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Improving Habitat Restoration for Native Pollinators in San Francisco

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Improving Habitat Restoration for Native Pollinators in San Francisco

by

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Table of Contents

List of Figures

List of Tables

Abstract

Pollinators are responsible for 67 to 98% of flowering plant reproduction while 90% of all plants are flowering. This does not change in urban environments and focusing on habitat restoration in cities is important for the conservation of species. This paper focuses on urban habitat restoration in San Francisco for three species: *Callophrys viridis*, *Icaricia icarioides missionensis*, and *Bombus californicus*. These three species are all native of San Francisco and are all threatened by loss of habitat within the city. The problems these species face in urban environments, as well as the successes and failures of other habitat conservation programs, can help conservationists better design projects to improve native pollinator population. The organizations planning these restoration projects need to understand how the species interact with the environment. *Bombus californicus* requires ground-nesting habitat while *Icaricia icarioides missionensis* requires three lupine species for larval feeding. As seen with New York City's sidewalk gardens and the success of *I. icarioides missionensis* population restoration on San Bruno Mountain, having a combination of scientific, community, government, and non-for-profit interest helps restoration projects become a success. *C. viridis* only has community and non-for-profit interest in the form of Nature in the City while *B. californicus* has some scientific interest, but little else. To ensure that these species, as well as others are properly conserved, the City of San Francisco must get involved with planning efforts, especially when it comes to caring for parks. It is also important that non-for-profits and community involvement be encouraged in the form of citizen science and smaller gardens and sidewalk gardens to create pollinator networks. By having this level of involvement, the city of San Francisco can become a haven for native pollinators.

Introduction

City environments are often seen as unsuitable areas for habitat restoration. The dense population of humans, restructuring the entire ecosystem, and other anthropogenic effects make it difficult to support native plants and animals within city limits. However, cities are not separate from the environment, they are a part of it. To assume that because cities have a condensed human population they cannot be useful for conservation is incorrect and damaging to species that have a small habitat range (Wouter and Dyke, 2007). Cities can provide viable and useful habitat for pollinators, if restoration managers, land planners, and environmental organization know how to design, how to research, and how to improve these projects.

Why pollinators are important

Pollinators are one of the most important parts of an ecosystem. Flowering plants (angiosperms) make up 90% of all plants, and 67 to 98% of all angiosperms require pollinators (Ollerton et al., 2011). This is still true in city environments. Urban green spaces can help beautify the city, provide recreation areas, ease the burden on storm sewers, and help reduce the urban heat island effect (City Planning Commission, 2008). San Francisco boasts having 220 parks (see Figure 1), totalling 5,693 acres (23.04 square kilometers) of park space (Harnik et al., 2016)**.** Those parks are filled with flowering plants like the California Poppy (*Eschscholzia californica*) and Blue Blossom (*Ceanothus thyrsiflorus*) that require pollinators to survive. Ecosystems with pollinators are healthier and have a greater amount of species richness; increasing the diversity of flowers, birds, and other insects. (Wouter and Dyke, 2007).

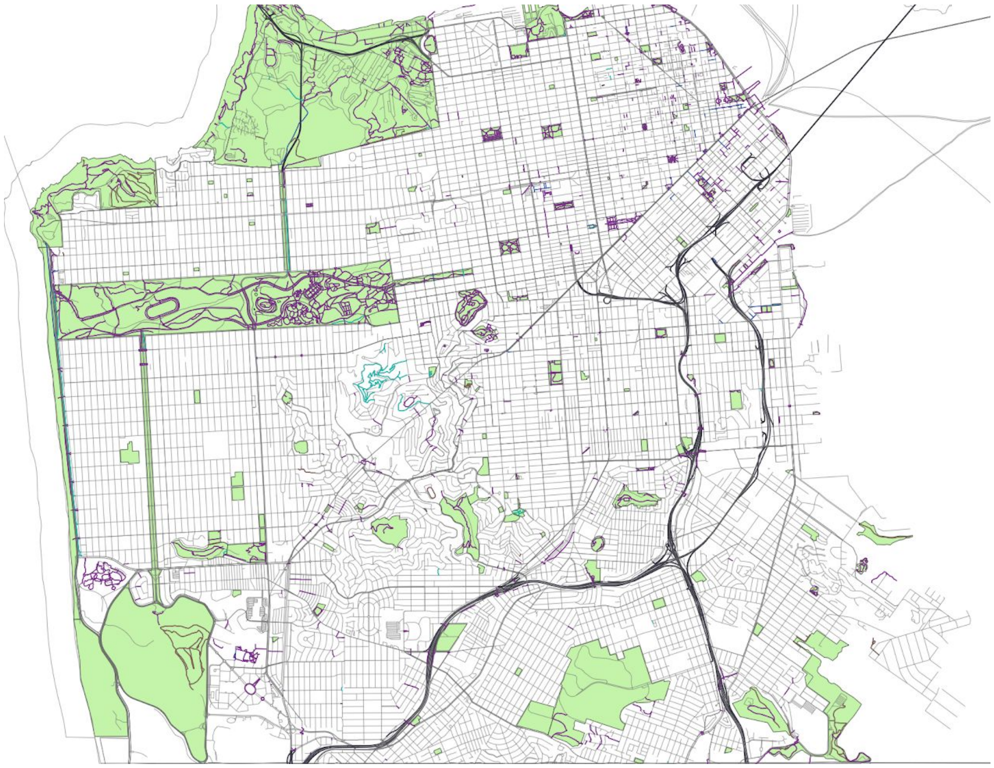

Figure 1: Image of San Francisco's Green Space (Harnik et al., 2016).

While it may seem as though nature reserves and national parks are adequate enough to protect native pollinator populations, they are not. Some pollinators only have habitat within a city, such as the Green Hairstreak Butterfly (*Callophrys viridis* (*C. viridis*)). This species has a habitat range of approximately four miles (~6.44 km) (Langston, 1974), and the widest part of San Francisco is only about 7.2 miles (~11.58 km) (Google Maps, 2018). Even species with larger ranges such as the California Bumblebee (*Bombus californicus, B. californicus)* need space to breed, nest and feed, and by not providing habitat space within a city there can be a loss of species diversity.

With so many green spaces present, it is possible to make a viable native pollinator habitat network.San Francisco has the green space needed, with several larger parks such as the Presidio and Golden Gate Park providing plenty of area for native habitat restoration. Smaller parks can be linked together using habitat corridors along sidewalks and road, providing slices of habitat that might have nectar bearing plants or resources to build nests. The amount of green space in San Francisco can provide an opportunity to help protect the city and state's native pollinators.

The Species

This paper focuses on three species found in and around San Francisco, detailed in Table 1. These species are the focus of this paper because they provide a look at conservation on different levels. *Callophrys viridis (C. viridis)*, the Green Hairstreak Butterfly, has a very small habitat range, which is conserved by a non-for-profit within the city. *Icaricia icarioides missionensis (I. icarioides missionensis),* the Mission Blue Butterfly, was put on the U.S. Endangered Species List in 1976 and has two major federal agencies working to conserve and protect it. *Bombus californicus (B. californicus)*, the California Bumblebee, has the largest range of the three species, is a generalist, and the non-for-profit Xerces Society for Invertebrate Conservation works to give out information on the species, though focused conservation efforts for this particular species are lacking. With these three species, there is a good idea of what information is out there, what information is needed, and how can restoration projects inside of San Francisco be improved.

Table 1: Brief overview of the three species and the ongoing conservation work. (Golden Gate National Conservancy, 2018; Nature in the City, 2018; and The Xerces Society, 2018)

Pollinator	Image	Ecosystem	Organization	Conservation Projects	Necessary Plants
Green Hairstreak Butterfly *Callophrys viridis*		Coastal Bluffs and Dunes	Nature in the City	Maintain three habitat corridors in the Inner Sunset Neighborhood to help connect populations	*Vaccinium myrtillus, Cornus sanguinea,* and *Rhamnus cathartica*
Mission Blue Butterfly *Icaricia icarioides missionensis*		Coastal Scrubland and grassland	Golden Gate National Park Conservancy and The U.S. Fish and Wildlife Service	Oldest conservation program (1984), GGNPC focusing mostly on planting the Lupines for the caterpillars	*Lupinus albifrons, Lupinus formosus,* and *Lupinus variicolor*
California Bombus Bumblebee *Bombus californicus*		Oak Woodland Savannah	Xerces Society	Helps agencies/organizations train land managers, citizen scientists, and other people for pollinator conservation issues, creates plant lists and conservation guidelines	Generalist, will pollinate any flowering nectar species

Callophrys viridis: Green Hairstreak Butterfly

C. viridis is a small butterfly, only about the size of a nickel, with a wingspan between 26 and 30 mm (averaged from the literature, Langston, 1974; Brown and Opler, 1967). *C. viridis* is native to San Francisco and its habitats are coastal bluffs and dunes. It is known for being a bright green, iridescent color (Figure 2) in both its larval stage and adult stage, which helps them blend in with the plants (Brown and Opler, 1967). *C. viridis* is a spring butterfly and is found in the highest concentrations between March and April, though they can be seen between February and June (Langston, 1974).

Figure 2: *C. viridis* on flower in the habitat corridor. In the top right corner there is a pink flag marking the present of the native plant species *Erigeron glaucus* (Seaside Daisy) (Nature in the City, 2018)

Conservation of *C. viridis* habitat is important because these butterflies do not have a wide habitat range. Most individuals only fly a few hundred feet from their birth habitat (usually between 30 and 70 meters) , and the range is around four miles (~6.43 km). The largest populations tend to be right on or near the coast (Langston, 1974). San Francisco is only about 7.2 miles wide (~11.58 km) (Google Maps, 2018). With such a small habitat range and most of it being in developed areas like San Francisco and Oakland, *C. viridis* does not have the luxury of having untouched habitat somewhere away from the city. Going farther inland in the Bay Region, the habitat changes from coastal bluff and dunes to chaparral, habitat that does not support the species. Furthermore, because it does not fly very far from its birth habitat, habitat fragmentation can cut individuals off from one another and cause inbreeding in a population.

Studies have shown that conserving native habitat for *C. viridis* can improve population numbers and species richness among other small animals, including birds, small mammals, insects, and plants (Wouter and Dyke, 2007). Parasitic wasps and the White-Crowned Sparrow (*Zonotrichia leucophrys*) are two groups that benefit from the presence of *C. viridis* (A. Hasselbring, Nature in the City, pers. comm.). In general, areas that have a diverse array of native pollinator populations also show an increase in overall flower health and species richness (Matteson and Langelleto, 2017), which is important if city planners want parks and green spaces to have a wide variety of flowers.

The Green Hairstreak Corridor is one such place where this increase in species richness can be seen. Before the corridors were created, most of the open space was dominated by one or two types of non-native grass, usually *Avena fatua*, or Wild Oat, and lacked diversity in insect and bird species. The most common pollinator seen in the area was *Apis Mellifera*, or the Western Honey bee (A. Hasselbring, Nature in the City, pers. comm.). After the corridors were restored, there was an increase in both vegetation and animal populations. The addition of ten to fifty native plant species to promote the population of *C. viridis* has nearly doubled the amount of native vegetation present, with some plots having over 100 different species of vegetation (Nature in the City, 2018).

C. viridis is an important species for the health of San Francisco's green spaces. It is necessary for some conservation efforts to happen because it has such as small range. If this species is not conserved, it will go extinct. Furthermore, it promotes a diversity of species, both plant and animal, that can make San Francisco beautiful and diverse.

Icaricia icarioides missionensis: The Mission Blue Butterfly

The butterfly *I. icarioides missionensis* is very well-known around the Bay Area and has been the subject of numerous conservation efforts to prevent its extinction. This is a small butterfly has a wingspan of between 20 and 34 mm and a lifespan between seven and ten days for adults (averaged from the literature, Lindzey and Connor, 2011; U.S. Department of Fish and Wildlife, 2017; Golden Gate National Recreation Area, 2017) and has bright blue, sometimes purplish, wings that are iridescent (see Table 1). It is a coastal scrubland and grassland species that can live at a variety of altitudes, sometimes as high as 213 m (Lindzey and Connor, 2011). They are a late spring, early summer species that often last until June (Golden Gate National Recreation Area, 2018).

The habitat of *I. icarioides missionensis* has been restricted due to development, invasive species, fires, grazing, and other disturbances. At this time, the largest pockets of the butterfly are found at nine locations: 1) Twin Peaks 2) Fort Baker 3) Marin County 4) San Bruno Mountain 5) the Marin Headlands 6) Golden Gate National Recreation Area 7) Laurelwood Park 8) Skyline Ridge and 9) Golden Gate Park (Golden Gate National Recreation Area, 2018). San Bruno Mountain currently hosts the largest known population at around 18,000 individuals (Golden Gate National Recreation Area, 2018; Lindzey and Connor, 2011). The population at Twin Peaks is around 500 individuals and there are several small pockets of the species around San Francisco (Golden Gate National Recreation Area, 2018).

The conservation of *I. icarioides missionensis* started in 1984. The population was on a steep decline so the U.S. government declared it an endangered species in 1976, with the U.S. Department of Fish and Wildlife and the Golden Gate National Recreation Area taking on the task of restoring the habitat and population (U.S. Department of Fish and Wildlife, 2018). *I.*

icarioides missionensis is unique in that its larvae require three specific lupine species to be present for them to feed on (see Table 1). This has been a main focus for restoration projects as without these lupines, the species would not survive (Figure 3).

Figure 3: From left to right: *Lupinus variicolor* (the varied lupine), *Lupinus albifrons* (the silver lupine) *and Lupinus formosus* (the summer lupine); the three host plants that are needed for *I. icarioides missionensis* to survive (Golden Gate National Recreation Area, 2018).

