% - *Clarkia rhomboidea* (diamond clarkia), 33% - *Solidago canadensis* (Canada goldenrod)
B. insularis	16	19%- *Gilia capitata* (blue gilia)
B. melanopygus	11	18% - *Chamaebatia foliolosa* (bearclover)
B. mixtus	19	42% - *Perideridia parishii* (Parish's yampah), 11% - *Spiraea splendens* (mountain spiraea)
B. rufocinctus	4	50% - *Solidago canadensis* (Canada goldenrod)
B. sylvicola	2	100% - *Eriogonum nudum* (nude buckwheat)
B. vandykei	109	9% - *Cirsium vulgare* (bull thistle), 35% - *Phacelia hastata* (silverleaf phacelia), 9% - *Solidago canadensis* (Canada goldenrod), 14% - *Stachys albens* (hedge nettle)
B. vosnesenskii	479	19%- *Chamaebatia foliolosa* (bearclover), 8% - *Cirsium vulgare* (bull thistle), 5%- *Hackelia nervosa* (Sierra stickweed), 5%- *Perideridia parishii* (Parish's yampah), 18%- *Phacelia hastata* (silverleaf phacelia)

Other Pollinators

During 2015 bumble bee and vegetation surveys surveyors also made note of any observations of monarch butterflies (*Danaus plexippus*) and milkweed plants (*Asclepias cordifolia, Asclepias speciosa,* and *Asclepias fascicularis*) on plots. Surveyors observed 89 monarch butterflies on 63 unique plots with an average of 0.18 ± 0.58 monarch butterflies per plot across all plots (Fig. 21, Fig. 22). Milkweed plants were observed on 21 plots and ranged in estimates of 1-50+ plants per plot (Fig. 21, Fig. 22). There were 12 plots with 1-10 milkweed plants, four plots with 11-30 plants, three plots with 31-50 milkweed plants, and two plots with >50 milkweed plants. Only 6 of the plots where milkweed was found were also locations where monarch butterflies were observed during surveys.

Surveyors also noted any observations of hummingbirds in survey plots during bumble bee surveys and identified them to species when possible. A total of 60 hummingbirds were observed on 32 unique plots: 4 Anna's Hummingbirds (*Calypte anna*), 2 Calliope Hummingbirds (*Selasphorus calliope*), 16 Rufous Hummingbirds (*Selasphorus rufus*), and 38 unidentified hummingbirds. There was an average of 0.12 ± 0.57 hummingbirds observed per plot across all plots (Fig. 23, Fig. 24).

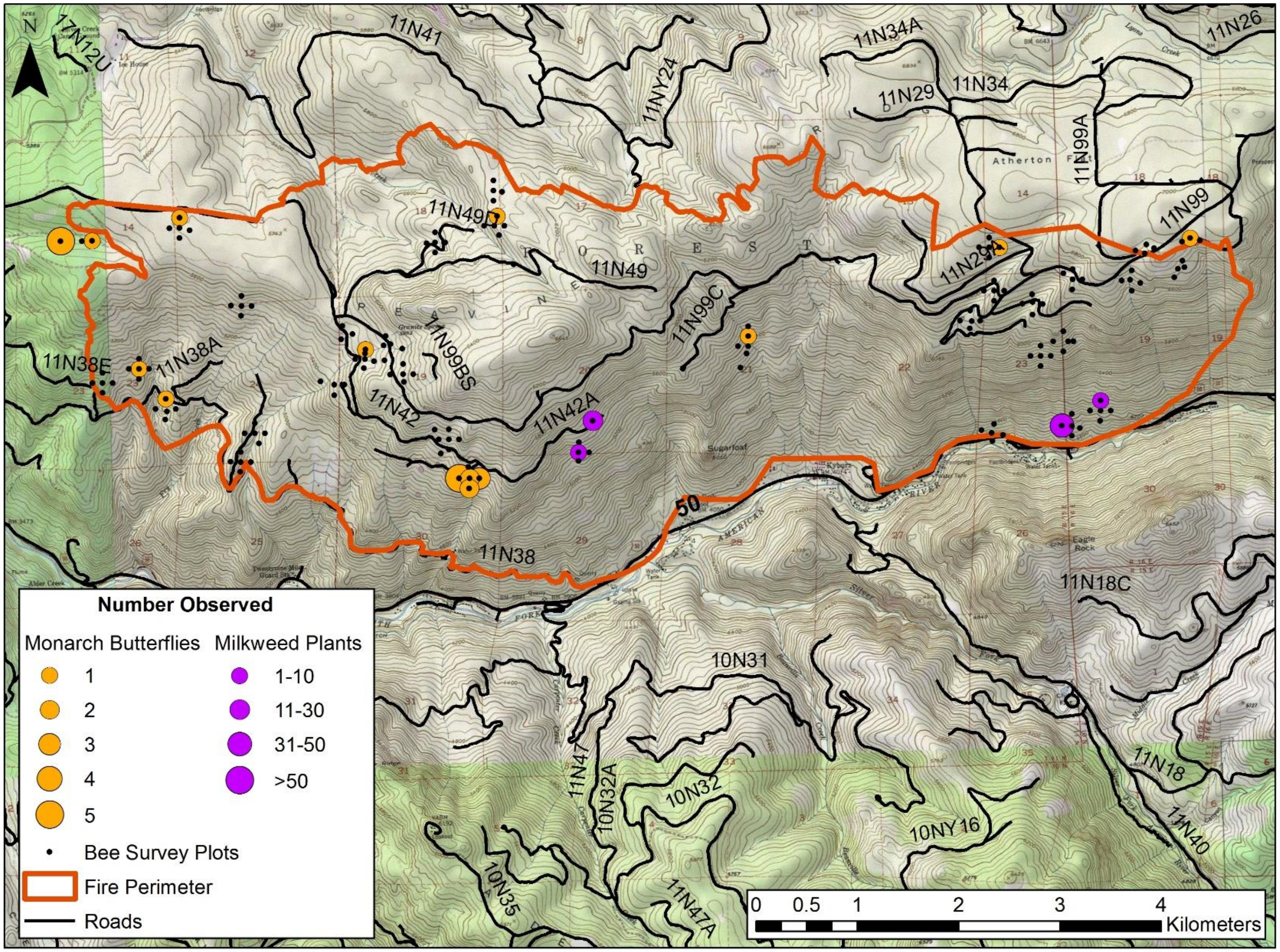

Figure 21. The location and number of monarch butterflies observed during bumble bee surveys by plot on the Fred's fire in 2015.

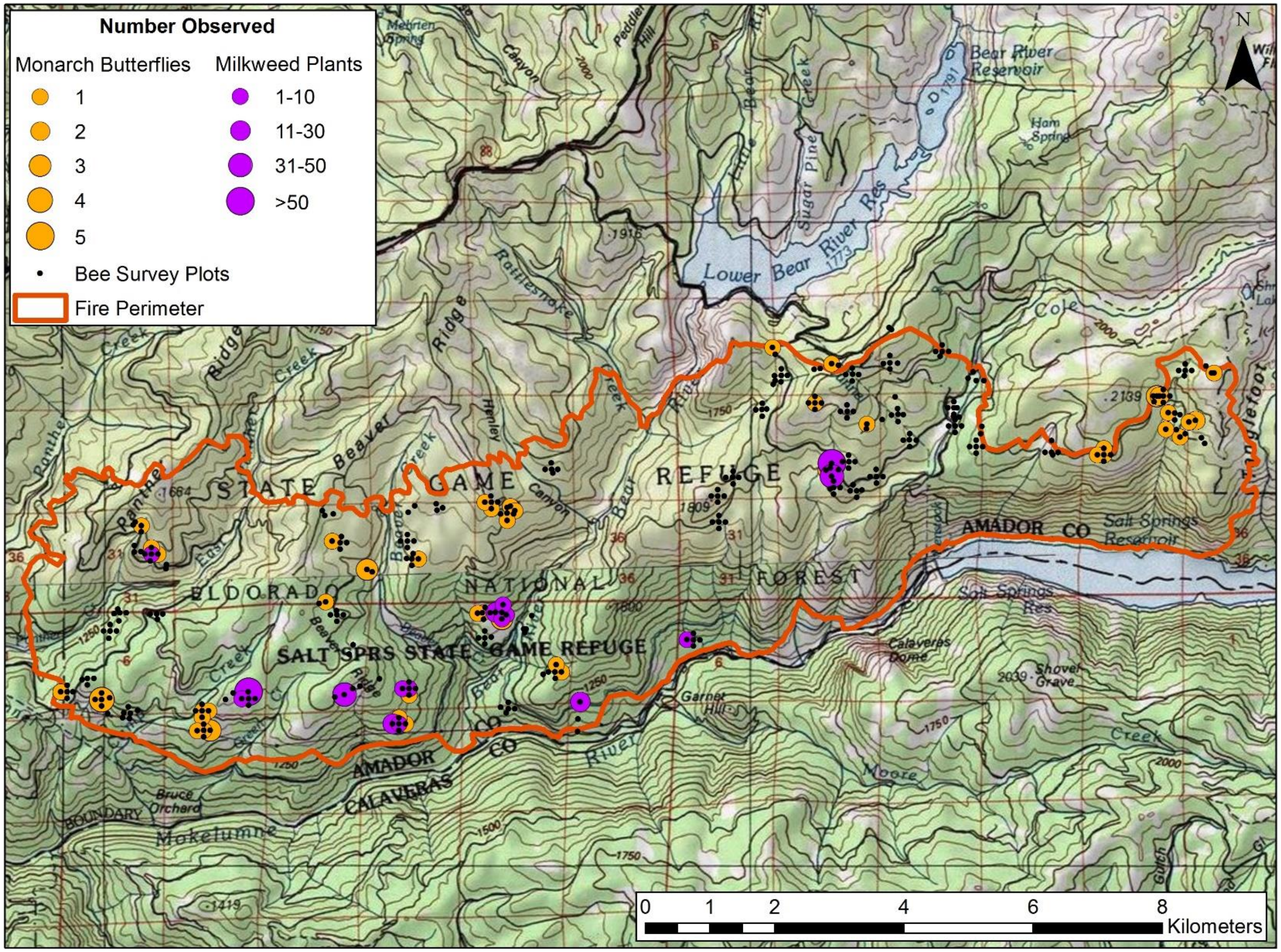

Figure 22. The location and number of monarch butterflies observed during bumble bee surveys by plot on the Power fire in 2015.

