

Comparative Study of Bee Diversity in Restored Habitats in the Presidio San Francisco

Submitted by:

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Background and Objectives

The San Francisco Bay area is a biodiversity hotspot where a multitude of different habitats converge. This dense clustering of species is vulnerable to climate change as it affects sea level rise and temperature patterns. It is important that species and their associated populations and distributions be recorded to document the natural history of the area and to provide a baseline for monitoring changes in species composition and distribution. In March 2004, students from San Francisco State began sampling bee diversity in the Presidio. The 2004 study recorded patterns of bee diversity at different levels of land degradation and restoration (Woods *et al.*, 2005).

The 2004 study sampled a total of nine sites of varying habitat type and quality within the Presidio. Five sites were restored habitats of varying age at the time of sampling. These include Crissy Field, Inspiration Point, Lincoln and Pershing, Lobos Creek, and World War II Memorial. Two additional sites, Battery Marcus Miller and Southern Site comprised small areas of relatively intact native habitat. These sites represented the least amount of land disturbance while two more sites, Fill Site 6 and Forested Site represented the opposite end of the degradation spectrum. The study began in March of 2004 and sampling took place once a month until October 2004 with a total of seven samples for each site. The study recorded 2,418 bees, representing 23 genera and 60 species in the Presidio. The most diverse sites were Southern Site, Fill Site 6, and Lobos Creek with 37, 29, and 28 species respectively. These sites also had the highest abundance with 490, 535, and 526 specimens while the other sites had numbers ranging from 282 to a mere 60 individuals. The 2004 study indicates that habitat degradation and human disturbance are not necessarily limiting factors on bee species diversity or abundance since the three sites with the greatest bee diversity included a restored site, a land fill, and a relatively intact native area. The conclusion of the 2004 study not only posed more questions about bee diversity, but also created an excellent baseline for future surveys to learn more about these vital creatures and how they interact in one of San Francisco's most important natural resources. Here we report results of a follow up survey in 2008 to discover more about this bee community and also gain a more accurate representation of the Presidio's bee diversity.

Methods

In April of 2008, we began sampling bees at four sites in the Presidio, three from the previous survey and one new location (Figure 1). Thompson Reach (TR), formerly referred to as Fill Site 6, was an old landfill covered in non-native radish and grasses during the 2004 study. It was restored in 2005 and now has a tree-lined creek and has been planted with a variety of native plants. There were 29 bee species collected there in 2004 and this survey identifies changes in this community's bee diversity and abundance and uses the two bee surveys to assess the success and health of the restoration project. Lobos Dunes, formerly referred to as Lobos Creek, was a baseball field before it was restored in 1996, eight years before the 2004 survey. The 2004 survey collected 28 bee species, three of which were unique to the site. This survey evaluates how the bee community has changed as the site has matured. A similar or increased species count would indicate that the site has remained healthy habitat for bees since its restoration a decade ago. An increase in oligolectic bees, those that visit a narrow range of plant species, versus polylectic or generalist bee species would be consistent with a maturing bee

community. This measure is more difficult to apply since flower visiting patterns are known for only a subset of the bees that occur in the Presidio.

The World War II Memorial site (WW) is an area adjacent to the memorial. The survey conducted in 2004 seized a unique opportunity to create a baseline of bee abundance and richness immediately after the site was transformed. The current survey provides a look at a single community as it establishes and changes from the time that the habitat was created. Although the WW site was probably historically dominated by coastal scrub vegetation and sandy soils, in 2008 the WW site was characterized by sparse vegetation, bare ground and clay-like compacted soils. We chose the fourth site sampled in this survey, Baker Beach (BB), because its habitat type (coastal sand dunes adjacent to the beach dominated by bushy lupines,) had not been sampled previously for bees and thus might support bee species not found in the other habitats.

We used pan traps to sample bees at all four sites. Pan traps are a standard method for sampling flying insects, flower visitors in particular. The traps consist of plastic bowls of three different colors, white, blue, and yellow. The bowls are filled 0.5-1 inch from the top with slightly soapy water. We used the same sampling regime as Wood et al, 2005 which was adapted from the LeBuhn protocol (LeBuhn *et al.*, 2003). The LeBuhn protocol calls for 30 pant traps per site but the previous study used 21 pans to accommodate the smaller sites and avoid over sampling (Woods *et al.*, 2005). Pans were placed every 5 meters on two 50 meter transects arranged in an "X" or "+" pattern. Bowl color order was chosen each time using a random numbers table. Traps were put in place before 9am and collected after 3pm. Insects were strained from the bowls and separated by bowl color within each site. Specimens then were sorted, pinned and identified to species or morphospecies. All identifications were confirmed by bee specialist, Robin Thorp from the University of California, Davis, using the 2004 specimens as a cross reference. Bee abundance, species richness, and between site and between study similarity indices were analyzed using Estimate S version 8.2.0 (Colwell 2009).