This species of butterfly is an incredibly important part of San Francisco's history, even taking its name from the Mission District, where it was originally found (Lindzey and Connor, 2011). It is a species that delights people who see and provides very important work in pollinating flowers, particularly lupines. If this species were to go extinct, San Francisco could lose one of its symbols.

Bombus californicus: The California Bumblebee

The *Bombus* genus is one of the largest genus for pollinators in the United States, with over 250 known species (Carvell, 2002). *B. californicus* is a species with a wide range, extending through all of California and even into parts of Nevada and Oregon (Soltz, 1987). This particular species is a generalist species; it feeds from many plants and inhabits the Oak Woodland Savanna (see Table 1) that is often found near grassland habitats. It is a ground nesting bee that lives in small colonies that have between 50 and 400 individuals (Cueva del Castillo et al., 2015).

Starting in the 1980s there was a drastic reduction in the number of queens found foraging (only two were found in 1980). This led to an overall reduction in population, which has been linked to a 13-fold reduction in nectar producing flowers (Soltz, 1987). This causes problems because as the number nectar producing flowers started to drop, other pollinators and animals were unable to find food. This drastic reduction in nectar producing flowers is because *B. californicus,* and most other bumblebee species, are keystone species in terrestrial ecosystems (Carvell, 2002). Without *B. californicus* present, the amount of species diversity in an ecosystem decreases dramatically.

B. californicus is a keystone species, mostly because it is a generalist species. It does not require a specific flower to be present to survive. This means that *B. californicus* can pollinate a wide variety of plants, helping to fertilize flowers that may be required for other species, such as *I. icarioides missionensis* to survive. In general, the *Bombus* genus populations are positively associated with species richness for nectar producing plants (Mcfrederick et al., 2006).

While it may seem like a waste to focus on this species in San Francisco, especially since is has such a wide range, compared to *C. viridis, B. californicus* is important to the ecosystem. It is a keystone species and having a small colony in a restored plot of land can greatly increase the chances of success for other native species (Goulson et al., 2002). Also, because *B. californicus* is a generalist species, it is much easier to restore habitat as there only needs to be a focus on having ground nesting materials and nectar producing flowers. Most restored plots for native pollinators should have these two aspects and this can greatly increase the chance of success as

B. californicus can ensure a wide variety of nectar-producing flowers that can help attract other pollinators. *B. californicus* is an important species to consider when looking into habitat restoration, even within city environments.

Objective of the Paper

How can we improve native pollinator habitat in an urban setting to promote healthy populations in San Francisco? By looking at how these three species are conserved inside and outside of San Francisco, how an urban environment might affect habitat conservation, and lessons learned from other cities' restoration projects, we can improve urban habitat conservation projects. First, I will discuss the conservation efforts for *C. viridis, I. icarioides missionensis,* and *B. californicus* inside and outside the city to determine what works and what does not. Then, I will discuss some of the specific problems San Francisco might face when designing a habitat a habitat conservation plan. These problems are the presences of the invasive *Apis mellifera (A. mellifera)*, or the Western Honey bee, ozone pollution, and habitat fragmentation in a city. Next, I will look at Chicago, IL and New York, NY to see where their pollinator conservation strategies succeeded and failed. Finally, I will discuss management suggestions that may help San Francisco and other cities create native pollinator habitats that are successful in preserving native pollinator populations.

Methods

There were two pieces of my research methods: interviews and peer-reviewed journal articles. I read through peer reviewed articles in an attempt to better understand what the three species needed, challenges faced by conservationists, and threats to the habitat. The purpose of this paper was to develop a way which we can better conserve habitat in urban environments and to do that, I needed to understand what worked for past projects. From there, I decided to expand my research to other cities and their attempts at increasing native pollinator habitat. I only researched cities with at least three peer-reviewed journal articles attached to them.

San Francisco habitat is mostly a mix of wetland, coastal scrubland, grassland, and sand dunes. The city is approximately 46.89 square miles (about 121.4 square kilometers) and has more than 220 parks and green spaces (Census Tract, 2010). It has a Mediterranean climate, characterized by mild winters and distinct wet and dry seasons. It is also part of the "fog belt" a strip of land that is often covered in fog due to the winds and cool air from the ocean blowing onto land and the water condensing (Golden Gate Weather Services, 2006).

I chose *C. viridis, I. icarioides missionensis,* and *B. californicus* as my three main species of interest for this paper because they created a well-rounded look at the different types of pollinators that are present in San Francisco. *C. viridis* is a butterfly with a very small habitat range and, while it is not a specialist, it is also not a generalist species and does prefer certain dune plants. *I. icarioides missionensis* is a butterfly species that is a specialist, requiring three specific lupine plants to present in order for the larvae to survive (See Table 1 and Figure 3), but it also has a larger habitat range and has been under the protection of the U.S. government since 1976. *B. californicus* is a generalist species with an extremely large habitat range, being found all over California and in parts of Nevada and Oregon. However, this bee species also does not have any particular group or organization focusing on its conservation, unlike the other two species. These species represent a variety of pollinator type as well as organizations that can be involved in habitat conservation, from government to small non-for-profits.

I interviewed Amber Hasselbring from Nature in the City to understand the Green Hairstreak Corridors in the Inner Sunset district of San Francisco as *C. viridis* is one of the most threatened species with the smallest range of the three species. This gave me insight into how small organization made up of mostly volunteers handled creating and maintaining habitat within the city and provides insight as to how these grassroots organizations can be used to help promote native habitat in green spaces that already exist. For *I. icarioides missionensis* I reviewed several government grey papers, action recovery plans, and information gained from government websites to learn about how the population was faring and what was being done to protect it. The action plan for habitat recovery for the Twin Peaks area was especially useful in providing a good idea of why that particular population of butterflies failed to improve as much as the San Bruno population as well as how they were going to improve the population. For *B. californicus* I reviewed articles and books suggested to me by the Xerces Society for Invertebrate Conservation. Out of all three organizations, the Xerces Society had the broadest information when it came to conservation strategies for the bee. The information in general was broad and focused more on the *Bombus* genus as a whole rather than this particular species.

Conservation Inside and Outside the City

Callophrys viridis

C. viridis relies entirely on habitat conservation in the city of San Francisco. It has a small range, and most individuals do not leave their natal habitat (Wouter and Dyck, 2007). Parks and corridors in San Francisco are imperative for their protection and restoration, and Nature in the City is working to ensure that the populations around San Francisco are connected.

The Green Hairstreak Corridor was started in 2006, organized by lepidopterist Liam O'Brien in association with Nature in the City, a small non-for-profit based in San Francisco. There were two small, hilltop populations of *C. viridis* located in the Inner Sunset District of San Francisco that were isolated from each other. Furthermore, the habitats were overrun with invasive grass species such as *Avena fatua*, which decreased the amount of nectar and larval plants present (Nature in the City, 2018). The plan was to connect the populations using habitat corridors in the Inner Sunset District (Figure 4). This would allow the populations to breed and have more area to find nectar and larval plants. The design included using San Francisco native dune plants, such as *Eriogonum latifolium* (coast buckwheat), *Erigeron glaucus* (seaside daisy), and *Acmispon glaber* (deerweed).

Figure 4: Map of the Green Hairstreak Corridor located in the Inner Sunset District(Google Maps, 2018). The two green spaces are small parks with the main two populations of *C. viridis.*The Green Hairstreak Corridor has extended down towards Taraval Street to increase the amount of area for the pollinators to nest.

The original idea was to simply flood the area with native plants and see what happened (A. Hasselbring, Nature in the City, pers. comm.). All of the plants used in the restoration were taken from areas around San Francisco and were used to attract and guide the butterflies and provide the larvae with plants to eat. Since 2010, Nature in the City has added more than 15 backyard nurseries and "street parks" to improve the flow of butterflies from one population to the next as well as establish new populations around the Inner Sunset District (Figure 4). The planners for the habitat corridors realized that they needed to balance larval plants and nectar plants since, at first, they used mostly larval food plants. This knowledge was crucial in what finally allowed the *C. viridis* population to grow (A. Hasselbring, Nature in the City, pers. comm.).

Over time, they changed and restructured the habitat corridors to better suit the butterfly population. Discovering that there needed to be more of a balance between the larval and nectar food plants was the first lesson Nature in the City learned. They also learned that sites facing west had a higher rate of larvae and butterflies than sites facing east. This is because the chrysalis and *C. viridis* are dependent on sunlight and if the species is not warm enough, it can cause them to die (Langston, 1974).

Figure 5: Volunteers restoring the habitat along the corridor, removing invasive species and planting native ones (Nature in the City, 2018).

The population has grown slowly, with the first *C. viridis* adult seen on a restored plot in 2011. The population has continued to grow steadily with over a dozen seen in 2013 (Nature in the City, 2017). Currently, there is estimated to be about 500 adults present (A. Hasselbring, Nature in the City, pers. comm.). There have been other benefits to having the habitat. Other plants and animals such as the White-Crowned Sparrow (*Zonotrichia leucophrys*) and certain species of parasitic wasps increased. The number of native plants has also increased. Before the sites were restored, there were between five and ten native plants with most plots covered in Ice Plants (*Disphyma crassifolium*) and invasive grasses (Figure 5). With the continual management of the area, some plots have over fifty native plants with others having as many as one hundred.

Some of those have been purposefully planted by Nature in the City, but others have appeared naturally, able to compete with other native plants (A. Hasselbring, Nature in the City, pers. comm.). This strategy is an adaptive management strategy and is useful when creating conservation plans. Being able to adjust habitat and methods to better suit a species is what makes restoration projects a success.

Nature in the City has done great work in improving the habitat of *C. viridis* and the population has slowly been increasing, but the biggest problem that is stopping this project from taking the next steps in restoration is the lack of monitoring. Nature in the City did very basic butterfly counts before the restoration and have done no organized butterfly counts after the restoration. Their data has been what has been observed during work days and tours but little else. They have made some observations that has helped them improve the habitats, such as adding more nectar plants and focusing more on the western slopes than eastern ones, but this lack of data means they cannot apply for grants and they do not know how successful the population is (A. Hasselbring, Nature in the City, pers. comm.). Furthermore, there has not been an organized, peer-reviewed scientific study on the population, so there is no way to know if it is still improving or not. The data is qualitative data and it is a good start, especially for smaller non-for-profits looking to restore a habitat, but if the city of San Francisco wanted to do a more extensive *C. viridis* habitat restoration project, they would not have data to help focus the project.

Icaricia icarioides missionensis

The butterfly *I. icarioides missionensis* has a long history of conservation projects since its declaration as a federally endangered species in 1976. Recovery plans from the U.S. Fish and

Wildlife Service were developed in 1984 and passed to the Golden Gate National Recreation Area soon after with a focus on developing native habitat in San Francisco, Twin Peaks, San Bruno Mountain, and the Golden Gate National Recreation Area (GGNRA, 2018). The recovery plans focused on three specific plant species: *Lupinus albifrons, Lupinus formosus,* and *Lupinus variicolor.* These are the three species that are required for *I. icarioides missionensis* habitat restoration to be a success.

While the adults of this species are generalists, taking pollen from many different plant (though preferring the Asteraceae (sunflower) family), the larval form is a specialist. It only eats from the three lupine species mentioned above (U.S. Department of Fish and Wildlife, 2018). Without these three plants, it is impossible to sustain a population.

Lupines, in general, are fairly easy to plant and can colonize most habitats. Another benefit of lupines is that unlike other plant species, they are not sensitive to harsher environments and can grow well on road cuts and rock outcrops (Weiss and Murphy, 1990). However, there are many problems that come with planting lupines as the biggest restrictions to their success are wind and invasive species. Grasslands are among one of the most disturbed environments in California, with almost 90% of grasses being non-native invasive annuals from the Mediterranean region of Europe (Weiss and Murphy, 1990). Species such as *Avena fatua* and *Briza maxima* take over the area and choke out native plants. Managing the grassland habitat can keep invasive species from taking over the environment.

Between 1982 and 2000, there was a 40% increase in *I. icarioides missionensis* found in the San Bruno Mountain in study transects (Longcore et al., 2010). This increase was so significant, that the population has been classified as self-sustaining and other restoration sites regularly remove adults from the area and transplant them into less dense populations to add some genetic diversity (Longcore et al., 2010). Where Longcore et al. (2010) found the highest concentration of *I. icarioides missionensis* was on the Northwestern study area of San Bruno Mountain, where the grassland was better monitored and protected from invasive plants. This study showed that a focus on protecting the grassland habitat from weeds and succession to native coastal woodlands is the best way to help promote native populations. As of 2017, the Golden Gate National Recreation Area has estimated that the San Bruno Mountain population has about 18,000 adults, the Skyline Ridges about 2000, and Twin Peaks about 500 (GGNRA, 2018).

Figure 6: A map of the Twin Peaks site in San Francisco (Google Maps, 2018).

The population at Twin Peaks (Figure 6) is the smallest of the monitored populations and between 1997 and 2007 rapid monitoring of the area showed that the population was in decline (see Table 2) leading to an action recovery plan for the area. This decline was thought to be because the loss in lupine species since the area was not regularly managed for invasive species (Wayne et al., 2009). Also, they noticed that areas that had higher numbers of the three lupine species were in areas with high wind. *I. icarioides missionensis* is a weak flyer and wind is a reason for the death of adults (Wayne et al., 2009).

The problem with this study is that the adults for *I. icarioides missionensis* only live for six to ten days (GGNRA, 2018), so it is entirely possible that Twin peaks did not have a proper schedule to try and capture and count the adults. Looking at Table 2, it is clear that there are at least a few males and females present since there are eggs present. This data was collected in April in all of the years, though on different days and weeks. Because the surveys were not performed on the sames days of the same years, the data could be skewed. The data collected was also the result of rapid monitoring, not of long term data collection, which means that they went out, marked down if butterflies were present, and then left. This may have been the result of an underfunded agency who did not have the ability to do long-term scientific studies, which resulted in poor data analysis. The Golden Gate National Recreation Area has the Twin Peaks population at around 200 as of 2017 and this recovery action plan was written up in 2009, so it is entirely possible that the Twin Peaks plan has been working.