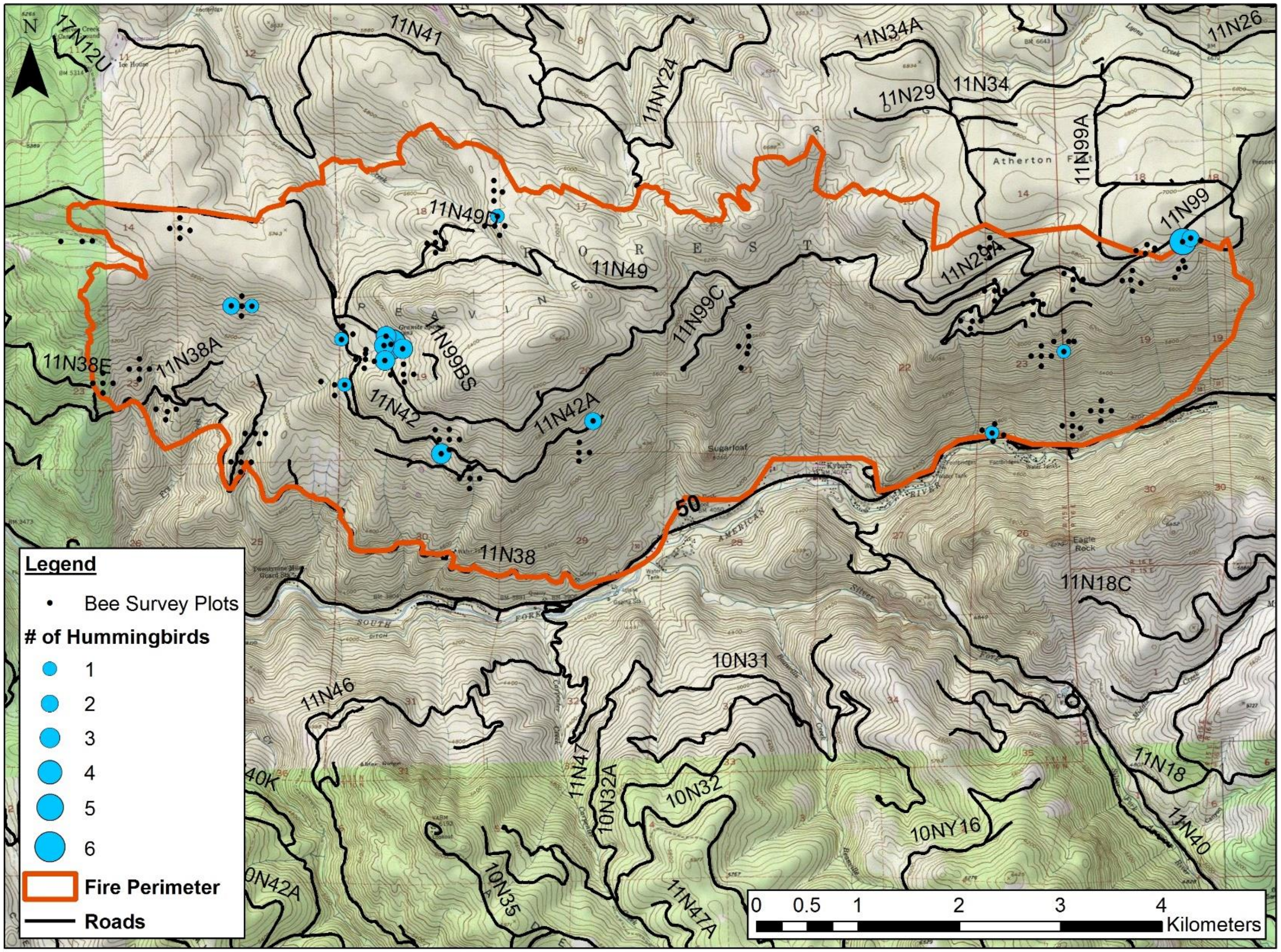

Figure 23. The location and number of hummingbirds observed during bumble bee surveys by plot on the Fred's fire in 2015.

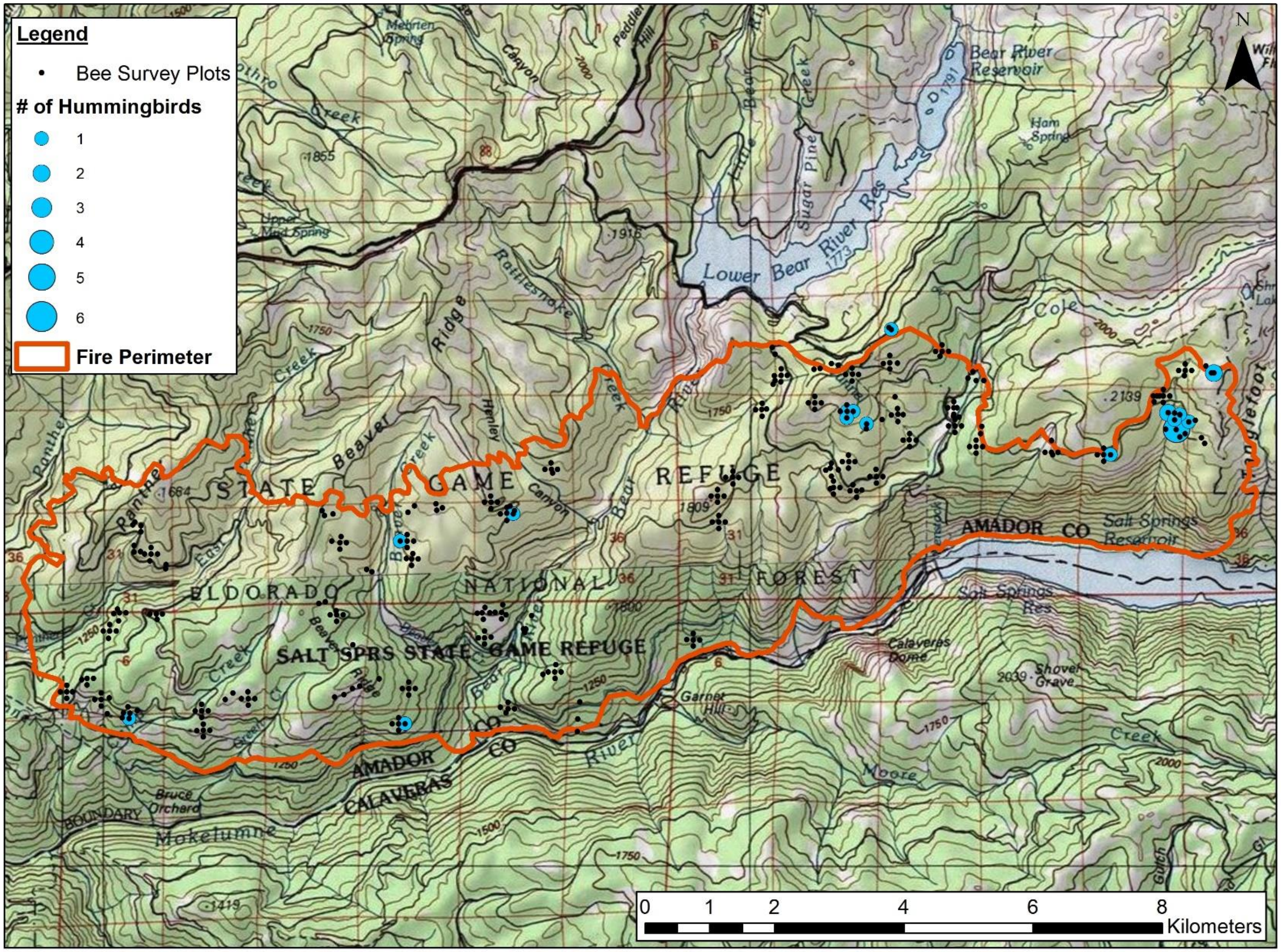

Figure 24. The location and number of hummingbirds observed during bumble bee surveys by plot on the Fred's fire in 2015.

DISCUSSION

We found 12 bumble bee species (including two cuckoo, or parasitic, species: *B. fernaldae* and *B. insularis*) across all surveys in montane upland and riparian plots on the Fred's and Power fires, accounting for 46% of the estimated 26 bumble bee species in California and 60% of the estimated 20 bumble bee species in the Sierra Nevada (Thorp et al. 1983). The majority of the individual bumble bees we captured were of 2 common species (*B. vosnesenskii* and *B. vandykei*), with the remaining species represented by relatively few captures each. Other researchers have observed similar distributions of species within bumble bee communities in the Sierra Nevada and elsewhere, and evidence suggests that the relative rarity of many species is due to related to their having narrower diets than common species (Goulson and Darvill 2004, Goulson et al. 2005, Griswold and Ikerd 2008). Some common species like *B. vosnesenskii* may also emerge earlier than other species in the spring to obtain an advantage in finding nest sites (McFrederick and LeBuhn 2006), but nest sites for species that utilize rodent burrows or tree cavities seem unlikely to be a limiting factor in our study areas.