Results

Between April 25, 2008 and April 5, 2009, 975 bees were collected in the pan traps representing six families, 18 genera, and 26 species with an additional seven female morphospecies and four male morphospecies. Six of these species were not recorded in the previous survey and a few of the species names and identifications have changed since the 2004 study. An additional new species (*Stellis nr franciscana*) was netted at Lobos Dunes. We excluded it from our comparative analysis since it was not found in the pan trap samples, perhaps because it is a nest parasite of other bees and less likely to visit flowers or be attracted to pan traps than other non parasitic bees in the area. Contrary to our expectations, only one of the new species, *Colletes hyalinus gaudalis*, came from the newly sampled BB site and it was also recorded from the WW site. Table 1 lists all the species found in pan traps for each site in 2004 and 2008 and includes corrected names and new identifications. Figure 2 illustrates abundance of bees caught in the Presidio over the nine sample dates. Bee abundance is highest in June and July with 428 and 246 bees caught respectively. The other sampling periods have relatively low abundance averaging 50 bees between the four sites. Bee abundance drops off sharply during the October (14.X.2008) sampling that only yielded 8 specimens amongst the four sites. However, this is

characteristic of most insect activity during fall and winter months. Overall, bee species richness and abundance at the three previously sampled sites were greater in 2004 with 47 species and 1283 individuals compared to 36 species and 878 individuals in 2008. Figure 3 shows bee abundance by date and location. Thompson Reach and World War II samples account for the majority of the large peak representing 91% of bees sampled during June and July. Lobos Dunes has lower, but more consistent bee abundance with two small peaks during May (25.V.2008) and February (27.II.2009). The only non-native bee we found was the honeybee, *Apis mellifera*.

Estimate S was used to compare the 2008 data from Thompson Reach, Lobos Dunes, and World War II Memorial to the data collected at those sites in 2004. Male morphospecies were not included in the data sets used for the program. Thompson Reach was of particular interest because it had the second highest species diversity in the 2004 survey and its habitat was altered entirely when it was restored in 2005. In 2004, the site had a species richness of 26 and a bee abundance of 495, but the bee community changed dramatically after the restoration resulting in a species richness of 20 and an abundance of 400 when sampled in 2008. Species richness excludes male morphospecies. Twenty of the species previously recorded at the site were not present in 2008 and six of those species comprised a significant portion of the bee community (Table 1 and Figure 4). Significance was assigned if four or more individuals of a species were collected at the location during the survey. These six species may have been extirpated during the tumultuous restoration and did not colonize the new habitat either because they were no longer present in the surrounding area or because the restored site no longer possessed necessary nesting and/or foraging qualities. Also, two of the most abundant species *Ceratina acantha* and *Lasioglossum incompletus* decreased significantly, more than 50%, since the 2004 survey. On the other hand, eight species were recorded for the first time in Thompson Reach. Most of these species were represented by small numbers between 1 and 3 so it is likely that they were either rare at the site or were simply captured while passing through. However, two of the new species, *Lasioglossum kincaidii* and *Halictus ligatus*, were in high abundance, 101 and 41 respectively, so these two species comprise a major component of the new bee community and most likely nest and forage within or nearby the site. *Halictus ligatus* was not recorded at any of the other sites in this survey or the last. In addition, three species previously recorded in low numbers had increased significantly which means their population grew at least 50%. The Thompson reach/Fill Site 6 communities sampled in these two surveys have a Jaccard similarity index of 0.35. This index calculates what degree two groups or samples have in common with one another. The more alike they are in species composition the closer the index it to 1.0, the less alike the closer the index is to 0. This low index value indicates a substantial change in Thompson Reach's bee community post-restoration. In 2004, the site had a Simpson's diversity index of 5.42 and an evenness of 0.21. A community's evenness or equitability indicates how evenly distributed individuals are amongst the different species in that community. The more even a community is the closer the figure will be to 1.0 and the higher the diversity index will be. In 2008, the site had a Simpson's diversity index of 5.92 and an evenness of 0.30. This slight rise in diversity and evenness since the restoration suggests that the habitat is of better quality and thus supports a healthier community of bees.

Bee diversity and abundance has diminished markedly at Lobos Dunes. A total of 27 species and 496 individuals were recorded in 2004 and only 22 species and 186 bees, in 2008. All nine major species' populations decreased significantly, which is more than 50% (Figure 5). There were three new species sampled in LD in 2008, *Habropoda miserabilis*, *Lasioglossum (Evylaeus) sp.3*, *Specodes sp.3*, but all were singletons. *Habropoda miserabilis* was only collected once in 2004 at Lincoln and Pershing New. Two of the three oligolectic bees from the 2004 survey, *Hesperapis pellucida* and *Anthidium palliventre*, declined more than 50% in the 2008 samples and the third, *Megachile perhirta*, was absent from the 2008 samples. The communities observed in these two surveys have a Jaccard similarity index of 0.63. In 2004, the bee community at Lobos Dunes had a Simpson's diversity index of 7.65 and an evenness of 0.28. In 2008 the site had a diversity index of 9.34 and an evenness of 0.42. The dramatic drop in overall bee abundance at this site between surveys causes the 2008 community to have a higher evenness value than the 2004 survey even though the community has lost species.

The bee diversity at the World War II Memorial site dramatically increased from 15 species to 26 species and the abundance more than doubled from 192 individuals collected in 2004 to 391 in 2008 (Figure 1 and Figure 6). Of the 18 new species, five have a significant population indicated by a sample greater than three individuals. Four of the new species to the site *Andrena chalybea*, *A. caerulea*, *Panurginus melanocephalus*, and *Hesperapis pellucida*, are oligolectic specialist bees. We also observed five species, with significant increase in abundance (Figure 1.). On the other hand, five species with previously substantial populations decreased in numbers by more than half or were completely absent in the case of *Lasioglossum (Evylaeus) sp. 1*. The communities observed in these two surveys have a Jaccard similarity index of 0.32. In 2004, the bee community had a Simpson's diversity index of 6.19 and an evenness of 0.41. In 2008 the site had a diversity index of 4.28 and an evenness of 0.16.