Table 2: Mission blue butterfly monitoring data at Twin Peaks (Wayne et al., 2009)

Year	1997	2001	2002	2003	2004	2005	2006	2007	Total
Larvae					1		1		2
Total Adults	10		1		1				12
Male	6		1		1				8
Female	3								3

Unidentified	1								1
Eggs		14	103	23	84	143	43	22	432

There were two main staples of the Twin Peaks Recovery Action plan: introducing males and females to the area from the San Bruno population, and managing the habitat better. The San Bruno population is self sustaining, at 18,000 individuals, taking a few males and females at a 5% removal rate is safe and sustainable for the population (Wayne et al., 2009). This would help increase the genetic diversity of the population, decreasing the inbreeding effect among individuals and making the population healthier. Until the population is self-sustaining, as in the case of San Bruno Mountain, it is imperative that reintroduction continue to happen (Wayne et al., 2009).

Planning on increasing the distribution of the 3 lupine species and control the invasive species is also important. In the action recovery plan, Wayne et al. (2009) noted that the lupine species have been in a steady decline, being taken over by woody plants and invasive grasses. The total population of lupines present in the data collection sites has decreased almost 34% between the initial start of the project (1997) and the end of the project (2007). They also found that nectar sources were scarce. Even though it is the larvae that are specialists and require the three lupine species to be present, with the takeover of non-native invasive grasses, the amount of nectar plants present for adults has been decreasing steadily, though not at as high of a rate as the lupine species, only about 12% decrease between 1997 and 2008 (Wayne et al., 2009).

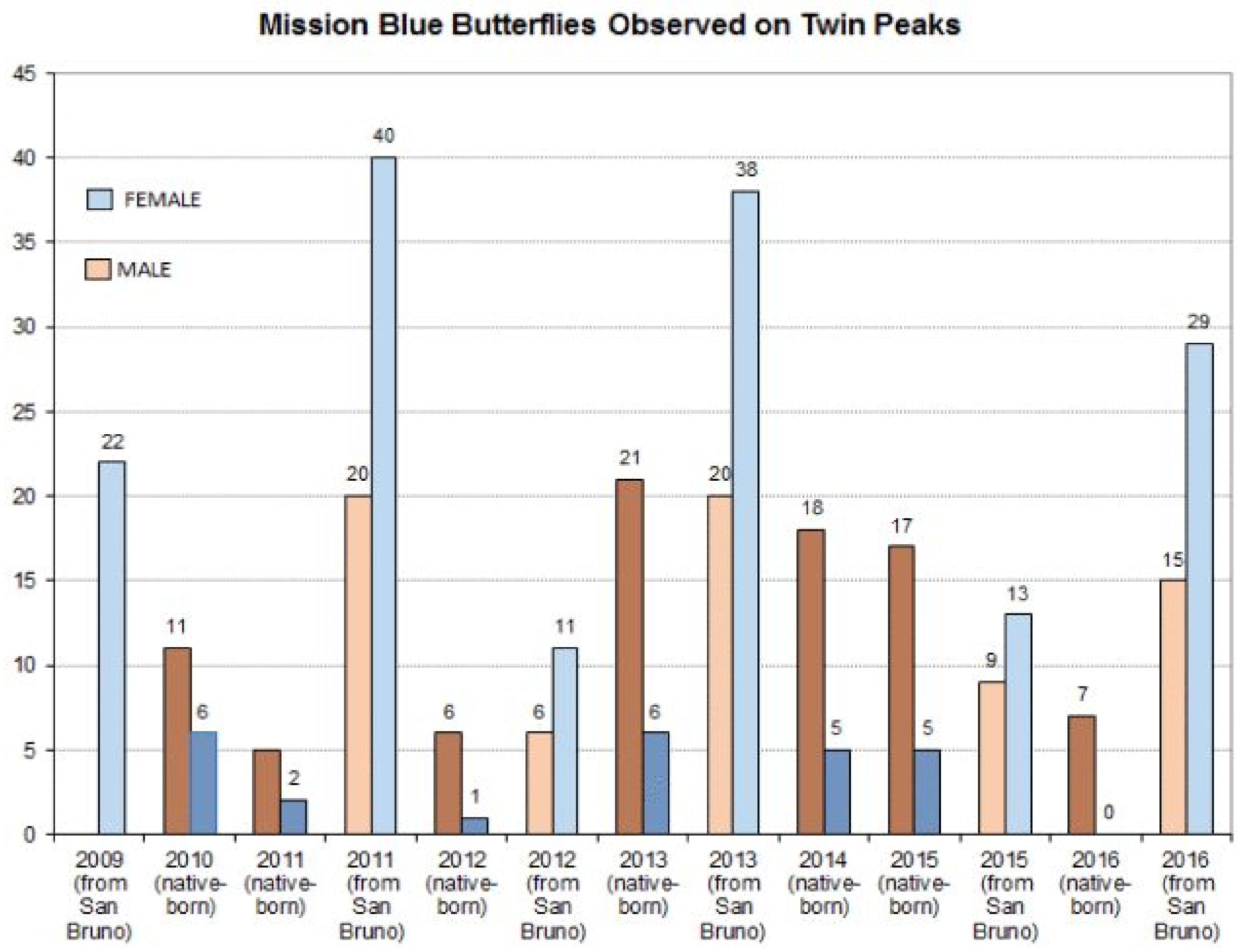

Figure 7: Graph showing the results of introducing butterflies from San Bruno after action recovery plan (Save Mount Sutro Forest, 2017). Adult population counts were taken from Twin Peaks and then butterflies from San Bruno were transplanted to balance out the number of males and females and boost the population.

Overall, the Twin Peaks Action recovery plan focuses mainly on reintroduction and land management. San Bruno is a heavily managed area that regularly undergoes controlled burns and invasive species removal as well as regular planting of the lupines and nectar plants. This attention has led to San Bruno having the highest population of *I. icarioides missionensis* at 18,000 individuals as of the 2017 counts. Twin Peaks showcases a less managed practice and likewise has the lowest population of butterflies at approximately 500 individuals. Figure 6 shows the success of this transplant of San Bruno individuals to the Twin Peak Region. While there is an increase in native born males and females from 2010 to 2013, the population declines sharply in 2016, with only seven males present and zero females. What is interesting to note about Figure 6 is in 2014 there were no San Bruno transplants and the butterfly population stayed consistent, losing only one male.

This sudden drop could come from a lack of regularity in the study methods. Save Mount Sutro Forest is a non-for-profit working with the Twin Peaks staff to help monitor the butterfly populations. However, *I. icarioides missionensis* only lives six to ten days. If the monitoring took place a week after the larvae turned into adults, that could explain the sudden population drop. Also, while reading through the Twin Peaks Action recovery report, there was more of a focus on recovering the population by bringing in adults from the San Bruno population (Wayne et al., 2009) and while that may have helped, the area also needed to have a focus on restoring the lupine habitat as well. Another possibility for this sudden drop could have been because of the heavy rains the Bay Region experienced in 2016, causing some areas to flood. This is a disturbance that could have shifted the habitat. It is important that Twin Peaks continues to support plant habitat, balancing the lupine species and the nectar bearing species, and not focus solely on transplanting individuals from San Bruno.

Another area in San Francisco that focuses on the protection of *I. icarioides missionensis* has been Golden Gate Park. Because this park is one of the only areas in San Francisco that can support both scrubland and grassland habitat, it can support a small population. There has not been any formalized study on the population of *I. icarioides missionensis* in Golden Gate Park, as finding ways to monitor can be incredibly expensive and difficult. However, there have been several lupine planting efforts in recent years and an overall movement to rid the park of non-native and invasive species. Not only that, but the way the park is structured, there are several areas that are protected from the wind and, given the large size of the park, several corridors species can use to travel to other populations (MacDonald et al., 2012).

The best way to improve the population of *I. icarioides missionensis* is to focus on planting and maintaining a healthy and diverse lupine habitat. By focusing on this, and creating habitat in areas that are sheltered from the wind, *I. icarioides missionensis* has a chance to improve and grow. Once lupine is planted, it is relatively easy to care for, only needing protection from invasive species. *I. icarioides missionensis* is on the rise in some areas of the San Francisco Bay Area, and on the decline in others, but using both situations can better determine what works and what does not for this species.

Bombus californicus

B. californicus is unique of the three species discussed in this paper because there is no one group or organization that is focused on its conservation. It is a species that usually benefits from the restoration and conservation of habitat for other species, but rarely has a focus when designing and implementing restoration projects. The Xerces Society for Invertebrate Conservation has a website dedicated to collecting information that can be used to help agencies and organizations train land managers, citizen scientists, and other interested parties on pollinator conservation issues and does have a section on bumblebees and their importance, but there is no particular focus on *B. californicus* or the *Bombus* genus in particular. That does not mean that *B. californicus* can survive in any habitat. There are ways to promote population growth for this keystone species.

B. californicus is a ground nesting bee species. The queens, in particular, burrow underground and hibernate during the winter so it is imperative that ground nesting habitat be available (Goulson et al., 2002). *B. californicus* populations are positively correlated with openness and soil that is easy for the queens to till during the winter (McFrederik et al., 2006).

Goulson et al. (2002) placed *Bombus* nests in several different locations in several different substrate types including gardens, farmland, and parks in substrates that included soil, wood chips, and miscellaneous materials. All the nests that were placed in proper soil substrate, regardless of location, gained more weight than those placed in the other substrates. The average weight of all the nests before being placed in the substrate was approximately 130 +/- 8.2 grams. Afterwards, the average biomass of those placed in soil was 629 +/- 30.9 grams compared to the average 527 +/-34.5 grams gain in wood chips (Figure 7). With a biomass gain of almost 499 grams, the soil nests were bigger and more productive than nests found in other materials. Hive health is measured in biomass and not population numbers because of the large size of hives. Biomass includes the hive materials, larvae, eggs, and worker bees with larger hives being indicative of healthier and stronger populations. The nests placed in soils increased on average to a colony size of around 203+/- 15.4 individuals while those nests placed in other substrates only increased to about 100+/-29.9 (Goulson et al., 2002).

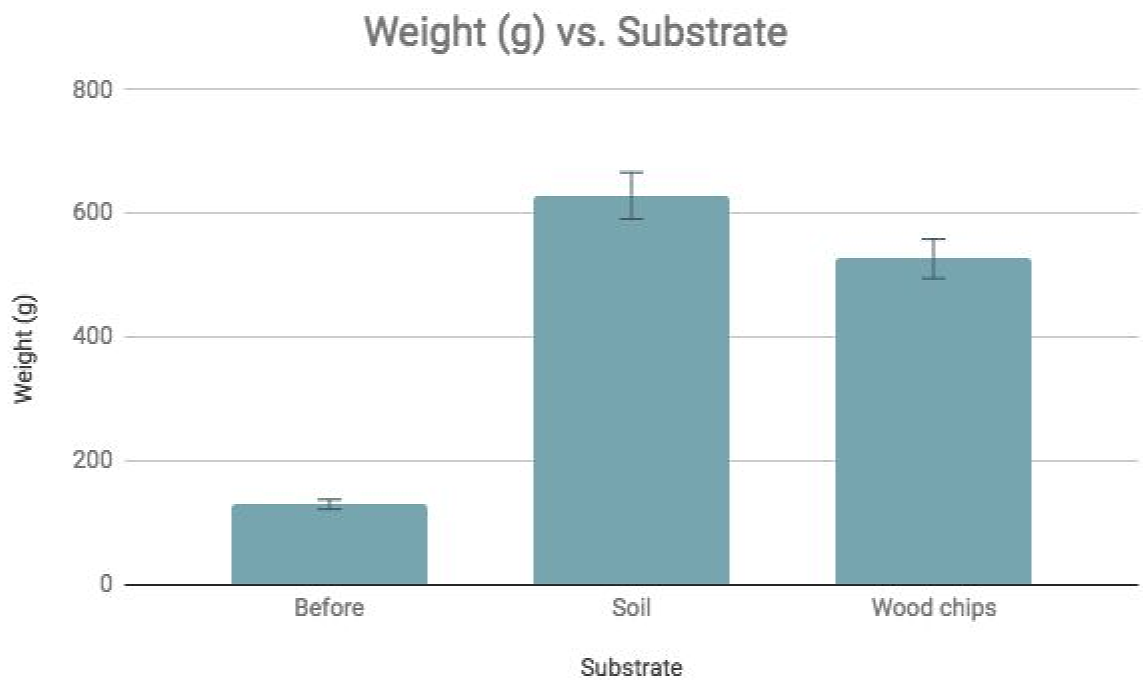

Figure 8: A chart depicting the difference between the weight of the hives in different substrates (Goulson et al., 2002).

Traffic near flowers increased when nests were placed in soil nearby. One hive had 23 distinct pollen types identified in the nest. Most areas with the nests in the soil had over 127 different foragers around the flowers. Furthermore, observing the site area for fifteen minutes showed that those areas with the nests in soils had a 100% visitation rate. Those with nests in wood chips had a 45% visitation rate, and those with miscellaneous substrate materials had a 25% visitation rate (Figure 8). The controlled area where there were no nests placed in the substrate often had a visitation rate between 0% and 15% (Goulson et al., 2002).