Understanding the characteristics that allow some plant communities to be used by bumble bees more than others is important for guiding management decisions that can support bumble bee conservation. At our two study sites, post-fire upland areas dominated by montane chaparral supported a noteworthy diversity and abundance of bumble bees. While bumble bee species richness was greater in riparian habitats, abundance was similar between riparian and upland plots. At our study sites there were relatively few meadows, and most riparian habitat was restricted to narrow borders along stream channels in low gradient areas. Previous research has demonstrated the importance of meadows and other riparian habitats to bumble bees in montane ecosystems (Kremen et al 2004, Hatfield and LeBuhn 2007), but our findings indicate that chaparral-dominated upland habitats, which are often much more extensive across montane landscapes than riparian vegetation, may also be highly beneficial to bumble bees. Additionally, riparian habitats are inherently fragmented and localized across montane landscapes, and for bumble bees, chaparral may provide north-south connectivity between more isolated riparian and meadow areas that tend to cluster along east-west corridors in the region (Lozier et al. 2013).

Some of the habitat characteristics that we found to be associated with bumble bees in montane chaparral were consistent with previous research in other post-fire ecosystems. We found that bumble bee species richness was negatively associated with the amount of overstory tree cover remaining after fire, consistent with bee species richness across multiple genera in New Jersey (Winfree et al. 2007) and with findings of bee abundance across multiple genera in Indiana (Grundel et al. 2010). Furthermore, our finding of a positive association between herbaceous cover and bumble bee species richness is consistent with previous research that found the same trend with insects in general after fire in North Carolina (Campbell et al. 2007), likely due to the increase in abundance of floral resources. Ne'eman and Dafni (1999) found the herbaceous plant community structure in post-fire landscapes favors larger social bee species compared to small solitary species and that the increase in available light and soil minerals in burned areas increases the magnitude and growth of flowering plants (Ne'eman et al. 2000). The temporary increase in available floral resources, in close proximity to nesting habitat provided by snags and bare ground may provide optimum nesting conditions (Taylor and Catling 2012, Bogusch et al. 2014). In burned pine forests in Central Europe, Bogusch et al. (2014) found that hymenopteran richness was orders of magnitude greater in burned forest compared to unburned forest (especially for at-risk taxa), with maximum species richness occurring 3 years after fire.

Similarly, Moretti et al. (2009) found a significant decrease in bee species richness and species composition in Israel and Switzerland as the time since fire increased and herbaceous cover decreased, with older post-fire sites eventually returning to lower levels of bee diversity observed at unburned sites.

Particularly useful for developing bee-friendly land management strategies was our finding that some chaparral species were much more heavily used by bumble bees than others. Estimated bumble bee species richness was positively affected by bearclover cover, which was the second most frequently used blooming plant species by foraging bumble bees. For our most common bee species, *B. vosnesenskii,* bearclover cover was an even stronger predictor of occupancy than herbaceous cover. Our findings suggest that within montane chaparral, bearclover is a primary floral resource whose presence may largely support foraging bumble bees. Conversely, mountain whitethorn and deerbrush were abundant on the landscape but were rarely used by foraging bumble bees. Pollinator surveys in Yosemite National Park during the early 2000's corroborate our results (Griswold and Ikerd 2008): over 3 years of sampling, 6 *Bombus* species (*B. fernaldae, B. insularis, B. bifarius, B melanopygus, B. mixtus,* and *B vosnesenskii*) were observed foraging on bearclover while only 3 *Bombus* species (*B. vosnesenskii, b. balteatus*, and *B. melanopygus*) were observed foraging on all *Ceanothus* species combined. In our study however, we recorded anecdotal observations of other insect pollinators foraging on mountain whitethorn and deerbrush in abundance, and previous research in California has shown the importance of *Ceanothus* for multiple genera of bees (Thorp et al. 1983, Potts et al. 2003), suggesting that land managers interested in meeting the needs of all native pollinators should not discount the possible importance of *Ceanothus* species.

Our findings provide land managers interested in bumble bee conservation with a rationale for prioritizing stands dominated by bearclover over *Ceanothus*-dominated stands when selecting which chaparral stands to retain. Because occupancy rates of individual bumble bee species were affected in different ways by habitat characteristics, where possible life history traits (e.g., nesting habits, floral resource associations, and elevational ranges) of particular bumble bee species (e.g., species of conservation concern, or species known to be present in the area) should be considered when assessing the relative value of different chaparral stands at a site.

While we found that bearclover was a primary floral resource for bumble bees in montane chaparral, we also observed a perennial forb, silverleaf phacelia, which, along with several other *Phacelia* species, is a frequent chaparral associate after forest fire (Quinn and Keeley 2006), to be highly preferred by bumble bees and used significantly more often than would be expected based on its relative availability in our study area. We also detected bumble bees foraging on three additional *Phacelia* species: Quick's phacelia (3 individual bees), low phacelia (6 bees), and caterpillar phacelia (1 bee). Our finding regarding the value of silverleaf phacelia and possibly the entire *Phacelia* genus to bumble bees was also supported by work in Yosemite National Park, where *Phacelia* was the 6th most frequently used plant genus for all bee taxa pooled (883 bees), and 9 bumble bee species were recorded foraging on silverleaf phacelia (Griswold and Ikerd 2008).

In our study, bearclover and silverleaf phacelia together accounted for one-third of all bumble bee captures, supporting previous suggestions that a small proportion of blooming plant species can support a large percentage of foraging bumble bees (Goulson and Darvill 2004, Goulson et al. 2005). Also interesting from both a life history and habitat management standpoint was the timing of use for these two primary forage plant species. Bearclover blooms heavily during April through early June in our study area, with limited re-bloom later in the summer. Although silverleaf phacelia is known to bloom as early as May (Baldwin et al. 2012), it increased in our study area through June and July as bearclover blooms became scarce. The temporal stratification in blooming by these two species suggests the value of heterogeneous upland habitat at a spatial scale that ensures a variety of forage species within average foraging distances for bumble bees; usually 100–1000 m (Elliot 2009). For an area to sustain multiple broods per year within a bumble bee colony, it must be rich in pollen and nectar from early spring when foundress queens prepare their nest stores, to midsummer when workers emerge to forage for subsequent broods, and finally into late summer and fall, when new queens increase their caloric intake to prepare for overwintering. Therefore, at least in the central Sierra Nevada, areas with a mosaic of bearclover and forbs (especially silverleaf phacelia) may best meet the needs of colonies from early spring queen emergence through fall preparation for hibernation.

We also found that a non-native plant species, bull thistle, was highly preferred by bumble bees for foraging, and was observed to be used by 6 bumble bee species (including 2 cuckoo species). Both native and non-native *Cirsium* spp. are well documented as forage species for bumble bees (Thorp et al. 1983, Williams et al. 2014). Non-native plants have previously been found to support bee communities across multiple bee genera (Tepedino et al. 2008), and could potentially play a role in conservation efforts, but only under careful consideration for possible deleterious consequences on other ecosystem components or processes (Schlaepfer et al. 2011).

Despite its clear value to bumble bees and other wildlife, chaparral within the Sierra Nevada is often treated as a nuisance in the context of reforestation and fire protection, and suppressed or removed by land managers (McGinnis et al. 2010). Our results indicate that some montane chaparral shrubs, and herbaceous plants that often associate with them after forest fire, are highly valuable for foraging bumble bees.

Management Suggestions

We urge forest managers to retain mosaics of montane chaparral shrubs and herbaceous vegetation where feasible in the context of post-fire forest regeneration efforts, to maximize bumble bee foraging resources across time and space. When chaparral removal does occur, our results suggest that stands dominated by bearclover should be prioritized for retention over stands dominated by *Ceanothus* species (e.g., mountain whitethorn, deerbrush), at least where bumble bee habitat conservation is a priority. However, we caution that some retention of other chaparral shrub species should be considered as well, to maintain a diversity of plants for other pollinators and wildlife species. Retaining diverse patches of herbaceous plant cover, including those species preferentially used by bumble bees in our study (e.g., silverleaf phacelia), would also be beneficial for bumble bees. To this end, chemical and hand treatments in plantations should be limited to target species so the disturbance to native herbaceous vegetation is minimized. Because we found that both upland and riparian variables predicted increased bumble bee species richness and because bumble bees require foraging resources that bloom across the spring, summer and fall, retaining chaparral patches that occur adjacent to riparian buffers may provide the greatest temporal continuity in foraging resources.

At higher elevations where bear clover is rare or absent, reforestation practices should strive to retain over the longer term forest canopy gaps where other shrubs and herbaceous plants may thrive and provide floral resources for bumble bees and other pollinators. Furthermore, managers may wish to consider actively seeding with forb species that are used frequently by bumble bees. Bumble bees are unable to move their colonies within a season, so the availability of pollen and nectar within the foraging radius of individual nests directly affects the size and success of bumble bee colonies and populations (Elliot 2009, Roulston and Goodell 2011). We therefore recommend that when mechanical or chemical treatment of chaparral plant species used by bumble bees does occur, it be delayed, where feasible, until after the local peak bloom period. For noxious weed abatement (especially noxious forbs known to provide bumble bee forage) where herbicide treatment must occur early in the season, we recommend re-seeding with native forage plants to replace foraging resources that are lost.

ACKNOWLEDGMENTS

This project was made possible by funding from the U.S. Forest Service Eldorado National Forest Office. We thank Erin Elsey for providing bumble bee training and assistance in bumble bee identification during the field season. We thank our field crew for collecting the data: Micheal Finnell (crew leader), Katie Burns, Keleigh Dietsch, and Brendan Tinsley. This project was conducted by The Institute for Bird Populations' Sierra Nevada Bird Observatory and is Contribution No. 533 of The Institute for Bird Populations.

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APPENDIX A. Seasonal timing of capture for each bumble bee species at each fire. Figures A.1 – A.9 describe captures on the Fred's fire and Figures A.10 – A.18 describe captures on the Power fire.