Baker Beach had a species richness of only 5 and a total abundance of 19 individuals (Table 1 and Figure 7). One of these species *Colletes hyalinus gaudalis* is a newly recorded rare species. We recorded only two individuals, one at Baker Beach and one at World War II Memorial. All species collected at Baker Beach also were found at the World War II Memorial, a site up the hill a short distance. It is likely that bees from those sites mix and probably forage at both sites. Some species that decreased significantly at World War II Memorial, such as *Bombus vosnesenskii*, were collected in relatively large abundance at Baker Beach so those species may be utilizing Baker Beach as competition for resources at World War II Memorial intensifies. Subsequent surveys could investigate community dynamics between the two sites and test whether Baker Beach acts as a buffer area for bee populations that are out competed or searching for additional food sources during lean times. Baker Beach had a diversity index of 3.76 and an evenness of 0.75.

Discussion

The three sites we revisited from the last survey changed dramatically in four years. While this was expected at Thompson Reach and the World War II Memorial, it was not expected at Lobos Dunes. Lobos Dunes was eight years old when it was surveyed in 2004 and we expected its bee community to either remain stable or increase in diversity as it matured. The survey of the bee community at Lobos Dunes in 2008 shows a 62% decrease in total abundance. All nine species that were thriving in 2004

experienced major declines between 50% and 80%. Only one species, *Ceratina acantha*, showed a threefold increase from 7 to 21 during that time. This increase may be due to a lack of competition from once dominant species no longer present at the site and not a cause of the decline of other species.

There are many potential causes for a wide scale decline including yearly differences in temperature and rainfall, disease, parasitism, human disturbance and a combination thereof. Disease and parasitism are probably not the main cause because all of the significant species, the species that were most likely nesting at the site, were affected equally and many pathogens and parasites are host specific and density dependent. Although public access to the site is restricted to paths, we observed maintenance of the site's vegetation throughout the course of the survey. Large black tarps covered the ground in many areas presumably to depress and remove the plants beneath. Unfortunately, the majority of the solitary bee species at Lobos Dunes are ground nesters and these vegetation control methods may negatively impact nesting and reproduction of bees. This is supported by the increase in *Ceratina acantha*, a species that nest in twigs (McIntosh, 1996). The less suitable nest space there is available the more susceptible the few successful nests will be to predation and parasitism (McIntosh, 1996). A downturn this significant at a mature restored site is troubling and requires further monitoring to identify the causes and prevent the situation from worsening.

The newly restored Thompson Reach and World War II Memorial sites attracted many bees that were present in other Presidio sites in 2004 (Table 1). The bee community at Thompson Reach is doing well considering all of the site's soil and vegetation, ie nesting and foraging resources, were removed for restoration only three years prior to this survey. The site has been colonized and the community appears to be diverse, abundant, and relatively healthy, but many species that used to be abundant four years ago are no longer present. Unfortunately, many of the missing species were found primarily or entirely at this location (Table 1.). Hopefully, these bee species still occupy other nearby areas and have not been lost from the Presidio. Although not collected at Thompson Reach in 2008, one individual of *Eucera actiosa* was collected at the World War II Memorial suggesting that bees are resilient and if there is suitable habitat they will persist. Further sampling around the site and in similar habitats will help determine if these species are still found within the Presidio and whether their decline at this site was due to the restoration or is being experienced by all populations of the species throughout the area.

The bee community at the World War II Memorial site has grown since the 2004 survey and experienced major shifts in community composition. The high number of species with growing populations suggests that the restored area at the World War II Memorial is attracting a good diversity of bee species and providing the nesting and foraging resources necessary for them to thrive. The significant decrease and disappearance of five previously abundant species was unexpected since their large numbers suggests that they had successfully colonized the site and were thriving. However, it is possible that these were early colonizers that thrive in areas of low bee diversity and recent disturbance. This may be the result of competition for resources, normal fluctuations in population, or something more serious. Future surveys at consistent intervals are necessary to identify population fluctuations and catch potentially serious phenomenon such as nesting disturbance, disease, and competition with nonnative pollinators.

Bee diversity and abundance at Baker Beach was dismal at best. There were blue and yellow lupines blooming in great abundance and a significant amount of bumble bee activity when the site was chosen, but few flowers were in bloom on subsequent visits. Bumble bees are not trapped as effectively in pan traps as other smaller bees (Roulston *et al.*, 2007). This may have contributed to the low numbers of *Bombus* even though two of the five species observed were from that genus.

The 2008 survey identified six species new to the Presidio raising the number of bee species recorded in the Presidio to 66. Future surveys could identify colonization patterns and help predict and prepare for changes in habitat composition due to climate change, and ease the transition. Additional sampling could also further our knowledge of the true bee diversity supported by the area's various ecosystems allowing us to better protect and preserve its invaluable pollinator diversity.