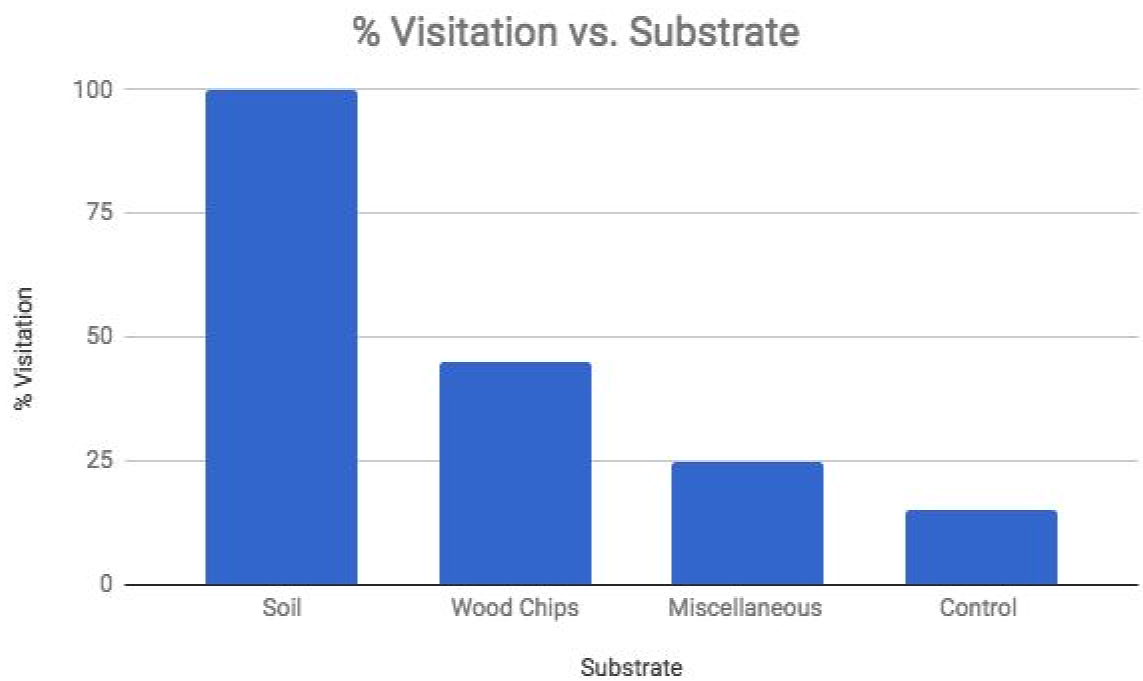

Figure 9: Comparison between the different substrates and how often they were visited by bees (Goulson et al., 2002).

The increase in hive biomass in soil conditions shows that conservation of *Bombus californicus* is reliant on the presence of soil and space in that soil to create the hives. Some garden projects and parks utilize wood chips in landscaping to help keep weeds under control, provide soil nutrients, and can provide some color to a garden. The Botanical Gardens in San Francisco use wood chips in some areas and several paths in Golden Gate Park have wood chips that line them. Furthermore, in some planters and sidewalk gardens there is a mix of gravel and wood chips present. In the flyers given by the San Francisco Permitting Department on designing a sidewalk garden, gravel and wood chips are two of the suggested materials used. This use of non-soil materials can make it difficult for *B. californicus* to find areas to nest, decreasing the amount of hives in the Bay Area. *B. californicus* is a generalist species so the focus needs to be on providing nesting habitat for the queens. Bee species that build nests in soil can have a more difficult time being conserved because the design of parks and gardens will often compact the soil, rendering difficult or impossible for soil nesting species to nest (Cane et al., 2006).

The data show that *B. californicus* is an important species to conserve. It is a generalist species, so it does not need special flowers present in an area like *C. viridis*, which requires dune plants, or *I. icarioides missionensis,* which requires three lupine species. This makes it much easier to conserve as it can easily be included with other projects, as long as there is an relatively open area with easy to till soil for nesting purposes. More than increasing the population, increasing the flower visitation rates is incredibly important in habitat restoration. Especially with smaller populations of pollinators, having *B. californicus* there to pollinate flowers that might not be visited otherwise until the population is more stable can mean a higher rate of success. The study by Goulson et al. (2002) shows that the type of substrate in an area can affect the visitation rates of an area and plants need high rates of visitation if they are going to be fertilized. Having habitat for *B. californicus* is relatively simple. Just ensure the substrate is soil so there can be ground nesting.

Special Considerations for Urban Areas

Apis mellifera: The Western Honeybee

The Western Honey Bee, or *Apis mellifera (A. mellifera*), as seen in Figure 9, has been the focus of conservation campaigns across the world. This small honey bee has attracted a lot of attention over the years due to Colony Collapse Disorder and its recognizable and charismatic nature. *A. mellifera* is the most common species of bee used to make honey and is considered a domestic species like cows, sheep, or chickens. However, *A. mellifera* is a damaging species because it is invasive, outcompeting native pollinators, transferring diseases, and hybridizing with other bee species.

Figure 10: Photo of *A. mellifera* (iNaturalist, 2018).

This species of honey bee was first brought over from Europe to the Americas in the 1600s by European colonists looking to produce honey commercially. From the East Coast, *A. mellifera* spread rapidly, finally reaching California in the 1850s after being brought over the Rocky Mountains (Head, 2008). After that, *A. mellifera* fundamentally changed the population and species make-up of the Americas, causing mass extinction of native pollinators as well as shifting the distribution of plant species (Head, 2008).

A. mellifera is a fast species of bee, traveling at about 7.5 m/s (do Carmo et al., 2004), while the average speed of *C. viridis* is about 2.2 m/s (U.S. Department of Fish and Wildlife, 2018). This speed allows *A. mellifera* to travel farther and faster than most butterflies, especially smaller ones such as *C. viridis* and *I. icarioides missionensis*. This speed also means that *A. mellifera* is able to visit more flowers than native pollinators, outcompeting the slower species. Most non-native species can forage at higher rates than their native counterparts, with some as much as 2 mg nectar/hour with larger commercial bees foraging more than smaller populations (Igns et al., 2006).

Most pollinators will only take a small portion of the nectar from a planting, leaving the leftovers for other pollinators to use when they visit the flower. This is beneficial to the flower because it ensures that it will get pollinated and its pollen will fertilize another flower. *A. mellifera* completely removes nectar from a planting, leaving little to no nectar left for other species (Paini, 2004). *A. mellifera* has also been documented at removing 99% of the pollen grain, while other species remove less than 0.1% (do Carmo et al., 2004). With only 1% of pollen remaining in a flower, chances that it will be pollinated by more than one insect or fertilize more than one flower is decreased significantly. Likewise, native pollinators will not have enough food to eat and will have to use more energy to find flowers with enough nectar.

This lack of food and increased competition for the remaining 1% of pollen and nectar left behind by *A. mellifera* means that native pollinators will be expelled from the environment, unable to compete with *A. mellifera. C. viridis* and *I. icarioides missionensis* have a harder time adapting to the presence of *A. mellifera. C. viridis* has a small habitat range and if *A. mellifera* were to take over, there would be no where for the butterfly to go. *I. icarioides missionensis* has a slightly larger habitat range, but requires the three lupine species to be present for its survival. If *A. mellifera* causes the lupine population to decrease because the plants are not being fertilized by enough pollinators, the larvae will have nothing to eat and the *I. icarioides missionensis* population will decline.

Colonies of *A. mellifera* tend to be much larger than most native bee colonies, with some domesticated colonies averaging 60,000 individuals (Kato et al., 1999). The average bumblebee colony (across all species) is between 50 and 400 individuals, the largest colony ever recorded being 1700 individuals (Cueva del Castillo et al., 2015). Assuming that 400 individuals is the average size of a bumblebee colony, that makes *A. mellifera* colonies 150 times larger than the average bumblebee colony, and 35 times larger than the largest colony ever recorded.

Another problem that *A. mellifera* causes for native bee species is the transfer of pathogens, particularly a virus known as Deformed Wing Virus (DWV). This virus is passed through a vector parasitic mite known as *Varroa destructor* that causes wing deformities in bees (Figure 10), often leading to premature death (Desai et al., 2012; Wilfert et al., 2016). *A. mellifera* that is the host. DNA analysis of the virus shows that the genome of the virus is closely linked to *A. mellifera* individuals in Europe, particularly in the Netherlands. When *A. mellifera* is introduced to an area, the prevalence of DWV in native bumblebee populations can increase 60%, and in some cases up to 80% (Furst et al., 2014). When researchers sequenced the mtDNA of mites found in Japanese native bumblebees, the mtDNA was the same sequence as those found in European mites (Goka et al., 2001). DWV is spread from *A. mellifera* to *Bombus* species due to sharing pollen and nectar sources (Li et al., 2011). Both species are generalists with a relatively large range and both species live in colonies, which increases the rates of infections.

Figure 11: Photo of bee with *V. destructor* and DWV (Courtesy of Matt Bearup, 2016).

New York City has banned honey bee hives within the city to help prevent the spread of diseases and resource competition between native pollinators and *A. mellifera*. This is a more recent measure. In 2016, one rooftop alone hosted more than 180,000 bees (New York Beekeepers Association, 2018)**.** Most people do not understand the *A. mellifera* is a dangerous, non-native bee that can cause just as much destruction as other non-native invasive species. When people want to conserve and save the bees, they tend to focus on this species, but the data above shows that *A. mellifera* causes more harm than good.

Bee keeping is a popular San Francisco past time with several honey bee groups present in the city. University of San Francisco even has a bee keeping ground on campus. This is because San Francisco has very lenient laws when it comes to beekeeping. There is no need for a permit and you can have bee hives anywhere in the city (SF Environment, 2018). The largest beekeeping group is the San Francisco Beekeepers Association with 180 members, each owning one hive and many owning five (San Francisco Beekeepers Association, 2018). This means that there are between 10,800,000 and 54,000,000 honey bees in San Francisco, and that is for one group. Because San Francisco's laws are so lenient, many more people own *A. mellifera*, which can easily outcompete native pollinators, especially when numbers get into the millions of individuals. To have 10,800,000 bumblebees in San Francisco with colony sizes of 400, there would have to be 27,000 colonies. San Francisco is 121.4 square kilometers which means there would need to be one bumble bee colony every 0.0044 square kilometers (or about one colony every 0.0017 square miles).

Even though *A. mellifera* is a domesticated species with beekeepers keeping hives in a specific location, it is common for feral beehives to set up in the wild. A study conducted near London, England, found that non-native bees in transport to crops were able to escape up to 57% of the time (Igns et al., 2006). *A. mellifera* is not like other domesticated farm animals that can be easily contained, they have to fly away from the hive to find food and therefore they can easily set up feral colonies in the wild and in parks.

Having *A. mellifera* colonies throughout San Francisco, and other cities is dangerous, and not just for native pollinators. Even if *A. mellifera* hives can pollinate every flower that needs to be pollinated, they cannot interact with the environment the same way. *B. californicus* is a ground nesting species, which means it changes the soil where the hives are located. It might mix the soil, create pockets that can be flooded during rain, and creates spaces where plants cannot grow. *A. mellifera* is not a ground nesting species, usually making hives in trees and other tall structures. If *B. californicus* were to go extinct, it could have far reaching implications because one of the ecosystem services, tilling the soil, is no longer provided. Likewise, many pollinators are keystone species and if they go extinct, the entire ecosystem could experience a decrease in species richness. Everything from plants to insect-eating predators could experience localized extinction because of the loss of one keystone species. Finally, from a conservation perspective it is not a good idea to rely solely on one pollinator species to pollinate. If DWV mutates and becomes deadlier or another disease invades the hives and kills large amounts of *A. mellifera*, there will be no other species to pollinate, which could lead to massive amounts of extinction. By having a large variety of native pollinators, the ecosystem is more stable. If a bee species population decreases one year, a butterfly and ant population can still pollinate.

The best way to keep *A. mellifera* from damaging native pollinator populations is for San Francisco to follow New York City's lead and ban honey bee hives within the city. Many people do not realize the damage these bees can cause and if they continue to grow, they could completely wipe out native pollinators, even if the city focuses on restoring habitat. By allowing *A. mellifera* to freely inhabit San Francisco, it becomes harder to protect vulnerable pollinators, even if habitat restoration is happening. This needs to start with some sort of permitting process. If San Francisco required a permit for *A. mellifera* colonies, there could be a cap on the number of colonies a person could have and the city could create spaces near parks where no beekeeping efforts could happen.

Air Pollution

Pollinators are impacted by air pollution in a unique way: affecting their ability to find flowers. Flowers that require pollinators to come visit put out special hydrocarbons called floral hydrocarbons. These hydrocarbons are used to put out a scent that will attract pollinators to the flower. This is why certain plants smell sweet, it is a signal to the pollinators that there is nectar for them to eat. Without this signal, pollinators would assume that there is no reason for them to visit a plant. Pollinators have relatively good eyesight for having simple eyes, they can see a variety of colors as well as colors on the infrared spectrum (Jürgens and Bischoff, 2017). These colors help them determine which flowers are good flowers to visit. Ozone interacts with the floral hydrocarbons to deteriorate them, thus masking the scent (Fuentes et al., 2016; McFrederick et al., 2008). Once the scent is neutralized, the flowers are unappealing to the pollinators. They might still look pretty and have a petal shape that encourages pollinators to land on them, but without the scent, they hold no appeal for the bees, butterflies, ants, beetles, and other pollinators.

Researchers have found that flowers have reduced visits after being exposed between 60 and 120 ppb (parts per billion) of ozone (Fuentes et al., 2016; McFrederik et al., 2008). With ozone levels predicted to increase in the future, this can have negative impacts on the plants. If insects do not visit plants due to not being attracted to them, the reproductive success of plants will decrease. This creates a feedback loop as less reproductive success means less pollinators and less pollinators mean less reproductive success.

In a study done by McFrederik et al. (2008) they found that any ozone over 0 ppb can affect the number of bumblebees attracted to a flower, with 60% of the bumblebees showing a clear bias towards flowers that were not affected by ozone. Furthermore, in areas with fake flowers and 120 ppb of ozone, the bees landed on both the artificial flowers and the real flowers at almost the same rate, unlike in areas that were not affected by ozone, where they almost exclusively landed on real flowers. At an ozone level 60 ppb, pollinator visits to flowers begin to drop off dramatically (Fuentes et al., 2016) with the most harm being at 120 ppb (McFrederik et al., 2006). San Francisco has yet to reach an ozone level of 120. However, it does have years where the 1-hr and 8-hr ozone max is above the 60 ppb threshold (Figure 12 and Figure 13).