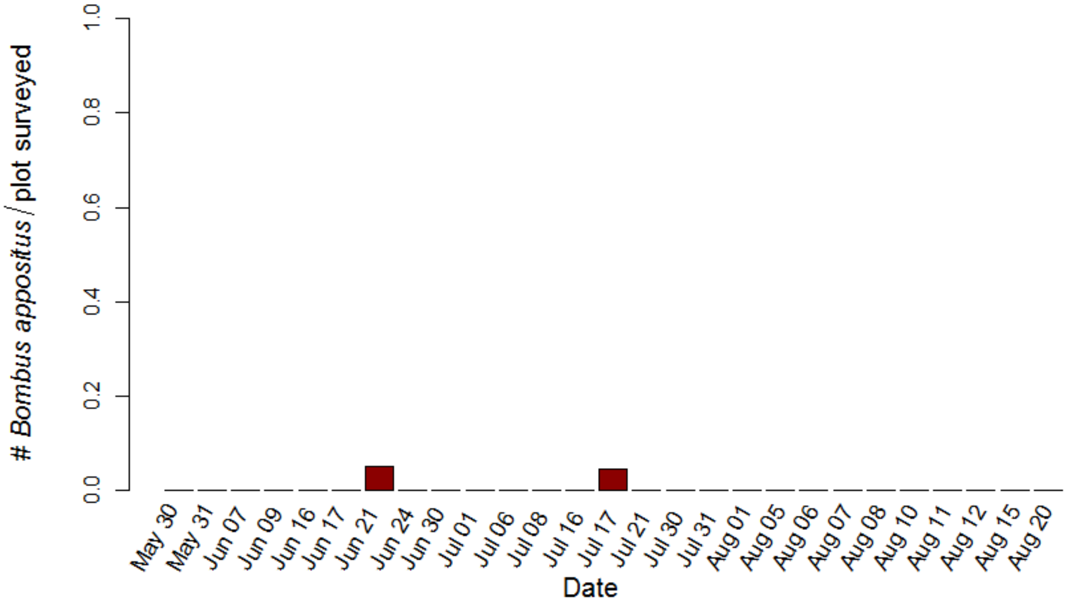

Figure A.1. The number of *Bombus appositus* captured per plot surveyed by date in 2015 on the Fred's fire.

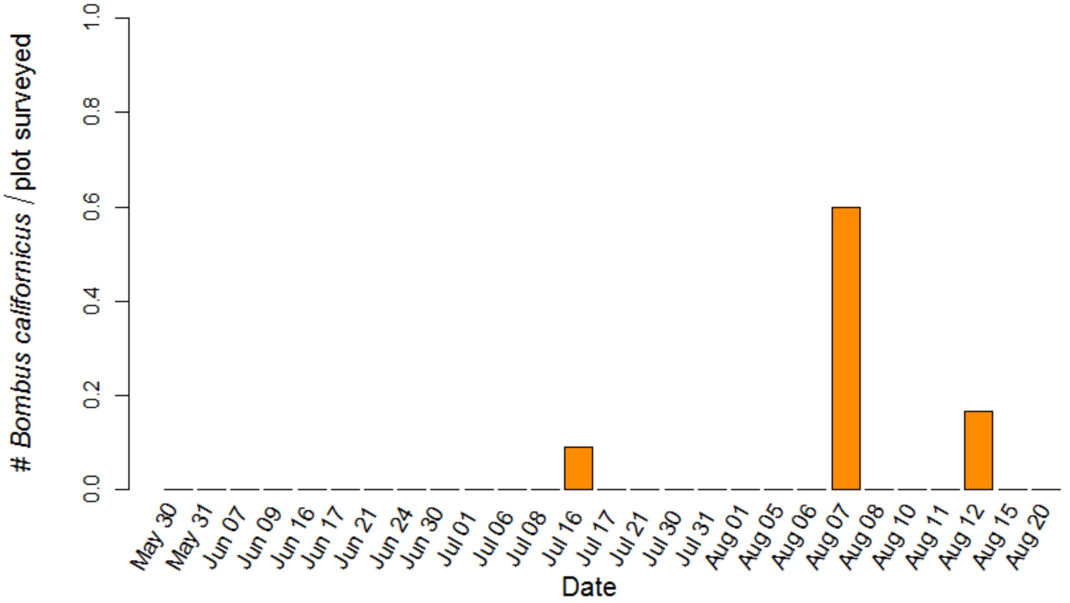

Figure A.2. The number of *Bombus californicus* captured per plot surveyed by date in 2015 on the Fred's fire.

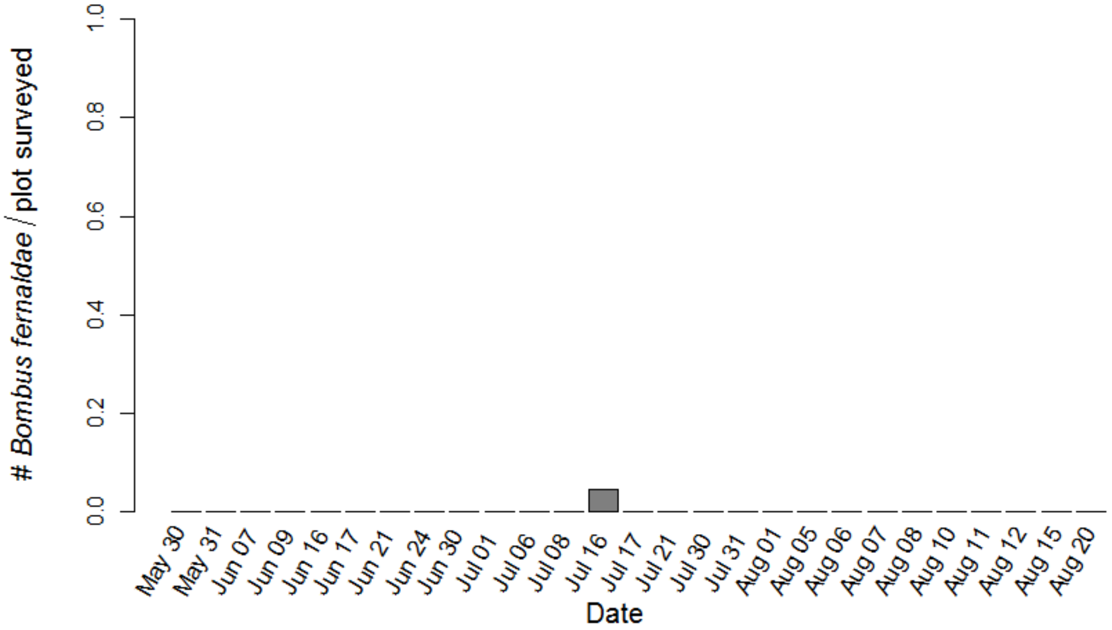

Figure A.3. The number of *Bombus fernaldae* (cuckoo species) captured per plot surveyed by date in 2015 on the Fred's fire.

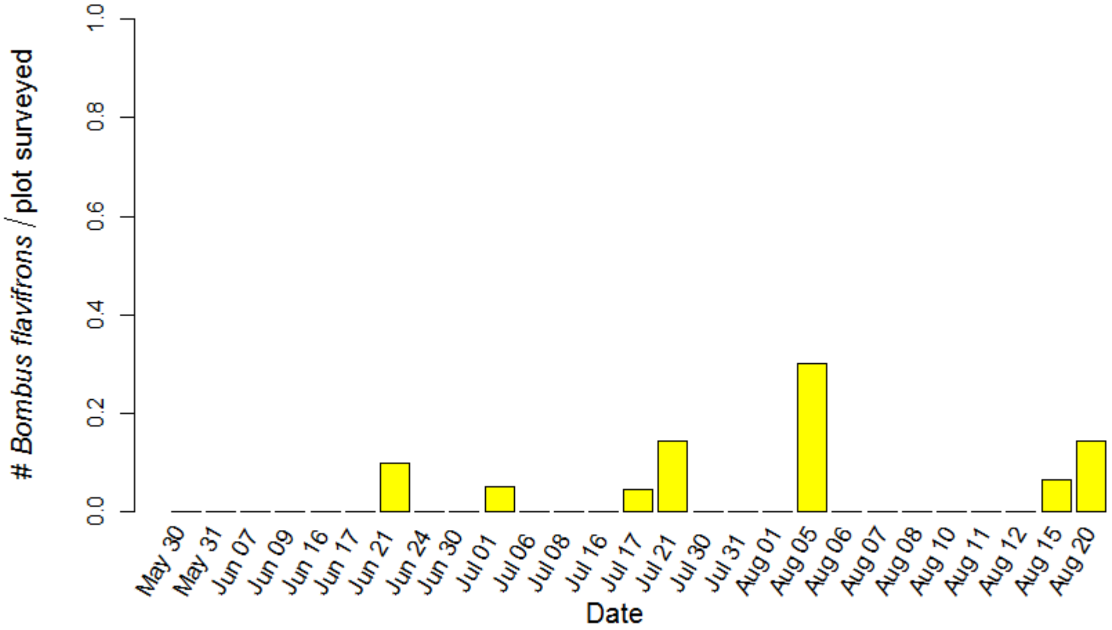

Figure A.4. The number of *Bombus flavifrons* captured per plot surveyed by date in 2015 on the Fred's fire.