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Thompson Reach '04 and '08 Comparison	2004	2008	Lobos Dunes '04 and '08 Comparison	2004	2008	WWII Memorial '04 and '08 Comparison	2004	2008		Baker Beach '08	2008
<i>Anthophora urbana</i> Cresson	13	0 A!	<i>Andrena (Leucandrena) barbilabris</i> Kirby	14	3 D!	<i>Andrena (Diandrena) chalybaea</i> (Cresson)	0	4 N!		<i>Bombus caliginosus</i> (Frison)	1
<i>Ceratina acantha</i> Provancher	45	4 D!	<i>Anthophora urbana</i> Cresson	2	0 A	<i>Andrena (Euandrena) caerulea</i> Smith	0	1 N		<i>Bombus vosnesenskii</i> Radoszkowski	6
<i>Diadasia bituberculata</i> (Cresson)	0	1 N	<i>Anthophora (Heliophila) curta</i> Provancher	1	0 A	<i>Panurginus melanocephalus</i> Cockerell	0	10 N!		<i>Colletes hyalinus gaudalis</i> Cockerell	1
<i>Diadasia enavata</i> (Cresson)	1	0 A	<i>Ceratina acantha</i> Provancher	7	21 I!	<i>Anthophora urbana</i> Cresson	2	0 A		<i>Lasioglossum (Dialictus) sp. 1</i>	3
<i>Epeolus minimus</i> (Robertson)	1	0 A	<i>Ceratina nanula</i> Cockerell	28	13 D!	<i>Ceratina acantha</i> Provancher	1	1 V		<i>Lasioglossum (Dialictus) sp. MB</i>	1
<i>Melissodes lupina</i> Cresson	6	3 D!	<i>Diadasia bituberculata</i> (Cresson)	1	2 I	<i>Ceratina nanula</i> Cockerell	0	1 N		<i>Lasioglossum (Lasioglossum) pavonotum</i> (Cockerell)	7
<i>Eucera (Synhalonia) actiosa</i> (Cockerell)	8	0 A!	<i>Habropoda miserabilis</i> Cresson	0	1 N	<i>Melissodes tepida timberlakei</i> Cockerell	1	0 A		Total Individuals =	19
<i>Apis mellifera</i> Linnaeus	3	1 D	<i>Melissodes lupina</i> Cresson	1	1 V	<i>Eucera (Synhalonia) actiosa</i> (Cockerell)	0	1 N		Total Species = 5	
<i>Bombus caliginosus</i> (Frison)	0	3 N	<i>Nomada sp. 1</i>	1	0 A	<i>Apis mellifera</i> Linnaeus	0	1 N		Morphospecies = 2 (Male Morphs = 1)	
<i>Bombus melanopygus</i> Nylander	1	8 I!	<i>Apis mellifera</i> Linnaeus	4	1 D	<i>Bombus caliginosus</i> (Frison)	1	3 I			
<i>Bombus vosnesenskii</i> Radoszkowski	7	20 I!	<i>Bombus caliginosus</i> (Frison)	1	3 I	<i>Bombus melanopygus</i> Nylander	0	2 N		A = absent	
<i>Colletes hyalinus gaudalis</i> Cockerell	1	1 V	<i>Bombus melanopygus</i> Nylander	2	1 D	<i>Bombus sitkensis</i> Nylander	1	0 A		D = decrease	
<i>Hylaeus rudbeckiae</i> Cockerell & Casad	1	0 A	<i>Bombus vosnesenskii</i> Radoszkowski	40	13 D!	<i>Bombus vosnesenskii</i> Radoszkowski	14	1 D!		I = increase	
<i>Agapostemon texana</i> Cresson	69	41 D	<i>Colletes hyalinus gaudalis</i> Cockerell	13	3 D!	<i>Colletes hyalinus gaudalis</i> Cockerell	0	1 N		N = new	