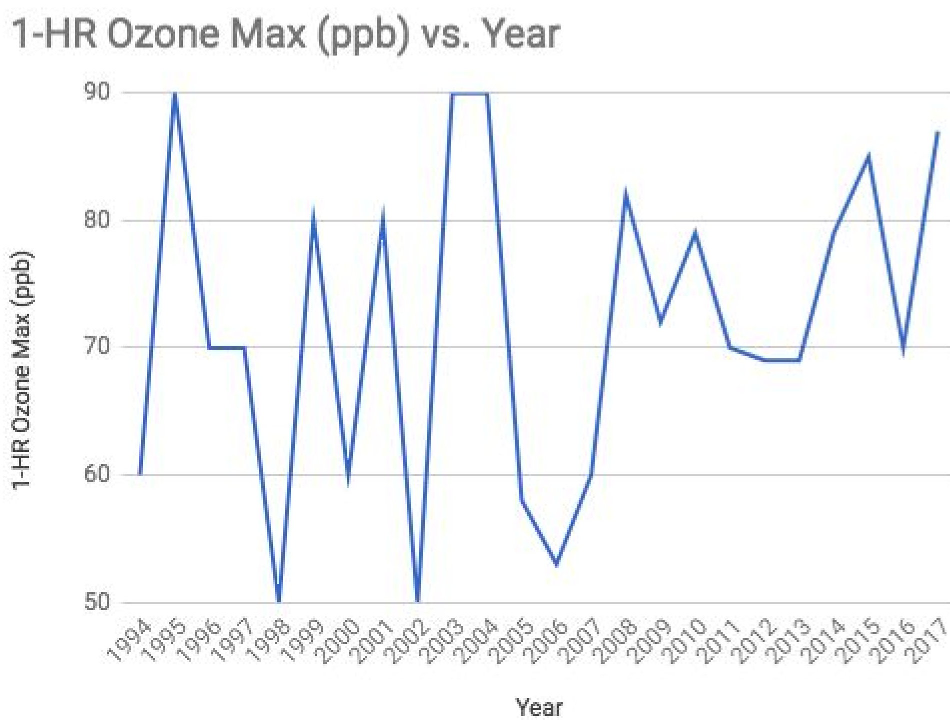

Figure 12: A graph detailing the 1-HR ozone max from 1994 to 2017. This was an average across the city of San Francisco using several data points and measuring stations. Data table can be found in the Appendix. Data gathered from the Bay Area Air Quality Management District (2018).

Figure 13: A graph detailing the 8-HR ozone max from 1999 to 2017. This was an average across the city of San Francisco using several data points and measuring stations. Data table can be found in the Appendix. Data gathered from the Bay Area Air Quality Management (2018).

In 2016, San Francisco's highest 8 hour ozone concentration was 57 ppb (Bay Area Quality Management District, 2018), which is lower than the 120 ppb estimated by researchers as the point at which floral hydrocarbons begin to lose their ability to attract pollinators (Fuentes et al., 2016). There has been no past evidence of multiple days with high concentrations of ozone, but the city does show that higher ozone becomes more prominent in the summer and there is evidence that ozone levels are rising yearly (Altshuler et al., 1995). Ozone is at its highest in San Francisco on the weekends, sometimes rising more than 12% between then and the weekdays (Altshuler et al., 1995). The information is averaged across the city and while the trendlines do show an increase from year to year, there is also more guidelines being implemented to decrease the amount of ozone cars and other pollutants put out into the environment.

The general trend is that ozone tends to be higher in the summer and lower in the winter (Altshuler et al., 1995). This is a problem, especially for *B. californicus* since their population peak tends to be in May and July (Figure 14). Both *C. viridis* and *I. icarioides missionensis* are butterflies that are more commonly found in the spring, but there are some adults that are seen in the late summer (Langston, 1974; GGNRA, 2018).

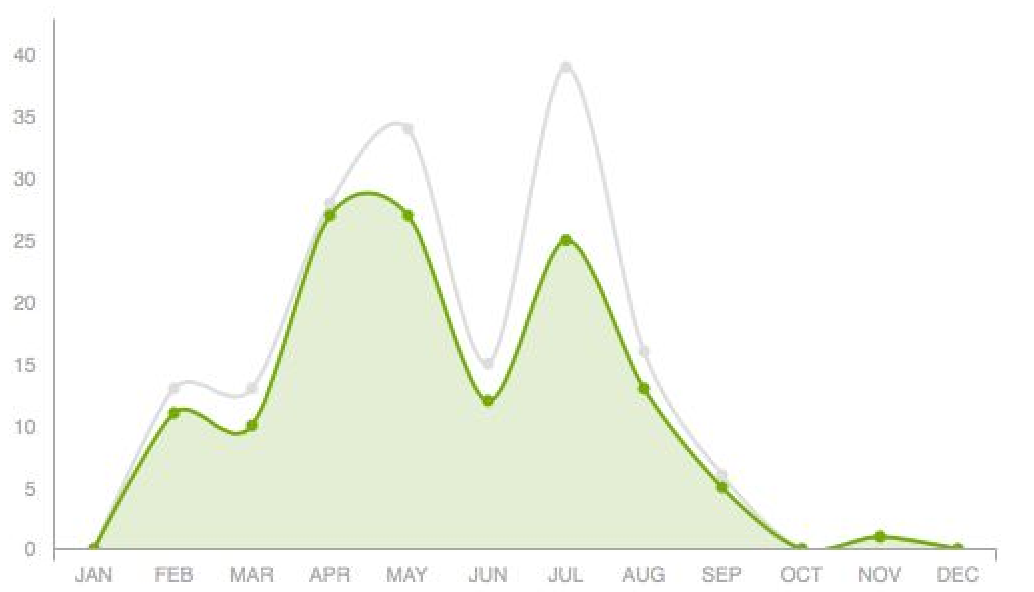

Figure 14: Observations of seasonality of *Bombus Californicus*. The green line is scientifically observed and verified and grey line is observed by citizens and verified. Shows the greatest level of population is in the summer, when San Francisco ozone is at its highest (iNaturalist, 2018).

Ozone, therefore, is something that must be considered when trying to improve habitat for native pollinators. Ozone, unlike other types of pollutants, is not emitted directly into the air. Instead, a chain of chemical reactions happens between the oxides of nitrogens (NOx) and Volatile Organic Compounds (VOC) in sunlight (Environmental Protection Agency, 2018). Most of these come from emissions from vehicle exhaust, gasoline vapors, electric utilities, and chemical solvents (Su et al. 2016). San Francisco is generally within the healthy range for ozone (between 0 and 100 in the Air Quality Index Score) (Air and Waste Management Association, 2016; Tao et al. 2013). It is best to continue increasing regulations of ozone producing pollutants. San Francisco has several years in which the 1-hr ozone max and the 8-hr ozone max are below the 60 ppb threshold (Figures 12 and 13)**,** but even as late as 2017 the 8-hr ozone max was 54 ppb and the 1-hr ozone max was 87 ppb, so there can be some improvements in lowering the overall amounts of ozone present in San Francisco.

Habitat Fragmentation

There are many problems that are associated with habitat fragmentation. Edge effects are one such problem. Habitats are rarely homogeneous throughout and there is often a gradient from the outer edge of a habitat towards the inner area where plants and species diversity shifts and changes. The outer edges of the habitat are often higher in disturbances from wind, rain, and predators, as there is less protection. Some species do very well in these habitats, such as deer or *A. mellifera* because they can withstand the rapid changes and higher rates of predation (Volpe et al., 2016). However, most species do not do well. Even if the area of the two fragments are the same, there is still less room for interior species as the edge habitat grows (Figure 15) (Banaszak-Cibicka and Zmihorski 2016).

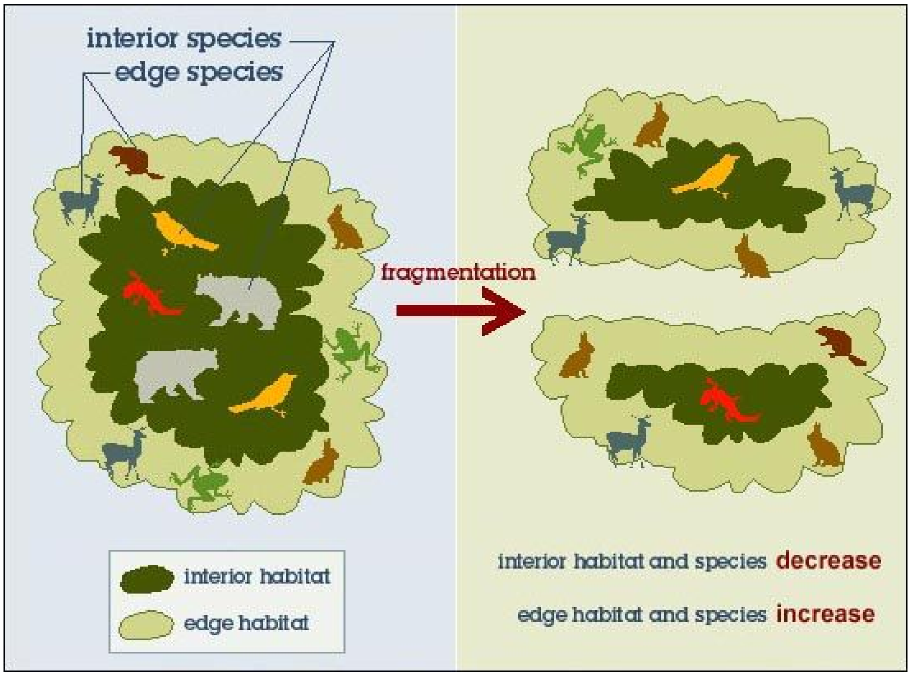

Figure 15: Edge effects, from sustainableinthefield.com (2015)

Habitat fragmentation also isolates populations, causing inbreeding and a decrease in the population. This inbreeding causes problems because damaging alleles that were masked by a mix of genes are now no longer hidden and can cause offspring to die or become infertile, which will lead to more inbreeding until the population eventually dies (Hadley et al. 2018; Hermansen et al. 2017). Habitat fragmentation has significant effects on increased selfing rate. In some areas of high habitat fragmentation, each of the thirteen species had some level of inbreeding. This made the pollinators less mobile and affected the plants as they did not have the same among of pollinators pollinating them, increasing their own rate of self-pollinating, sometimes having as much as 95% of the population be inbred (Steffan-Dewenter and Tscharntke, 1999).

A study by Cheptou et al. (2006) found that fragmented habitats reduced pollinator activities. In non-fragmented habitats, approximately 80% of the ovules of flowers were fertilized. In areas with higher habitat fragmentation, that percentage dropped to 20%. In these fragmented habitats, plants were more likely to be inbred and the visitation rates in a 15 minute period went from 100% to less than 15%.

Pollinators rarely stray far from their homes (Redhead et al. 2016). *C. viridis* can only travel between 30 and 70 meters from its natal habitat (Brown and Opler, 1967), which is between 100 and 230 feet. If a *C. viridis* population is separated by a space as little as 100 meters, they will likely not cross and breed with each other. Most bee species will not travel over a mile from their colonies and most butterflies will only visit a few flowers before returning home (Traveset et al. 2018).

In Tucson, Arizona, researchers sought to determine how habitat fragmentation affected the native pollinators within the city (Cane et al., 2006). They looked at fragments that ranged in size from 1 ha to the size of 1-4 bushes. Some species, mostly species associated with edge habitats and generalists, thrived in the fragmented habitat, often having much higher populations than those found outside of the city. Of the total ground nesting bee genus *Larrea* catalogued, 59 of the genus were generalist species, while 31 of the genus were specialist species (Cane et al., 2006).

This is taking into consideration ground nesting insects were almost entirely absent in the majority of the fragments and were underrepresented in areas where they were found (Cane et al., 2006). Ground nesting species were more at risk than other other species. *B. californicus* is a ground nesting bee species, as are most native butterfly species. The researchers did note that in larger habitat fragments of 1 ha did have some of the highest populations and species richness than the habitats that were only one to four bushes wide.

San Francisco does boast a large amount of parkland with 19% of the total city area (approximately 5,693 acres, see Figure 16) (SF Planning, 2018). Furthermore, 3,093 of those acres were designed for natural use, meaning there is not a lot of human recreation in the areas (Harnik et al., 2016). However, that does not mean that the habitats in San Francisco are not fragmented. One of the worst areas for open green space is South of Market, which has approximately 5.5 acres of open space per 1000 people, which is broken up to approximately 0.23 acres of public parks and 5268 residents (San Francisco Planning, 2008).

Figure 16: Map of existing park space in San Francisco. There are a few larger areas of green space such as Golden Gate Park, the Presidio, and Lake Merced Park but the rest of the city has patchy areas of open space (San Francisco Planning, 2008).

Areas with larger habitat spaces often have higher rates of species richness because the ecotones can be formed throughout an area (Desaegher et al. 2017; Hülsmann et al. 2015). On average, the species richness of butterflies decreased significantly as habitat size also decreased with a much faster rate of extinction, sometimes having species go extinct in 36-49 years (Krauss et al., 2010). Without large areas of habitat, it can be much more difficult to successfully protect a species, but that does not mean that no city can be successful.

In many places, private gardens and small sidewalk gardens can provide benefits for native pollinator species (Goddard et al., 2010). It is especially important to ensure that gardens and parks have a high percentage of native plants since native pollinator diversity can increase up to 35% when there is a large concentration of native plant because specialist species are more likely to have the specific plant needed for their habitat and native plants often act as shelter for other species (Bolger et al., 2000). Studies in England have shown that this attention to habitat quality, as well as corridors to connect isolated population, can increase the variation of species present by up to two species than in lower habitat quality (Angold et al., 2006).