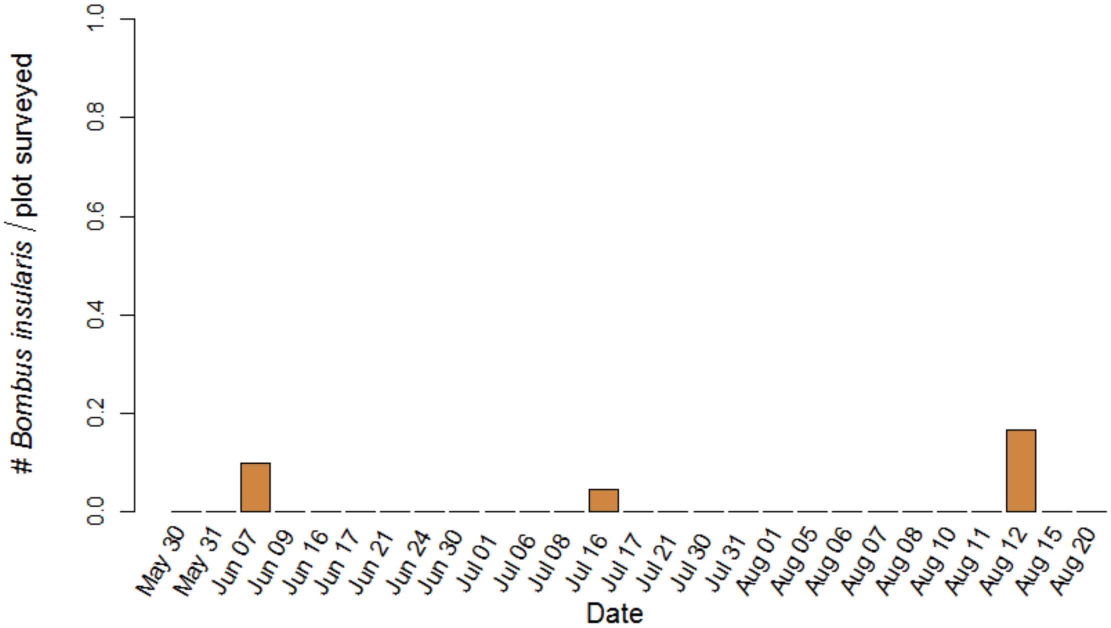

Figure A.5. The number of *Bombus insularis* (cuckoo species) captured per plot surveyed by date in 2015 on the Fred's fire.

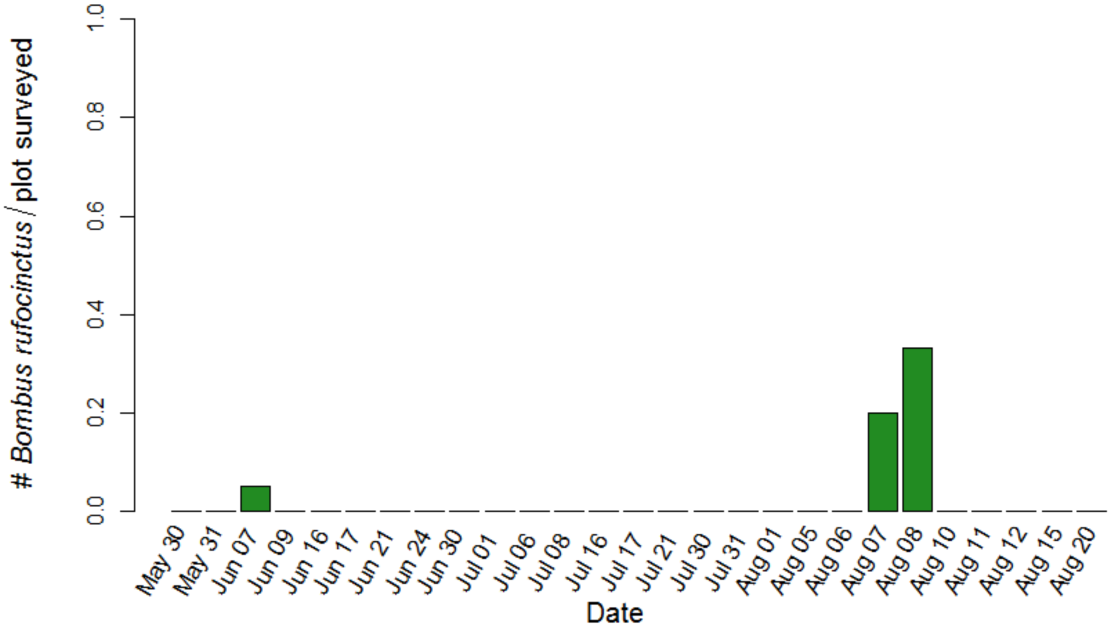

Figure A.6. The number of *Bombus rufocinctus* captured per plot surveyed by date in 2015 on the Fred's fire.

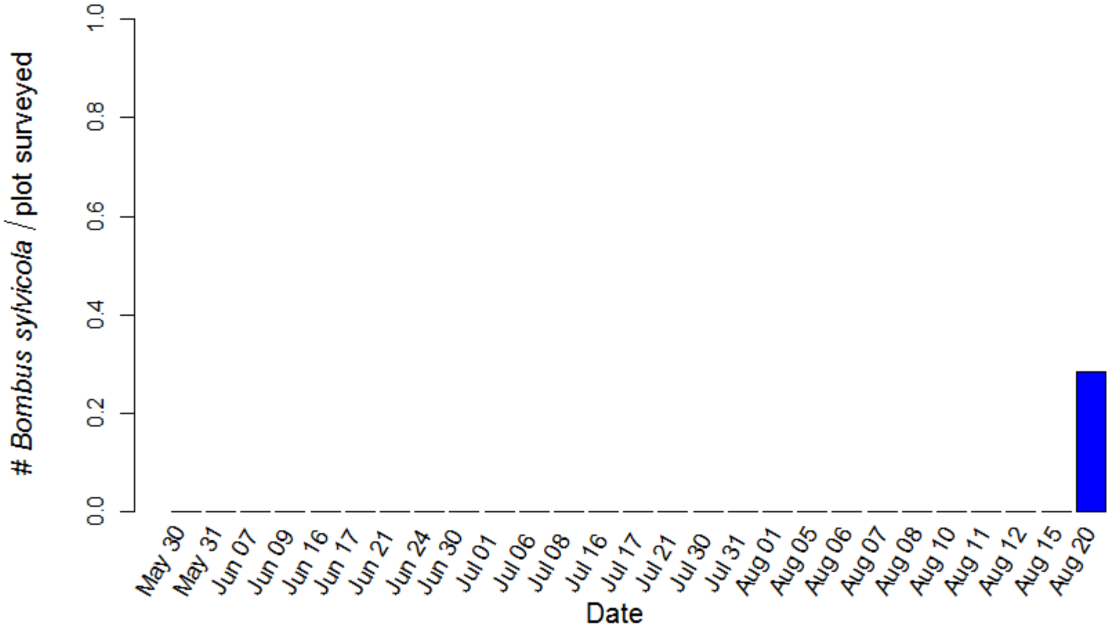

Figure A.7. The number of *Bombus sylvicola* captured per plot surveyed by date in 2015 on the Fred's fire.

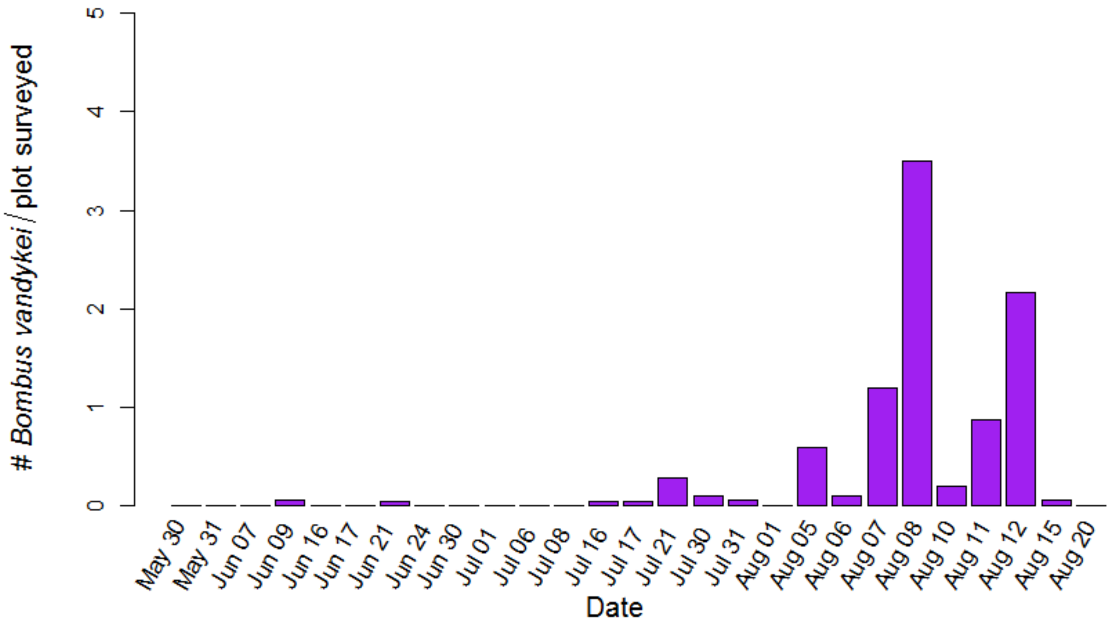

Figure A.8. The number of *Bombus vandykei* captured per plot surveyed by date in 2015 on the Fred's fire.