<i>Halictus ligatus</i> Say	0	41 N!	<i>Hylaeus rudbeckiae</i> Cockerell & Casad	1	0 A	<i>Agapostemon texana</i> Cresson	32	22 D		V = even	
<i>Halictus tripartitus</i> Cockerell	151	104 D	<i>Agapostemon texana</i> Cresson	43	14 D!	<i>Halictus tripartitus</i> Cockerell	23	106 I!		I = significant (change greater than 50%)	
<i>Lasioglossum incompletus</i> Crawford	112	31 D!	<i>Halictus tripartitus</i> Cockerell	2	1 D	<i>Lasioglossum incompletus</i> Crawford	30	140 I!			
<i>Lasioglossum kincaidii</i> Cockerell	0	101 N!	<i>Lasioglossum (Dialictus) sp. 1</i>	6	1 D!	<i>Lasioglossum kincaidii</i> Cockerell	0	16 N!			
<i>Lasioglossum (Dialictus) sp. 1</i>	3	32 I!	<i>Lasioglossum (Dialictus) sp. 5</i>	123	21 D!	<i>Lasioglossum (Dialictus) sp. 1</i>	12	38 I!			
<i>Lasioglossum (Dialictus) sp. 4</i>	4	0 A!	<i>Lasioglossum (Dialictus) sp. 8</i>	4	0 A	<i>Lasioglossum (Dialictus) sp. 4</i>	1	0 A			
<i>Lasioglossum (Dialictus) sp. 5</i>	3	2 D	<i>Lasioglossum (Dialictus) sp. MA</i>	1	0 A	<i>Lasioglossum (Dialictus) sp. 5</i>	0	1 N			
<i>Lasioglossum (Dialictus) sp. 7</i>	0	2 N	<i>Lasioglossum (Evylaeus) sp. 3</i>	0	1 N	<i>Lasioglossum (Dialictus) sp. 7</i>	0	2 N			
<i>Lasioglossum (Dialictus) sp. 8</i>	17	0 A!	<i>Lasioglossum (Lasioglossum) pavonotum</i> (Coc	68	27 D!	<i>Lasioglossum (Dialictus) sp. 8</i>	7	1 D!			
<i>Lasioglossum (Dialictus) sp. MA</i>	1	0 A	<i>Lasioglossum tegulariformis</i> Crawford	2	2 V	<i>Lasioglossum (Dialictus) sp. 9</i>	0	1 N			
<i>Lasioglossum (Dialictus) sp. MB</i>	3	0 A	<i>Sphecodes sp. 1</i>	1	1 V	<i>Lasioglossum (Dialictus) sp. MA</i>	0	1 N			
<i>Lasioglossum (Dialictus) sp. MX</i>	0	1 N	<i>Sphecodes sp. 3</i>	0	1 N	<i>Lasioglossum (Dialictus) sp. MB</i>	2	10 I!			
<i>Lasioglossum (Evylaeus) sp. 1</i>	1	0 A	<i>Sphecodes sp. MA</i>	4	1 D	<i>Lasioglossum (Evylaeus) sp. 1</i>	5	0 A!			
<i>Lasioglossum (Evylaeus) sp. 2</i>	1	0 A	<i>Hesperapis pellucida</i> (Cresson)	56	24 D!	<i>Lasioglossum (Evylaeus) sp. 2</i>	0	13 N!			
<i>Lasioglossum (Lasioglossum) pacificum</i> (Cockerell)	1	0 A	<i>Anthidium palliventre</i> Cresson	62	30 D!	<i>Lasioglossum (Evylaeus) sp. 3</i>	0	3 N			
<i>Lasioglossum tegulariformis</i> Crawford	0	1 N	<i>Dioxys productus cismontanicus</i> Hurd	6	0 A!	<i>Lasioglossum (Evylaeus) sp. MA</i>	0	2 N			
<i>Sphecodes sp. MA</i>	1	0 A	<i>Megachile (Xanth) perihirta</i> Cockerell	1	0 A	<i>Lasioglossum (Lasioglossum) pavonotum</i> (Cockerell)	5	1 D!			
<i>Sphecodes sp. MB</i>	1	0 A	<i>Osmia nemoris</i> Sandhouse	1							