If San Francisco wanted to greatly improve the species richness of its native pollinators with the spaces it currently has, having land planners focus on quality habitat with a variety of native plant species and corridors connecting the habitats is the best way to ensure that even with extreme fragmentation, native pollinators can be restored and conserved. It is important to connect isolated habitats, as was done with *C. viridis,* to increase interbreeding and provide more suitable habitat. It is also important for the quality of habitat to increase by ensuring that proper plants are available for both larvae and adults, as is needed with *I. icarioides missionensis.* Finally, the habitats have to be structured in such a way that there are spaces for nesting and egg laying, as is needed for *B. californicus.* When designing a habitat, it is connecting isolated populations, ensuring proper plants are present, and providing nesting and egg laying habitat can greatly increase the success of a restoration project.

Other Cities' Restoration and Conservation Strategies

The idea of restoring native habitat within an urban environment has been explored in other cities. Habitat fragmentation and loss is among one of the top concerns for conservationists as, without natural spaces there can be no habitat. Two cities tackled in this paper, Chicago and New York City, have both tried to improve native pollinator habitat and decrease the amount of habitat fragmentation. San Francisco can look at the successes and failures of these two cities, and others around the world, and implement similar strategies.

Chicago's Rooftop Gardens

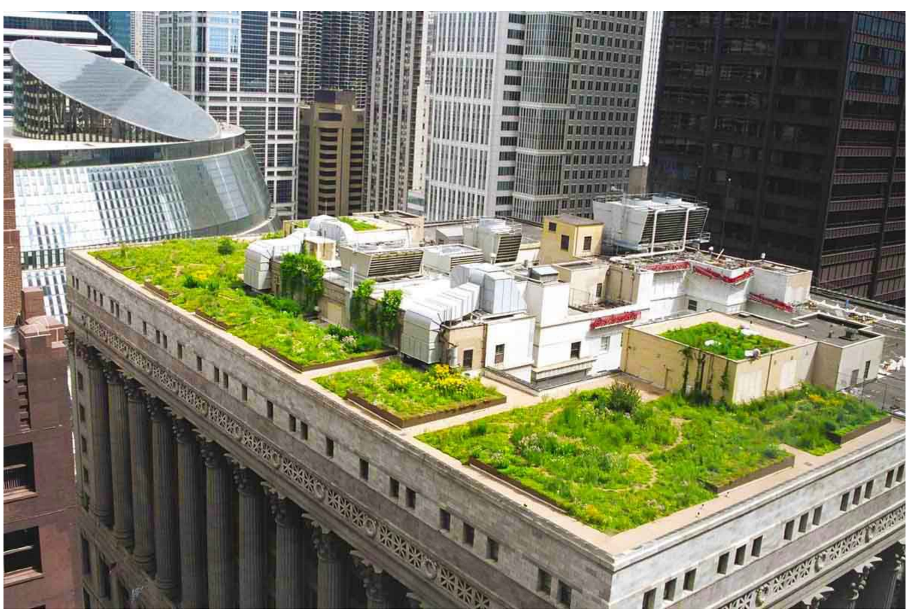

Figure 17: The City Hall rooftop garden in Chicago (Museum of the City, 2015).

An aerial image of Chicago, IL shows hundreds of rooftop gardens. These gardens were commissioned with the intent to help reduce carbon emissions, clean the air, provide places for people to relax, and provide habitat for pollinators (Lowenstein et al., 2014). These green roofs were mostly done with the intention of benefiting humans. The City Planning Commission of Chicago cited several reasons including easing the burden on sewer systems during storms, reducing urban temperatures, improving air quality, reducing energy costs, and providing an opportunity to start a system of urban farming (City Plan Commission, 2008). Pollinators were barely mentioned in the 2008 Sustainable Development Publication printed and distributed by the city, mentioning them only in the context of urban rooftop farming. However, conservationists did see an opportunity to use the space to promote native pollinator populations (Ksiazek et al., 2012).

In 2008, with 250 buildings having vegetative roofs and another 350 under construction (City Plan Commission, 2008), many conservationists believed this could be an opportunity to restore habitat that had long been lost in the construction of the city. The project was largely unsuccessful because most of the native Chicago pollinators could not reach the rooftops (Loder, 2014). City Hall (Figure 3) was the pilot project for the green roofs, with 38,800 square feet of gardens (3604.64 square meters) and over 20,000 plants and 150 different species (Chicago City Hall, 2018). However, this building is also over 110 feet tall (33.58 meters) and most pollinators do not have the wing structure or capabilities to fly that high off the ground. This is because their source of food is flowers and there are no flowers that reach 33 meters.

The tallest flowers tend to be about 80 cm tall (0.8 meters) with the average being between 30 and 60 cm. While some species of trees have flowers, these tend to rarely be taller than three to four meters (Tonietto et al., 2011). Pollinators do not have the wing structures or bodies to fly that high off the ground or withstand the wind that would be stronger, higher off the ground (Tonietto et al., 2011). Native bee species in Chicago are also mostly ground nesters, about 70%, they do not need to fly far from the ground (Lowenstein et al., 2014). All of this coupled together means the species were unable to reach the rooftops.

The rooftops that were closer to the ground did have species present, though in much lower abundance. Lowenstein et al. (2014) found that the rooftops had fewer species than restored prairies or even nearby parks (Table 3)

Table 3: A comparison of the three different areas Lowenstein et al. looked for different species richness (Lowenstein et al., 2014).

Type of Land	Rooftop	Park	Restored Prairies
Number of Species	15	30	55

This failure on the part of Chicago was largely because pollinators were not the concern with these rooftop gardens, humans were. Despite the opportunity to provide ground nesting habitat and plant native plants (City Plan Commission, 2008), there was no organized effort on the part of the city to provide nesting habitat or native plants. Even the study for Lowenstein et al. (2014) did not mention whether the species they were seeing were native or not. It was a good idea, but if Chicago wanted to conserve the native pollinator species, they needed to do more research and create a better plan.

That does not mean that cities need to choose between habitat conservation and human needs. A study done by Williams et al. (2001) found that in Chicago, bee abundance and species richness increased with higher human population density, sometimes as much as eight more species present. This is because human abundance can help foster diversity of native flowering plants. By having humans take care of sidewalk gardens, there can be a great abundance of native pollinators in the area. Sidewalk gardens are often small and can utilize space effectively, as seen with New York City and its sidewalk gardens.

New York City's Networks and Sidewalk Gardens

The city of New York had a similar desire to help increase native pollinator presence in the urban environment. Various environmental groups had started to put pressure on the city to help save the pollinators and members of the community recognized how the presence of urban gardens could provide some benefit to the environment and their neighborhoods (Matteson et al., 2008). New York City also wanted to promote a more environmentally friendly image, with popular attractions such as High Line Park, a park built on a no longer used train track, helping boost tourist revenue (Fetridge, 2008). It was decided that New York City would utilize the sidewalk space, building trails of flowers that led to parks and other green areas as well as protect pedestrians from cars and beautify the streets. The original project focused on the Bronx and East Harlem (Matteson et al., 2008), but has since spread throughout the city, creating a web of flower trails blooming with native plants and helping improve native pollinator populations and species diversity (Figure 18).

Figure 18: One of over 2000 sidewalk gardens designed in New York. Planted with mostly native plants (NYC Street Design Manual, 2006).

This project was largely successful, with some sidewalk gardens showing 95% of the pollinators as native, with only 5% as exotic (Fetridge, 2008), which is extremely successful. In fact, researchers compared the bee fauna documented in these sidewalk gardens to a 1520 ha (15.2 square kilometers) forest research preserve in the same region and found that the sidewalk gardens strongly resemble it (Table 4 and Table 5), with only a few specialist species absent (Matteson et al., 2008). This study done by Fetridge and associates shows that even in heavily urbanized areas, sidewalk gardens can help improve species diversity and population for native pollinators (2008).

Table 4: Percentage of bee species and individuals found in various taxonomic and ecological groupings within community gardens of New York City (Matteson et al., 2008)

Taxonomic/ecological grouping	% species (n = 54)	% individuals (n = 1,145)
Family		
Colletidae	11	26
Halictidae	32	26
Andrenidae	5.6	0.8
Megachilidae	22	17
Apidae	30	31
Exotic/native		
Exotic	19	27
Native	81	73
Floral specificity		
Oligolectic	11	3.5
Polylectic	89	97
Nesting site		
Cavity	33	46
Hive	11	19
Wood	1.9	1.6
Pith	1.9	7.0
Soil	44	25
Soft/rotting wood	7.4	1.2
Behavior		
Solitary/communal	56	50
Parasitic	5.6	2.6
Eusocial	35	39
Subsocial	3.7	7.9

Table 5: Comparison of the richness and species composition of urban gardens of New York City with Surveys of other location in a 150-km radius of New York City (Matteson et al., 2008).

Site	Reference	Sampling area (ha)	Sampling yr	Bee richness	No. species shared with urban gardens
Urban Gardens, East Harlem and the Bronx, New York and Bronx County, NY	This study	1.7	4	54	N.A.
Central Park, Manhattan, New York County, NY	J.S.A., new data	341	3[a]	58	29
Prospect Park, Brooklyn, Kings County, NY	J.S.A., new data	212	3[b]	59	34
Staten Island Freshkills landfill, Richmond County, NY	Yurlina 1998	10	4	57	28
Staten Island Parks[c], Richmond County, NY	Yurlina 1998	344	2	69	27
Black Rock Forest, Orange County, NY	Giles and Ascher 2006	1,520	1	144	31
Gardiner's Island, Suffolk County, NY	J.S.A., Goelet, and Kornbluth, unpublished	1,343	4	128	32
Pinelands Biosphere Reserve, Burlington County, NJ	Winfree et al. 2007	4.8	1	130	34

N.A., not applicable.
[a] Many records based on bees collected or observed by J.S.A. and colleagues during 2004–2006; others from study of historical material in the American Museum History (most collected 1960–1980).
[b] Most records based on bees collected or observed by J.S.A. during 2004–2007.
[c] Summed data from the following three Staten Island Parks: Wolfe's Pond Park, Blue Heron Park, and LaTourette Park.

Why was New York City so successful with improving the native pollinator species in the city? The city had spent years researching and studying the bee populations to understand what was needed. Researchers found what substance native bees preferred to nest in (Table 6) and the information was used by non-for-profit groups to design urban gardens.

Table 6: Percentage of species per nesting material. 54 species (13% of New York State Bee Fauna) were collected in the city and the preferred nesting materials were recorded and given to the City of New York to understand how to better design sidewalk gardens to promote species richness and population (Matteson et al., 2008).

Nesting Material	Cavities	Hives	Pith	Wood	Soft/rotting wood	Soil
Percentage of species	33%	11%	1.9%	1.9%	7.4%	25%

Using this information, New York City was able to tweak the gardens to promote a higher assemblage of native bee diversity. Researchers found that the cavity nesting bees were mostly exotic, so transforming the gardens into areas that were more suitable for wood nesters or soil nesters helped improve the population and diversity of native bees (Matteson et al., 2008).

Since 2008, the native bee species have continued to grow. Over 50 native bee species have been documented in the gardens of New York City, including five species of native bumblebees (Matteson et al., 2017. In some areas, over 100 bumblebee workers, with a density of 8 bees per 100 square meters have been recorded (Matteson et al., 2017). New York City has done a fantastic job in learning and tweaking what to do to promote these habitats.

One of the best things they have done to cut down on the amount of non-native invasive species in the city that could outcompete native pollinators, is make honey bee colonies illegal. As stated in the *Apis mellifera* section, honeybees can easily outcompete native species, and transmit diseases to them. By making these colonies illegal within city limits, there is a bit more control over the non-native species of pollinators that might cause populations to fall (Matteson et al., 2017).

New York City still has challenges as a native pollinator habitat. Buildings, streets, bikes, and other hazards can limit the movement of pollinators and at the moment, these urban gardens tend to be more beneficial to bee species than other pollinator species, such as butterflies or ants (Matteson et al., 2017). However, these little plant corridors, similar to Nature in the City's Green Hairstreak Corridors, can provide food, shelter, and guidance to other habitat areas. With habitat fragmentation being almost a given in cities, New York City shows that having rich, native plant oriented gardens, can help promote a high level of species richness (Matteson et al., 2011), and knowing a bit about the species and the challenges they face can make a big difference in the success or failure of an urban habitat restoration project.

Figure 19: A example of a sidewalk garden design from the New York Department of Environmental Protection. You can see the use of flowering plants as well as trees and native shrubs (New York Department of Environmental Protection, 2018)

There are several mentions of pollinator, specifically native pollinator habitat restoration as a reason for creating and maintaining these sidewalk gardens. The general guidelines for city planning includes a section on native habitat restoration as well as a benefit for sidewalk gardens (NYC Street Design Manual, 2006; New York Department of Environmental Protection, 2018). They do mention some of the benefits humans have as well, such as rain gardens helping ease the burden on storm sewers (New York Department of Environmental Protection, 2018).

Furthermore, the zoning permits require that the minimum width of the sidewalk garden be 12 inches (30.48 cm) for there to be any actual impact (NYC Parks, 2018). The gardens are not perfect, however. Many of the plants are exotic and non-native (Matteson et al., 2008) which can attract non-native pollinators. Likewise, as seen in Figure 19 there are still rocks and compacted dirt, which can affect the ability for ground nesting species to nest. Still, these sidewalk gardens are a step in the right direction and do provide some clear benefits.