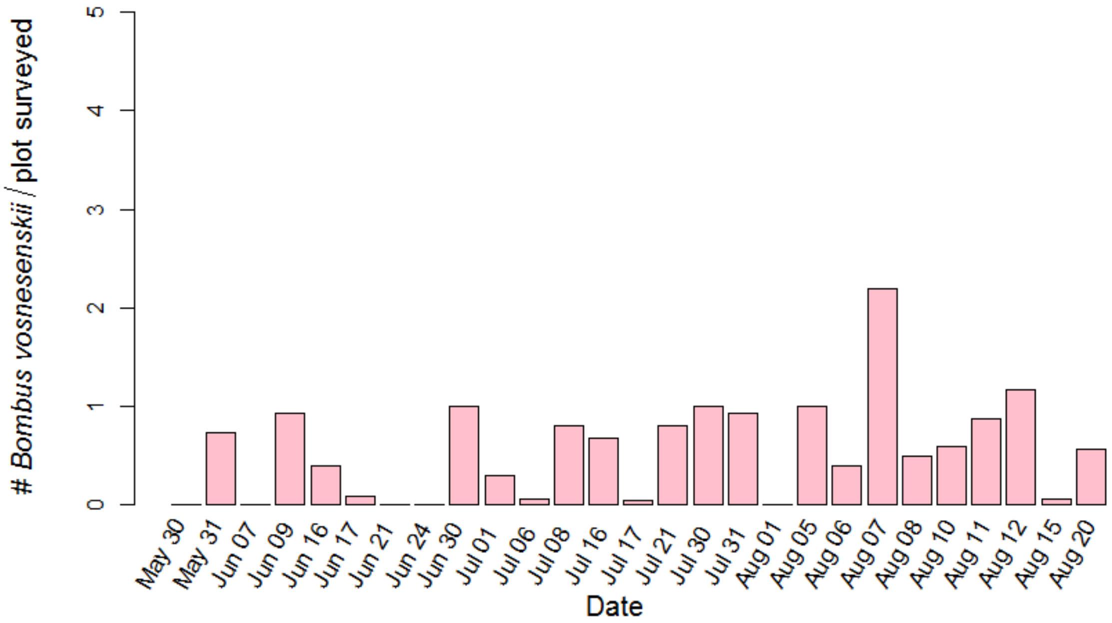

Figure A.9. The number of *Bombus vosnesenskii* captured per plot surveyed by date in 2015 on the Fred's fire.

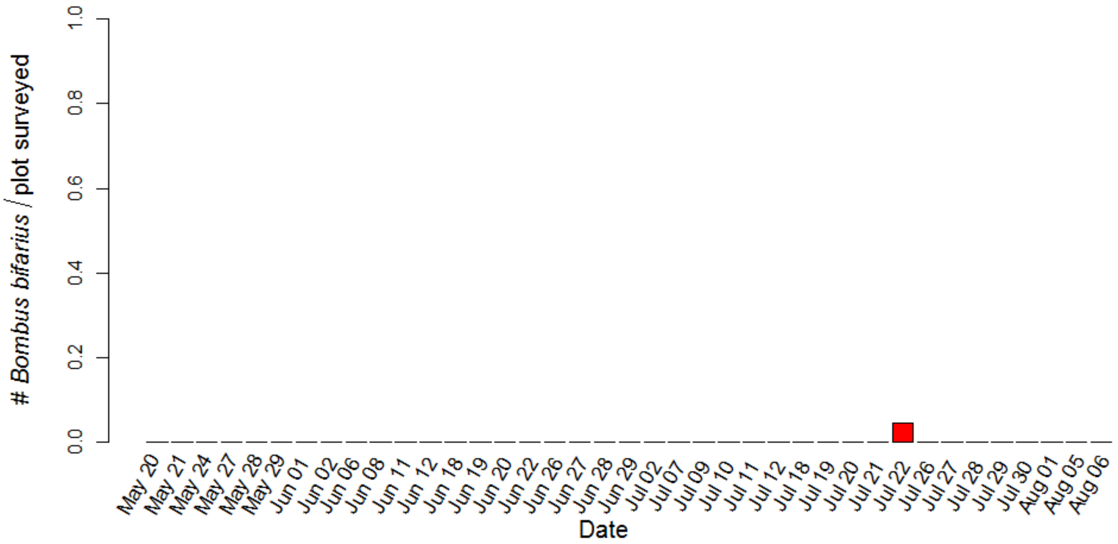

Figure A.10. The number of *Bombus bifarius* captured per plot surveyed by date in 2015 on the Power fire.

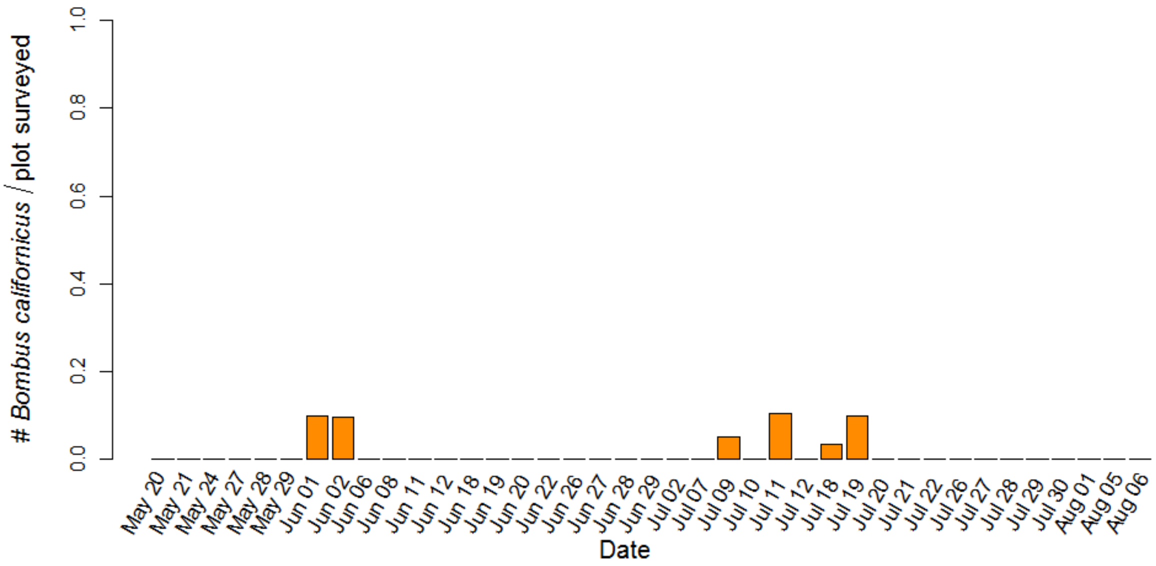

Figure A.11. The number of *Bombus californicus* captured per plot surveyed by date in 2015 on the Power fire.

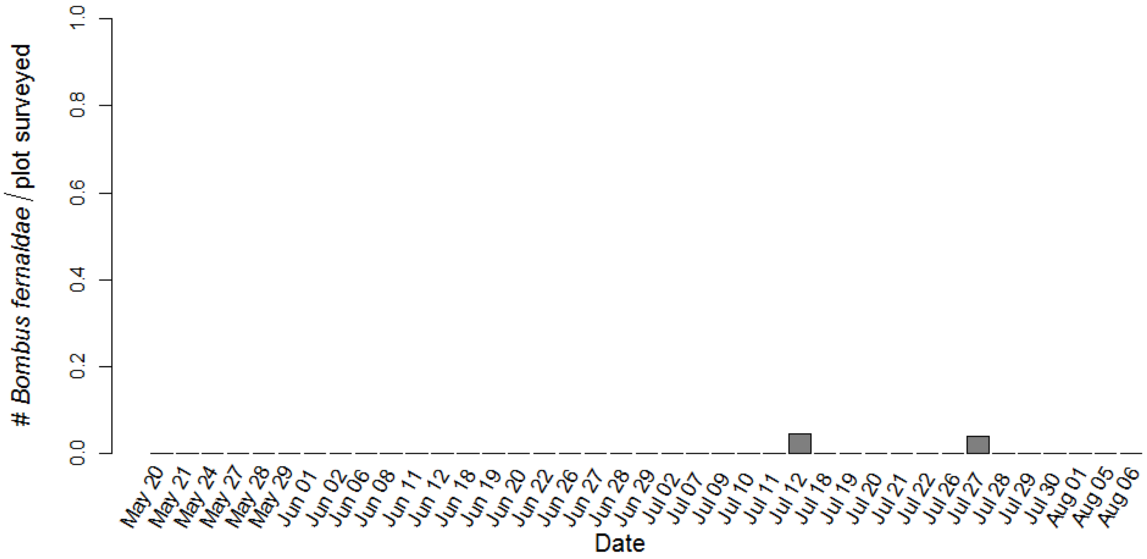

Figure A.12. The number of *Bombus fernaldae* (cuckoo species) captured per plot surveyed by date in 2015 on the Power fire.

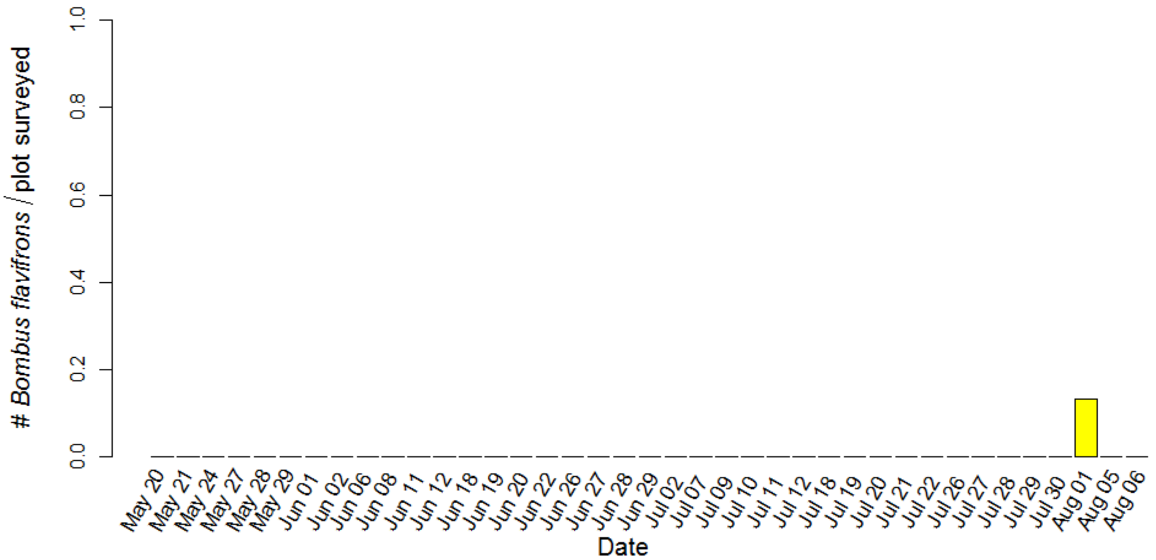

Figure A.13. The number of *Bombus flavifrons* captured per plot surveyed by date in 2015 on the Power fire.