Figure 1. Study Sites for Presidio Bee Surveys. Lobos Dunes (LS), Lobos Forest (LF), Hospital Site/Southern Site (HL), Purshing Old (PO), World War II Memorial (WW), Baker Beach,(BB), South Rock/Battery Marcus Miller (SR). Crissy Field (CF), Thompson Reach/Fill Site 6 (TR), and Inspiration Point (IP). Sites in blue were surveyed in the 2005 study. Sites in Yellow were surveyed both in 2005 and 2008. The orange site (BB) was surveyed only in 2008.

Figure 2

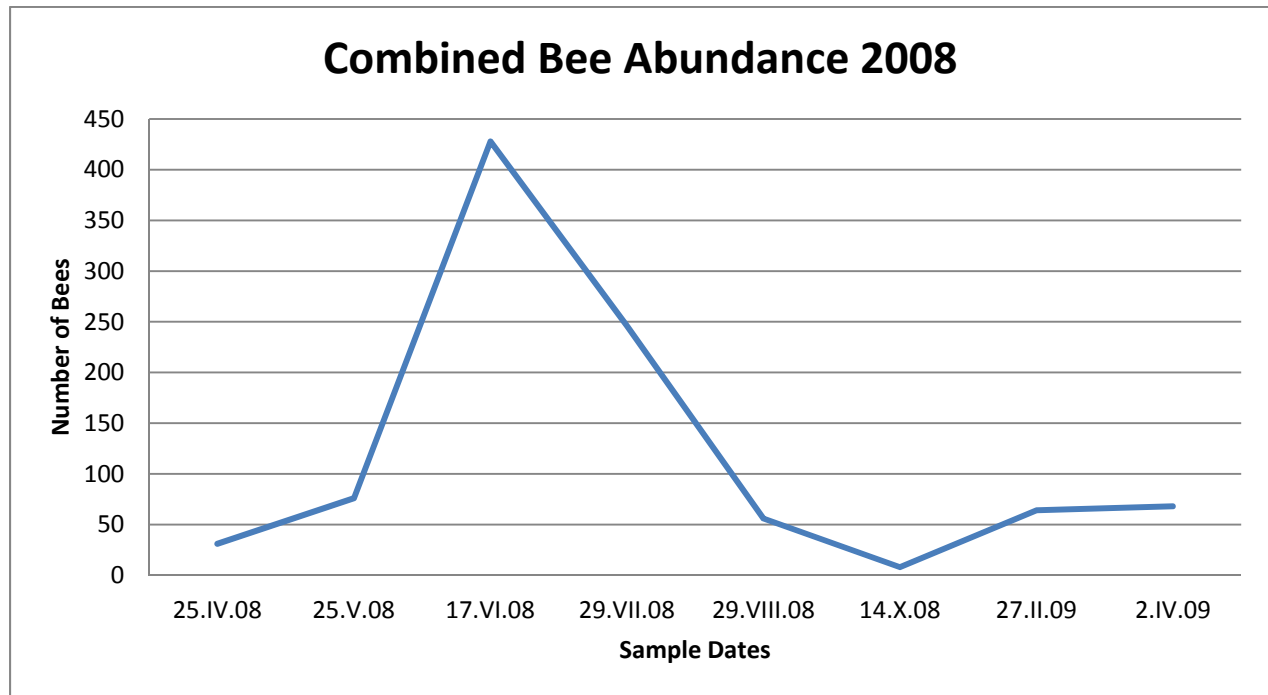