New York City also was pressured by several environmental groups as well as voters to implement plans for native pollinator habitat. The New York Restoration Project was the main group active in campaigning for city planners to start including native habitat for insects. Furthermore, a city poll stated that 39% of New Yorkers do not think there is enough green space and 90% wanted more (NYC Street Design Manual, 2006). The New York City government partnered up with local universities, including Brown and New York University, to conduct the studies that would make these sidewalk gardens successful. Furthermore, in 2011 the Department of Environmental Protection implemented three neighborhood demonstration areas to monitor the effectiveness of the green spaces in terms of human benefits (such as storm water protection) and native species benefits (NYC Street Design Manual, 2006). There are grants available to continue planting and studying these plots from the New York State Department of Environmental Conservation and several non-for-profits such as the Citizens Committee for New York City (NYC Street Design Manual, 2006). It is this push for both community and government involvement that really helped make these sidewalk gardens successful.

Management Suggestions

Species Specific Suggestions

Learning about the species, the area that will be restored, and filling in knowledge gaps can be the difference between success and failure for a restoration project. New York, NY spent time learning about the species in the area, partnering with Fordham University and environmental groups such as the New York Restoration Project to create a plan that would be successful. San Francisco, Chicago, and New York City each had successes and failures when it came to restoring native pollinator habitat (See Table 7).

Table 7: A table discussing the benefits, problems, and successes for the San Francisco, New York City, and Chicago when native pollinator habitat was restored.

Cities	Benefits	Problems	Successes
San Francisco	Interest in the Environment	Not a wide focus on native pollinator species from Universities	Community involvement and non-for-profits Adaptive management strategies by Nature in the City made them able to restructure habitat corridors
New York City	Cooperation between Government, Scientists, and the Community	Very condensed urban population	Sidewalk Gardens to attach populations A connection with the government, community, scientists, and non-for-profits to create a plan that would work
Chicago	Government involvement Listing benefits to pollinators on permits and city plants	Focus too much on human benefits leading to ineffective habitat restoration Not a focus on native pollinators	A shift in focus to the sidewalk gardens and parks Learning native pollinators were ground nesters

C. viridis needs to have solid data and numbers if the Green Hairstreak Corridor Project is going to continue to be improved. To ensure its long term success, having a monitoring program is key. Monitoring when the adults are present and when the larvae are present at the same time every day during the mating season for several years at several different sites will give a better indication as to which populations are growing, which ones are decreasing, and which ones are staying the same. From there, Nature in the City will be able to look at the habitats and see what is different about them. Perhaps one habitat has a higher population of a certain type of flower. Perhaps it is further back from the road. This data can help guide the project further along and allow them to shift and change the habitat to be better suited to the needs of the species.

For *I. icarioides missionensis* the focus needs to be on protecting the lupines while ensuring there are still enough nectar plants present for the adults. San Bruno Mountain is a heavily managed area and it has benefited in having the largest known population that is also self-sustaining. Twin Peaks chose to focus on transplanting individuals, but has not had the same success. The lupines and native nectar plants are the key to keeping *I. icarioides missionensis* populations strong. By managing for invasives and organized planting efforts for native species, there can be success for restoration.

Finally, *B. californicus* has no focused project. Having open soil for it to nest in is key to promoting population growth. Several sidewalk gardens, parks, and green spaces have wood chips present in them rather than open soil, which limits the population size for *B. californicus*. This can be avoided if plans were made to ensure a certain percentage of soil was present in each sidewalk garden or green space. Since *B. californicus* is a generalist, simply having open soil area and flowering plants that require pollination should be enough to improve populations around San Francisco.

Mixed Use Habitats

The City of New York promoted the native plant sidewalk gardens, which helped connect isolated populations, as an attempt to beautify the city, helping make it more aesthetically pleasing for tourists, and the citizens that lived there (Fetridge et al., 2008). In Chicago, having rooftop gardens would help regulate building temperature and offset some of the greenhouse emissions the city produced (Lowenstein et al., 2014). Even promoting the native habitat for any one of the three species discussed in this paper can help promote a greater diversity of plants in the city, something that can beautify it and make gardeners happier with healthier plants (Goddard, 2010). If an organization wants to create native habitat for a particular plant or animal, it helps to have some sort of human implication to convince the city government to create the greenspace. From outdoor green spaces improving the concentration of office workers, to parks providing a place for community gathering, to providing a carbon sink to offset climate change effects.

In the zoning permits for New York City and several of the city land planning documents, native pollinator restoration is mentioned alongside several other, more human focused ideas. Stating specifically that native pollinator habitat restoration is a benefit to the sidewalk gardens helps focus projects into benefiting the native pollinators. Stating several other benefits that help humans, such as relieving the storm sewers of the potential flooding, helps convince people who may not care about pollinators or who may not want to use their taxes to save some insects.

Chicago did mention pollinators in the city planning documents, but it was in the context of urban farming. This, again, can be useful in helping convince people that native pollinator habitat restoration is important. However, pollinators were always mentioned in relation to urban farming, not separate from it, and there was no mention of native pollinators specifically. This lack of specificity makes it easy for people to see *A. mellifera* present in rooftop gardens and count it as a success, despite the fact that this is an invasive species.

For San Francisco, the San Francisco Department of Public Works lists the benefits of sidewalk gardens as providing wildlife habitat, reducing flooding, and increasing property values, as well as several other environmental and anthropogenic benefits (SF Public Works, 2018). This ensures that landowners have several appealing reasons to plant a sidewalk garden. If their building is in an area prone to flooding, sidewalk gardens help with that. If they want to increase the price of the building, sidewalk gardens can help with that. With each of these benefits to humans, there are other benefits to pollinators with increased habitat, nesting materials, or nectar bearing plants.

Mixed use habitats provide benefits to more than just the species they are built to conserve. They can provide education opportunities, tourism, and environmental benefits, such as combating the urban heat island effect. By touting these benefits, it can be easier to design habitats for native pollinators. There does need to be specific wording that the area is useful for native pollinator habitat conservation, to increase the use of native plants, but mentioning the benefits to humans is a great way to get people excited about habitat restoration.

Community Involvement

Figure 20: Kids in Parks: Nature in the City, 2018, Volunteers helping restore Green Hairstreak Corridors (©Nature in the City, 2018)

Getting the community involved in a restoration project is a great way to ensure its success. One of the biggest challenges habitat conservationists face is monitoring. To determine if something is working, it requires monitoring. This is where the idea of community involvement, more specifically Citizen Science, can help restoration projects become successful.

The idea of using Citizen Science to monitor is a beneficial one to any city or organization looking to improve its habitat to better accommodate species. Studies have shown that places with some sort of monitoring were able to better determine what could be done to improve a habitat (Harding, 2001). Another benefit of having Citizen Scientists is that they can become more invested in the community, more invested in the conservation efforts, and more likely to help out by volunteering or planting native plants in their own backyards/garden balconies (Hafernik, 1992) or working on restoration projects in their neighborhoods (Figure 19).

Cities are actually at an advantage here that other habitat conservation areas do not have: more people are likely to visit the site. When there is a conservation area in the wilderness, only a select few people are going to go there to monitor, and most Citizen Science Monitoring techniques (the use of apps and web pages) might not work that far from civilization. Having a small park with native dune species and putting flyers in the mail telling people about *C. viridis* and having an app associated with sightings, has the ability to get many people out, looking for the butterfly. There is always cell phone reception in the city and most people walk by the corridors on a regular basis. A citizen science program would greatly help improve the monitoring of habitats within cities, allowing researchers and land planners to improve their projects continually, without having to spend more money on monitoring.

The Xerces Society has several citizen science programs that help improve knowledge of a population. These include a bumble bee watch, a western monarch count, and a western monarch milkweed mapper. These three programs work with experts to help increase the knowledge of the populations of these three species. People can upload where they have seen a species as well as upload photos for identification so that populations can be tracked and monitored. These programs can receive hundreds of data points that can then be used for researchers to track population sizes, where certain things are seen, etc. It is these data that can then be transformed into suggestions for improvement as well as see which areas are pollinator hotspots, and which ones can use a little work.

Figure 21: A brochure from Nature in the City about the self-guided tour that people can take to see the butterflies (©Nature in the City, 2018).

More than just Citizen Science, having an overall community outreach program can be integral to helping ensure the success of a project. The New York Restoration Project worked to get the citizens of New York involved in the restoration, eventually getting New York City to add the gardens to their planning projects. Nature in the City has several community outreach programs such as flyers (Figure 20), tours, and events to promote habitat conservation. By getting people involved, they can increase interest and that interest can help improve the success of conservation.

Government, Community, Non-for-profits, and Scientists

San Francisco has the opportunity and resources to create successful habitats for native pollinators.With the large amount of parks and the pride the city takes in being sustainable and eco-friendly, the seeds to turn San Francisco into an area where native pollinators can thrive, despite being in the city, are present. *C. viridis, I. icarioides missionensis,* and *B. californicus* all come with their unique problems and varying degrees of of help from various organizations and community groups, but if San Francisco, the community, non-for-profits, and researchers are willing to work together, adaptive management strategies can be implemented throughout the city.

Each of the three species discussed in this paper represents a varying degree of participation in habitat restoration from the community, non-for-profits, the government, and scientists. For habitat restoration to be successful, all four of these sections have to be present or else there is not enough support for the community. What made New York so successful in its attempt to improve native pollinator habitat was the presence of all four. Dr. Matteson and Dr. Langellato had several papers detailing the native bees present in the city. The New York City government had several branches working to create a plan that would work, including the New York Department of Environmental Protection, the New York City Planning Department, and the New York Department of Parks and Recreation. Furthermore, non-for-profits, such as The New York Restoration Project, worked to find and construct sidewalk gardens around the city and, on several levels, there was involvement from the community including school programs and tours of some of the gardens (NYC Street Design Manual, 2006).

I. icarioides missionensis follows a similar pattern as New York City. There is government involvement from the U.S. Department of Fish and Wildlife and the Golden Gate National Recreation Area. There is scientific involvement with *I. icarioides missionensis* being the topic of discussion for many researchers in and around the Bay Area, and there is non-for-profit and community involvement such as Save Mount Sutro tracking the Twin Peaks population and several groups organizing planting days for the community to get involved.

C. viridis has non-for-profit involvement with Nature in the City and a fair amount of community involvement including a Bioblitz and several planting days and tours one can take. However, the scientific community and government involvement is lacking. There are not a lot of peer-reviewed studies on the butterfly and the actual population numbers are not known, only estimated. There is no government agency at the city, state, or national level to help protect the species.

B. californicus has the least amount of involvement out of the three species. The Xerces Society for Invertebrate Conservation has some resources on the bee, but does not focus on it or create any habitat. There is also no active or organized community effort to help protect the bee. Unlike Nature in the City or Save Mount Sutro, both of whom organize planting efforts and have places to mark sightings, *B. californicus* is largely ignored by the community. While there are some scientific studies on the species, mainly Goulson, there are not studies that directly seek to find how to best conserve this species. Also, the government involvement is minimal. There are mentions of *B. californicus* in U.S. Forest Service handbooks (Koch et al., 2012), but it does not appear to be of concern for government protection on any level.

To ensure the protection of these three species, there has to be an organized effort from all four sectors mentioned above to create adaptable, and sustainable habitats. While getting the national government involved will help, as it did with *I. icarioides missionensis*, it does not necessarily need to be. A smaller focus at the city or state level can be enough to help designing and implementing projects. San Francisco has done a fairly good job at having sidewalk garden permits reflect the benefits not just for humans, but for pollinators as well**.** In fact, the permitting for San Francisco sidewalk gardens does some things better than New York City, such as including several native plant lists that are separated by drought tolerant and shade tolerant, give suggestions based on how much sun the garden will get (is it a west facing or east facing slope), and lists plants that will attract native pollinators and hummingbirds (San Francisco Public Works, 2018). The permits are relatively low cost and can be done practically anywhere in the city.

The government can also work closely with scientist and researchers to ensure that there is data on the species within the cities. Having a grant program to measure the number of native bee species in San Francisco or having restoration ecologists join planning teams to help design a project can be helpful as well. It can provide incentive for researchers to study the native pollinators of San Francisco and help non-for-profits and the government better plan their strategies. Adaptive management is extremely important when it comes to restoration projects. Because nature is dynamic and some things are hard to predict, such as how the loss of ground nesting bees will affect soil composition, the most successful restoration projects are the ones that adapt and change based one the information.

Nature in the City showcased adaptive management strategies perfectly by changing the ratio of nectar plants and larval plants, and changing where they planted to focus more on western slopes with more sun (A. Hasselbring, Nature in the City, pers. comm.). Likewise, Save Mount Sutro's *I. icarioides missionensis* population counts on Twin Peaks helps show where the governments restoration is failing and succeeding and can help refocus efforts or change how they manage the area (Save Mount Sutro Forest, 2017). Non-for-profits can help the government because they can be as narrowly focused or as broadly focused as they want. Unlike the San Francisco Planning Department, which has to take care of the entire city, Nature in the City can focus on a few areas.

The final piece for ensuring the success of native pollinator habitat restoration in San Francisco is the community involvement. As stated in the previous section, community involvement can be crucial to building and maintaining habitat. Community involvement and citizen science is also important in increasing the amount of data available for non-for-profits, government agencies, and scientists to use.

The idea of a BioBlitz, or a survey of species in an area, can be a great way to determine where potential populations are (National Geographic Society, 2018). A BioBlitz might show that there are a few *C. viridis* seen in the Inner Richmond District or that *B. californicus* is seen mostly on California poppies. Even seeing if certain plants in an area are present could indicate if an area is a potential candidate for habitat restoration and population transplant. Community involvement can help pressure the government into focusing on a species and provide scientists with much needed data. San Francisco has a long history of environmentalism and a love for natural areas, there are 220 parks in the city. The community has already rallied around *I.*

icarioides missionensis because it is a symbol named after a district in San Francisco, having more enthusiasm for *C. viridis* and *B. californicus* could help protect these species.