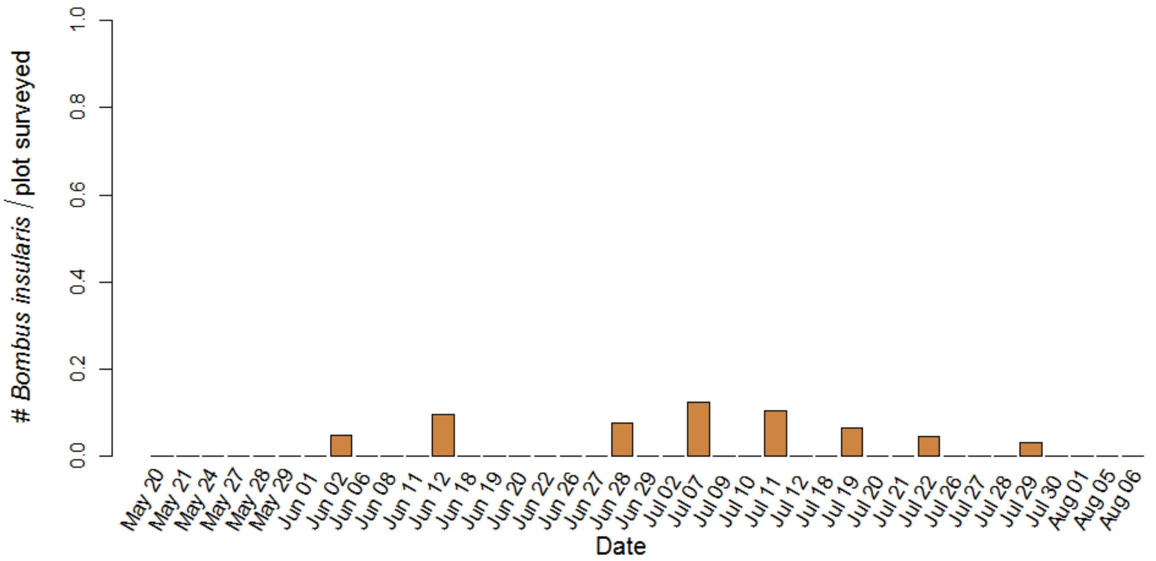

Figure A.14. The number of *Bombus insularis* (cuckoo species) captured per plot surveyed by date in 2015 on the Power fire.

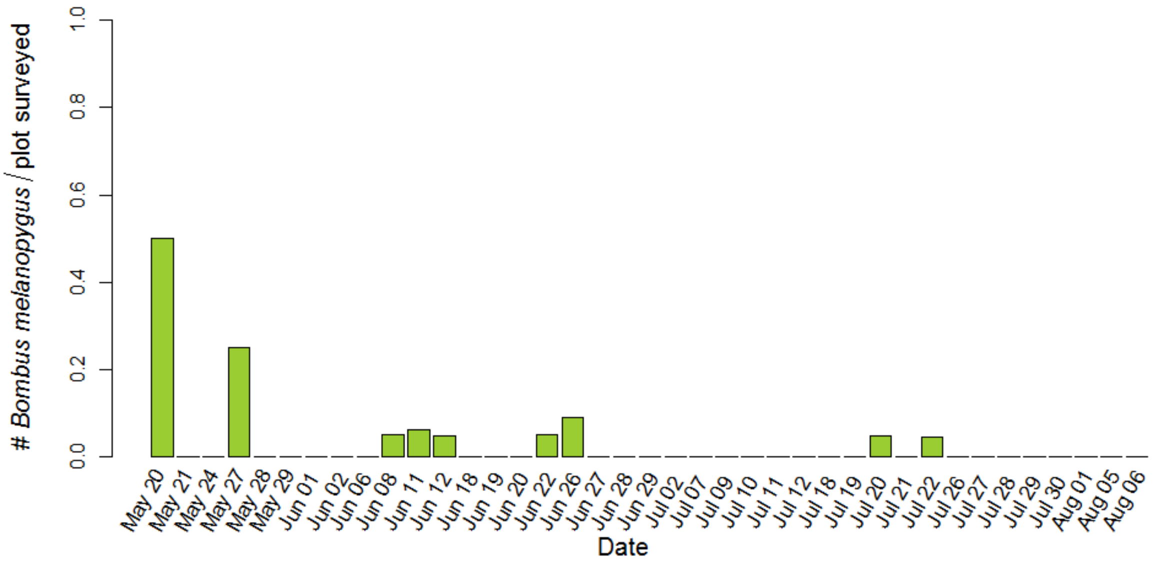

Figure A.15. The number of *Bombus melanopygus* captured per plot surveyed by date in 2015 on the Power fire.

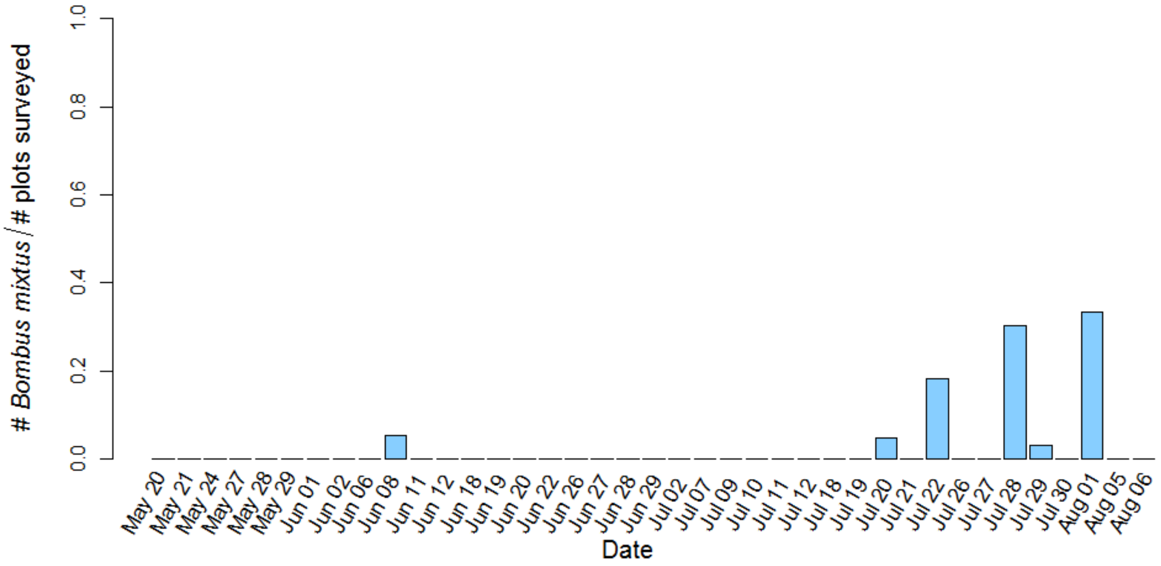

Figure A.16. The number of *Bombus mixtus* captured per plot surveyed by date in 2015 on the Power fire.

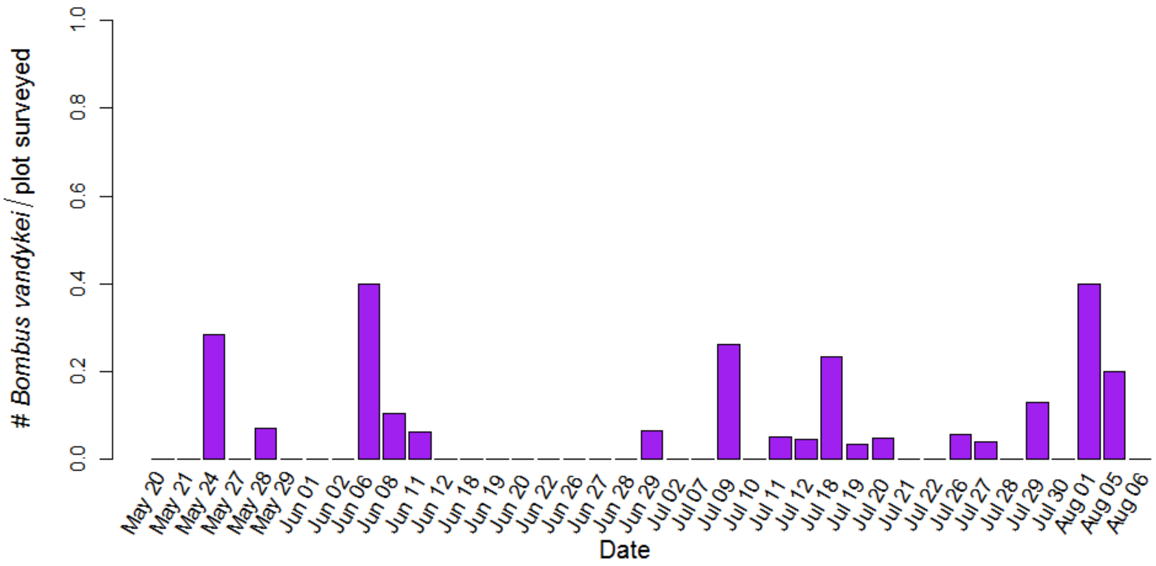

Figure A.17. The number of *Bombus vandykei* captured per plot surveyed by date in 2015 on the Power fire.