Figure 3

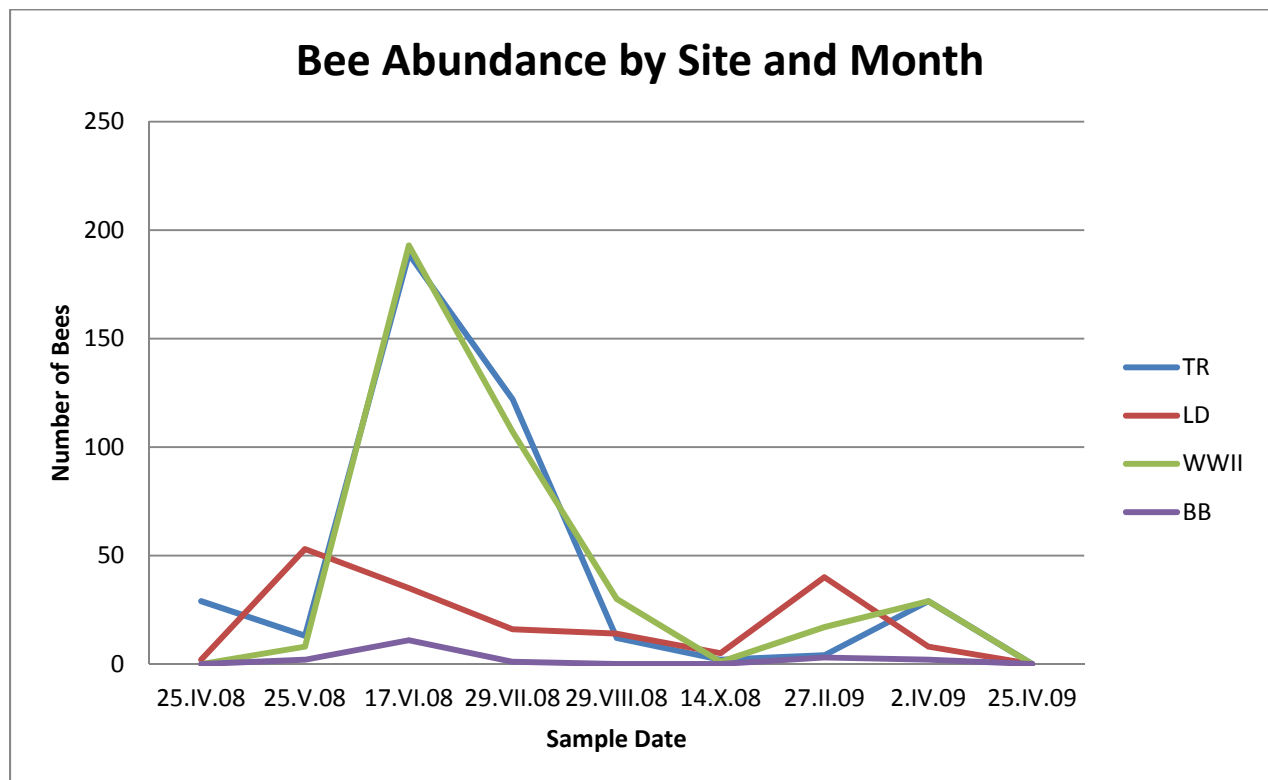


Figure 4

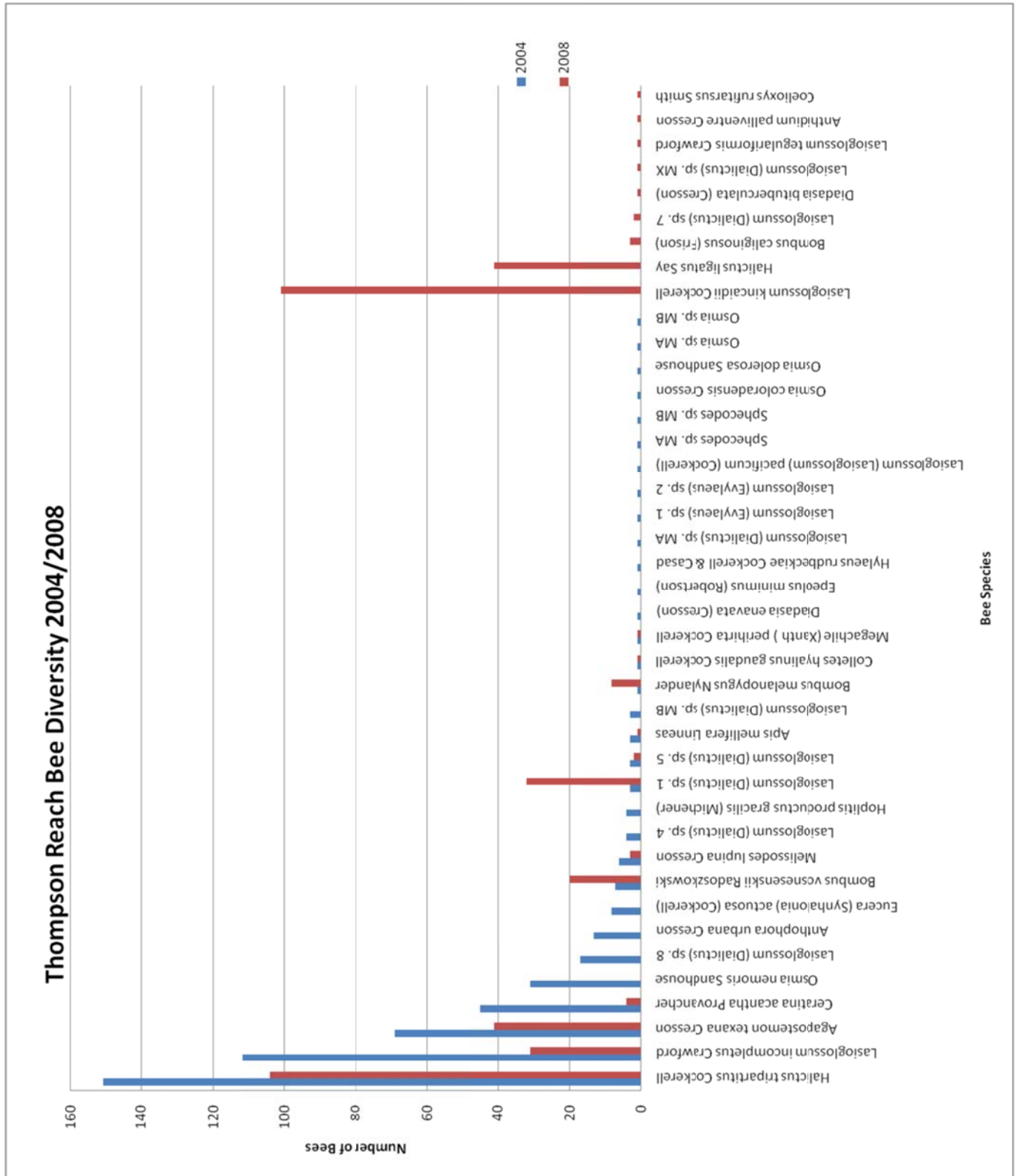


Figure 5

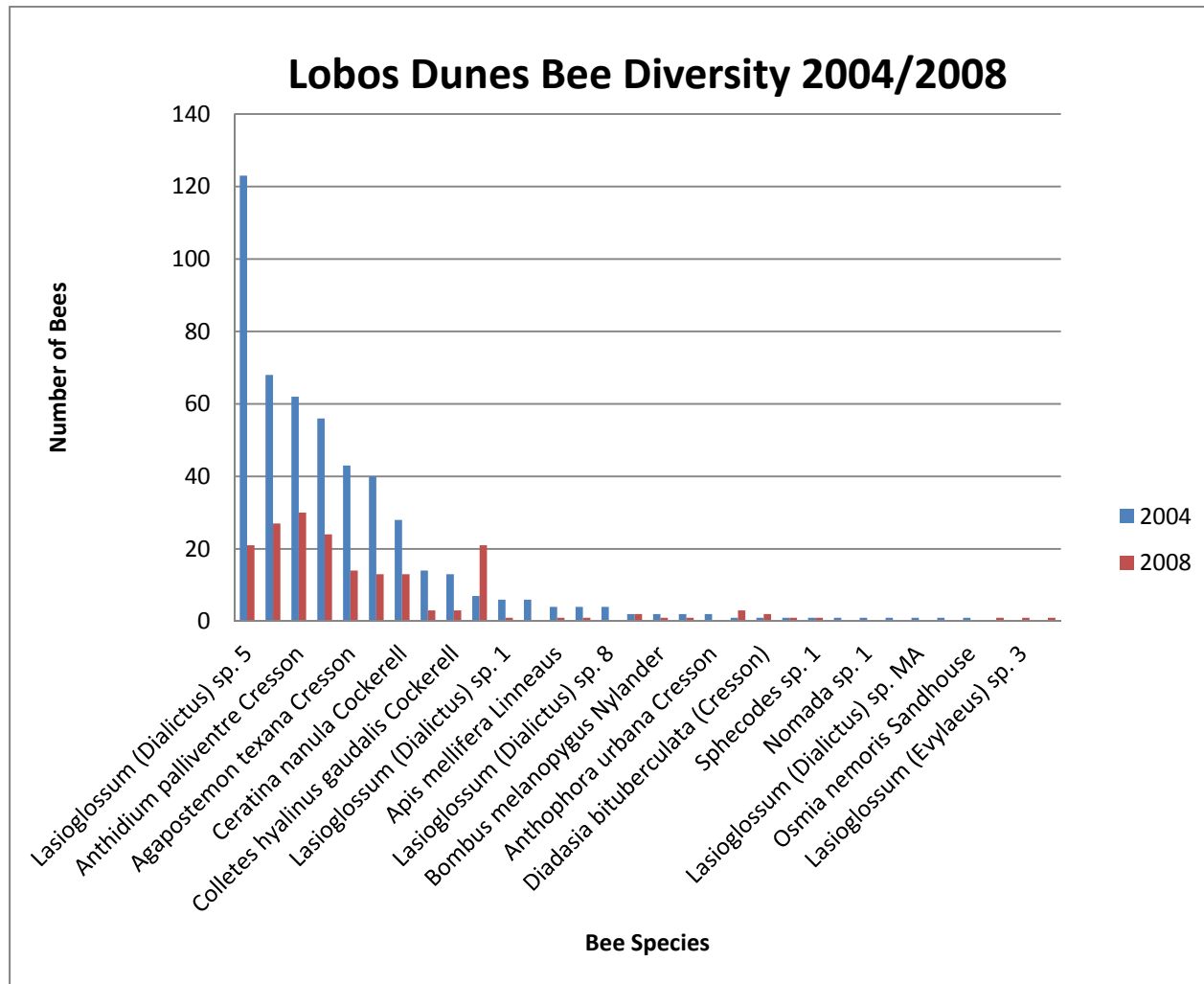


Figure 6

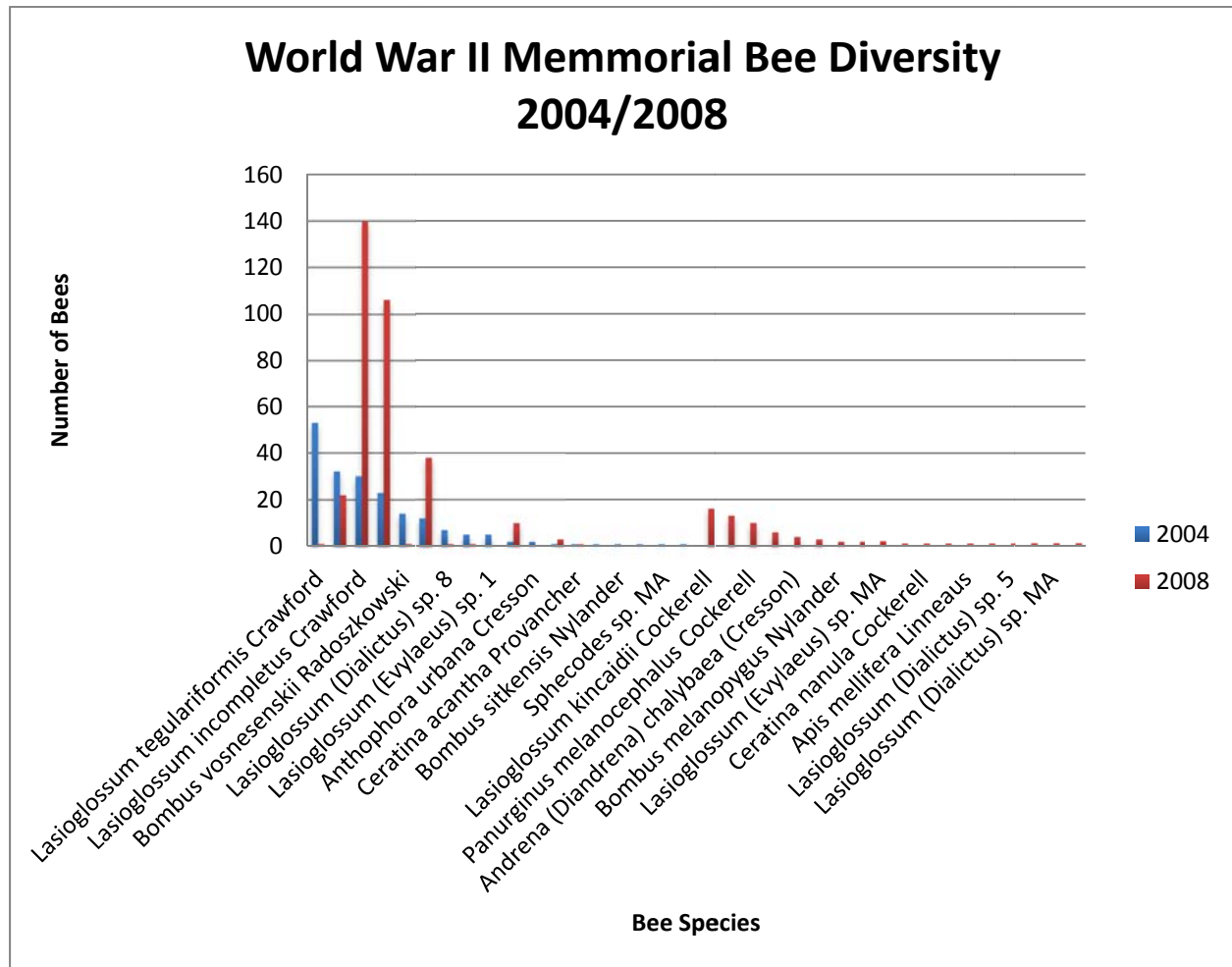


Figure 7