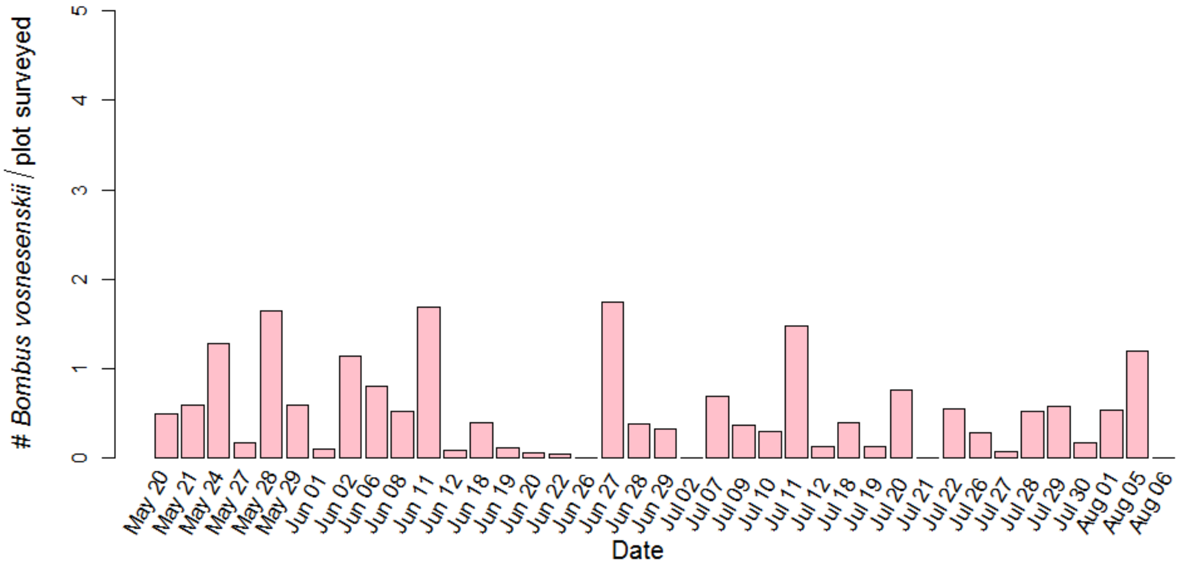

Figure A.18. The number of *Bombus vosnesenskii* captured per plot surveyed by date in 2015 on the Power fire.

APPENDIX B. Scientific and common names for all of the plant species on which bumble bees were captured, and the number of each bumble bee species captured on each plant species across all plots surveyed on the Fred's and Power Fires in 2015.

Plant Species	Common Name	*Bombus appositus*	*Bombus bifarius*	*Bombus californicus*	*Bombus fernaldae*	*Bombus flavifrons*	*Bombus insularis*	*Bombus melanopygus*	*Bombus mixtus*	*Bombus rufocinctus*	*Bombus sylvicola*	*Bombus vandykei*	*Bombus vosnesenskii*	Total Bombus
Agastache urticifolia	Horsemint	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Allium validum	Swamp onion	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Bistorta bistortoides	American bistort	0	0	0	0	0	2	1	0	0	0	0	2	**5**
Boykinia major	Stream boykinia	0	0	0	0	0	0	0	0	0	0	2	0	**2**
Brodiaea elegans	Harvest brodiaea	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Calystegia occidentalis	Western morning-glory	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Ceanothus cordulatus	Mountain whitethorn	0	0	0	0	0	0	0	0	0	0	1	3	**4**
Ceanothus integerrimus	Deerbrush	0	0	0	0	0	0	0	0	0	0	0	3	**3**
Ceanothus parvifolius	Little leaf ceanothus	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Centaurea solstitialis	Yellow star-thistle	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Chamaebatia foliolosa	Mountain misery	0	0	2	0	0	0	2	0	0	0	0	90	**94**
Cirsium occidentale var. californicum	California thistle	0	0	0	0	0	0	0	0	0	0	0	4	**4**
Cirsium vulgare	Bull thistle	0	0	3	1	1	2	0	0	0	0	10	37	**54**
Clarkia dudleyana	Farewell-to-spring	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Clarkia rhomboidea	Diamond clarkia	0	0	0	1	0	0	0	0	0	0	0	10	**11**
Clarkia unguiculata	Elegant clarkia	0	0	0	0	0	0	0	0	0	0	1	5	**6**
Delphinium glaucum	Sierra larkspur	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Dicentra formosa	Pacific bleeding heart	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Erigeron glacialis	Wandering fleabane	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Eriogonum nudum	Nude buckwheat	0	0	0	0	0	0	0	0	0	2	0	10	**12**
Eriogonum umbellatum	Sulfur Flower	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Eriogonum wrightii	Wright's Buckwheat	0	0	0	0	0	0	0	0	0	0	1	0	**1**

Plant Species	Common Name	*Bombus appositus*	*Bombus bifarius*	*Bombus californicus*	*Bombus fernaldae*	*Bombus flavifrons*	*Bombus insularis*	*Bombus melanopygus*	*Bombus mixtus*	*Bombus rufocinctus*	*Bombus sylvicola*	*Bombus vandykei*	*Bombus vosnesenskii*	Total Bombus
Erysimum capitatum	Western wallflower	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Eurybia integrifolia	Subalpine aster	0	0	0	0	0	0	0	0	0	0	1	1	**2**
Gilia capitata	Blue gilia	0	0	0	0	0	3	0	0	1	0	1	13	**18**
Hackelia nervosa	Sierra stickweed	0	0	0	0	0	1	1	2	0	0	1	25	**30**
Helenium bigelovii	Sneezeweed	0	0	0	0	0	2	1	1	0	0	0	16	**20**
Hosackia crassifolia	Broad-leaved lotus	0	0	0	0	0	0	0	0	0	0	2	11	**13**
Hosackia oblongifolia	Streambank lotus	0	0	1	0	1	0	0	0	0	0	0	2	**4**
Hypericum perforatum	St. John's wort	0	0	0	0	0	0	0	0	0	0	1	3	**4**
Iris hartwegii	Hartweg's iris	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Keckiella breviflora	Gaping keckiella	0	0	0	0	0	0	0	0	0	0	0	12	**12**
Lathyrus nevadensis	Sierra Nevada pea	0	0	0	0	0	0	0	0	0	0	2	2	**4**
Lupinus albicaulis	Narrow-winged lupine	0	0	0	0	0	0	0	0	1	0	1	8	**10**
Lupinus breweri	Brewer's lupine	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Lupinus polyphyllus	Large-leaved lupine	0	0	0	0	0	0	0	1	0	0	0	7	**8**
Lupinus stiversii	Harlequin lupine	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Madia elegans	Common madia	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Mertensia ciliata	Mountain bluebells	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Monardella breweri	Brewer's modardella	0	0	1	0	0	1	0	0	0	0	6	8	**16**
Monardella odoratissima ssp. glauca	Mountain pennyroyal	0	0	0	0	0	0	0	0	0	0	3	6	**9**
Monardella odoratissima	Pennyroyal	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Nasturtium officinale	Watercress	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Penstemon deustus	Hot-rock penstemon	0	0	1	0	0	0	0	0	0	0	0	5	**6**
Penstemon laetus	Gay penstemon	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Perideridia bolanderi	Bolander's yampah	0	0	0	0	0	0	0	2	0	0	2	0	**4**
Perideridia parishii	Parish's yampah	0	0	0	0	1	0	0	8	0	0	0	22	**31**
Phacelia cicutaria	Caterpillar phacelia	0	0	0	0	0	0	0	0	0	0	0	1	**1**

Plant Species	Common Name	*Bombus appositus*	*Bombus bifarius*	*Bombus californicus*	*Bombus fernaldae*	*Bombus flavifrons*	*Bombus insularis*	*Bombus melanopygus*	*Bombus mixtus*	*Bombus rufocinctus*	*Bombus sylvicola*	*Bombus vandykei*	*Bombus vosnesenskii*	Total Bombus
Phacelia egena	Low phacelia	0	0	0	0	1	1	0	0	0	0	1	3	**6**
Phacelia hastata	Silver-leaf phacelia	0	0	3	0	3	0	1	0	0	0	38	86	**131**
Phacelia quickii	Quick's phacelia	0	0	0	0	0	0	0	0	0	0	0	3	**3**
Potentilla gracilis	Slender cinquefoil	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Prunella vulgaris	Self-heal	0	0	0	0	0	1	1	1	0	0	1	2	**6**
Pseudognaphalium beneolens	Cudweed	0	0	0	0	0	0	0	0	0	0	1	0	**1**
Quercus vaccinifolia	Huckleberry oak	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Ribes montigenum	Mountain gooseberry	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Ribes nevadense	Sierra currant	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Ribes viscosissimum	Sticky currant	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Rubus parviflorus	Thimbleberry	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Senecio triangularis	Arrowleaf groundsel	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Sidalcea glaucescens	Checker bloom	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Solanum xanti	Purple nightshade	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Solidago canadensis	Canada goldenrod	0	0	1	1	0	1	0	0	2	0	10	18	**33**
Spiraea splendens	Mountain spiraea	0	1	0	0	0	0	0	4	0	0	0	0	**5**
Stachys albens	Hedge Nettle	0	0	0	0	0	1	0	0	0	0	15	3	**19**
Trifolium pratense	Red clover	0	0	0	0	0	0	0	0	0	0	0	7	**7**
Veratrum californicum	Corn lily	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Verbascum thapsus	Wooly mullein	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Vicia cracca	Vetch	0	0	0	0	0	0	0	0	0	0	0	1	**1**
	<u>Other</u>													
	In flight	2	0	1	0	1	0	2	0	0	0	7	15	**27**
	Grass	0	0	1	0	0	0	0	0	0	0	0	4	**5**
	Leaf	0	0	0	0	0	0	0	0	0	0	1	0	**1**
	Fern	0	0	0	0	0	0	0	0	0	0	0	1	**1**
	Pondersosa pine	0	0	0	0	1	0	0	0	0	0	0	2	**3**