San Francisco Habitat Restoration

There are three threats to the native pollinator populations in San Francisco: *A. mellifera*, ozone, and habitat fragmentation. These three problems can cause these populations to experience extinction, localized or entirely. Even if there is a balance between government, non-for-profit, scientific, and community involvement, these problems must be addressed if projects are to succeed.

The best way San Francisco can deal with *A. mellifera* is to ban it entirely and work to get rid of feral colonies the same way they would work to get rid of other invasive species. Because there are so many colonies currently being cared for in San Francisco with several organizations promoting beekeeping as environmentally friendly, it would work best to slowly go about banning the colonies, first requiring some sort of permit to keep bees and perhaps banning them in some parts of the city, like the Presidio. Overtime San Francisco could slowly start to decrease the number of hives a person could have until *A. mellifera* is fully banned.

The biggest obstacle that restoration managers face with *A. mellifera* is the fact that most people believe it to be environmentally friendly and necessary for plant reproduction. It is important, therefore, that scientists work with non-for-profits to explain the dangers *A. mellifera* has on the environment. This is likely to be the most challenging part of long-term restoration strategies since people have believed in the benefits of *A. mellifera* for a very long time and most websites that promote beekeeping also mention how beneficial it is to the environment. That is why researchers must also work with the government to keep regulations on beekeeping, especially in environments with sensitive species that are prone to extinction.

San Francisco has a low amount of ozone, especially compared to the rest of the country. However, that does not mean that there are not problems that come with having ozone present in the city. Studies have shown that any ozone levels above 0 ppb can affect a pollinators ability to find flowers (Fuentes et al., 2016; McFrederik et al., 2008) and while 120 ppb is the worst, there is a slow increase in negative affects starting at 10 ppb (Fuentes et al., 2016). Even though San Francisco has not, since 1994, experienced a 1-hr max ozone or an 8-hr max ozone over 120 ppb, it has experienced a 1-hr ozone max above 50 ppb every year since 1994, and an 8-hr ozone max above 50 ppb 15 times since 1999.

This is not a problem that restoration can solve, it has to be solved by creating more efficient vehicles and creating stricter air quality standards. There will probably not be a day in which ozone is at 0 ppb, but the lower the levels, the less harmful it is to pollinators and the flowers they pollinate. It would be useful to conduct tests outside of a lab. Both Fuentes et al. (2016) and McFrederik et al. (2008) conducted their research in a controlled environment. Knowing how San Francisco's pollinators react to the presence of ozone will help determine what the levels of ozone should be in the city.

One of the benefits to conserving populations in San Francisco is the number of parks and green spaces that are present. Because there are so many, there does not need to be a restructuring of the city, tearing down buildings to make more green space or dealing with trying to transform a park out of what was originally a parking lot. However, there are still ways in which San Francisco can improve habitat restoration. First, while there are a lot of parks, there are not a lot of habitat corridors. Most populations are still fairly isolated from one another and a way to fix this is with a combination of sidewalk gardens, habitat corridors, and other small planting efforts. Walking along to Masonic from Parker Ave. along Fulton street, the University of San Francisco has several planters that are full of *C. thyrsiflorus* and other native flowers (See Figure 22).

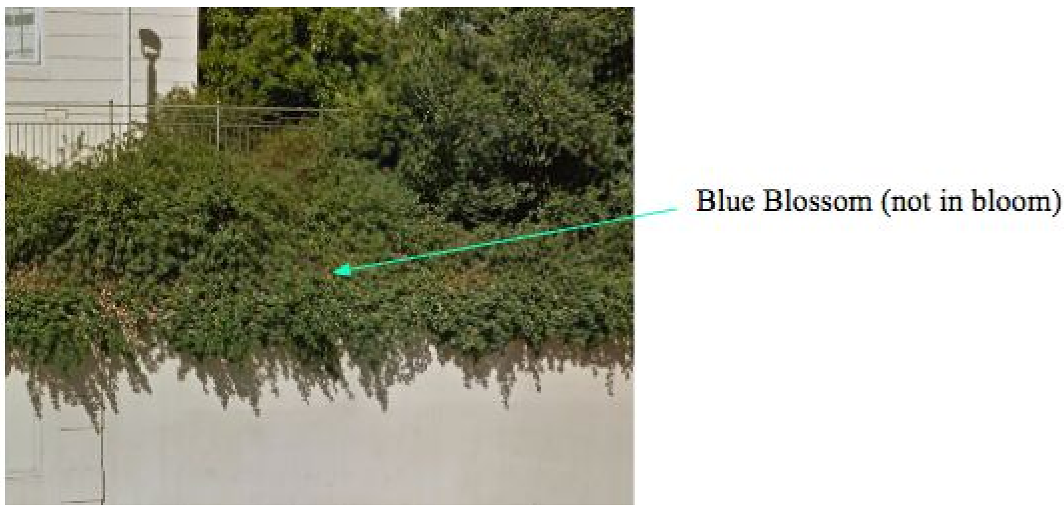

Figure 22: A photo of Campus along Fulton Street showing native *C. thyrsiflorus*.

On any one day when the flowers are in bloom there are several bumblebees that can be seen and even the occasional humming bird or butterfly. These planters do not take up extra sidewalk space but still provide a small area of nectar producing flowers and habitat that can help lead the pollinators to larger habitats, such as Golden Gate Park or the Lone Mountain Reserve.

At Golden Gate Avenue and Steiner Street there is a small park known as Golden Gate and Steiner Mini Park that is only two blocks away from Alamo Square Park. Having a series of sidewalk gardens with plenty of native plants would help guide native pollinators to the larger park (See Figure 23), helping the population not be so isolated.

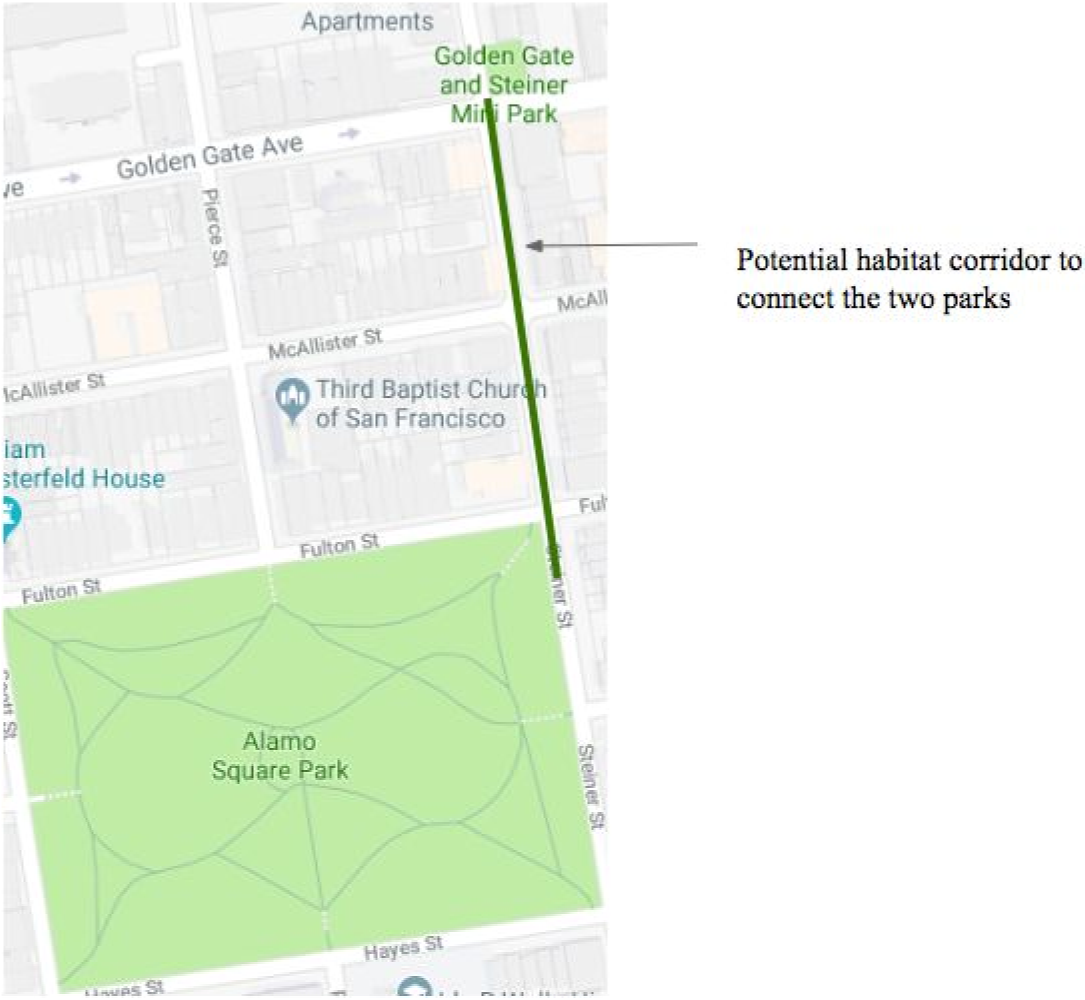

Figure 23: A potential sidewalk garden/habitat corridor to connect the smaller, Golden Gate and Steiner Mini Park and Alamo Square Park (Google Maps, 2018).

Also, Mt. Sutro Open Space Reserve is very close to Twin Peaks, which has the largest population of *I. icarioides missionensis* in San Francisco, having a series of sidewalk gardens, backyard gardens, and even rooftop gardens on the shorter roofs could help populations connect and grow, finding more habitat to lay eggs and find nectar.

The sidewalk gardens are not the only parts of restoration that need to happen. San Francisco has to do a better job at putting in native plants in the parks as well. Some of the larger parks, such as the Presidio and Golden Gate Park, do a good job at having a wide variety of native plants present that would benefit pollinators. Other parks, however, are often large grassy fields with little to no flowers present (See Figure 24). These parks have the opportunity to be the home of populations of native pollinators. Having a large area with plenty of nesting room and feed plants present will greatly help stabilize and protect populations.

Figure 24: Image of Alamo Park. There are invasive grasses and non-native trees present and no native plants present in this image. The rest of the park is very similar with a focus on non-native grasses and trees instead of native flowering plants (Google Maps, 2018).

Furthermore, because they are pollinators, that means flowers will be present. Having flowers present will help beautify parks and green spaces. Having natural areas be managed to promote native species is one of the best ways to ensuring a healthy population of native pollinators. Twin Peaks focused more on boosting the *I. icarioides missionensis* population and not on the management for the lupines and the population still is not considered self-sustaining. Having land managers decrease the presence of non-native plant species and increase the presence of native ones will promote healthy native populations. In some instances, there may not be a need to transplant species as once the land is full of native, they will find it on their own.

Conclusion

Having native pollinator habitat in a city may be difficult, it is not impossible to succeed. *C. viridis* is a small butterfly with a small habitat range, and yet by connecting hilltop populations in the Inner Sunset District with restored habitat corridors, Nature in the City has been able to vastly improve the population size to an estimate of approximately 500 individuals (A. Hasselbring, Nature in the City, pers. comm.). *I. icarioides missionensis* habitat restoration at Twin Peaks has shown that managing the habitat regularly as well as ensuring both nectar plants and larval feeding plants are present (a lesson also learned from Nature in the City) a population on the verge of localized extinction can improve. *B. californicus* has no localized, concentrated effort for the species which has proved to be a problem as there is not much data on the population size and not enough focus on creating proper nesting habitat.

The city environment also comes with its own set of issues, including the invasive *A. mellifera*, ozone pollution, and habitat fragmentation. *A. mellifera* is dangerous because it can outcompete native pollinators while also taking away their food source and even transferring viruses that can deform a bumblebee's wings. Ozone pollution can affect the floral hydrocarbons starting at 60 ppb. San Francisco has several years where the 1-hr ozone max was above the 60 pbb threshold and several years where the 8-hr ozone was above the 60 ppb threshold. Habitat fragmentation is probably more intense in a city environment since streets and buildings cut through the habitat at much more regular intervals. This habitat fragmentation can isolate populations as well as promote the presence of invasive species.

Chicago, IL and New York, NY are two cities that also saw an opportunity to improve native pollinator habitats, though New York City was much more successful than Chicago.

Chicago was focused more on the human aspect, with pollinators being an afterthought that was added more in relation to urban farming than conservation. New York City, after receiving pressure from many local groups, took the time to research the pollinators present in the area and work with local universities to develop a plan that would provide some benefit to local pollinators. They banned the use of commercial honey bee farming inside city limits, planted an abundance of native plants in the sidewalk gardens, and even cited in several city planning documents that the conservation of native pollinators was one of the reasons they were putting in sidewalk gardens and one of the reasons people would call and request the planting of sidewalk gardens.

Overall, in order to make habitat restoration in a city environment work, you have to understand the species, fill in the knowledge gaps, make data available, understand that restoration areas can be useful to both humans and pollinators, and promote community involvement. Restoring native pollinator habitat in a city environment can work, and it can work fairly well, it just takes a little bit of research and the ability to determine what went right and what went wrong.

Knowing the species also includes knowing the plants that need to be planted and their needs. Pollinators like *B. californicus* that are generalists can survive with a more varied diet, but pollinators like *I. icarioides missionensis* need specific plants and just planting them can lead to disaster. This is one of the reasons why the Twin Peaks population is decreasing, they did not take care of the plants and invasive species took over the habitat. Knowing the types of soils needed to keep the plants alive as well as dangers facing them. By learning that the invasive plants were encroaching on the lupine habitat because of lack of disturbance such as fire, the

Twin Peaks Action Recovery Plan now has a direction to go, they need to take a more active part in maintaining the habitat, they cannot let it go if they are also going to suppress fires.

Also, knowing the species requires knowing about the population size and how stable it is. Nature in the City has next to no information on how big the *C. viridis* is because they are not restoration ecologies and did not have the knowledge or the funds to conduct population sampling. Now that they are several years into the project, it has become difficult to continue to grow and improve. Perhaps this is something the city government could provide, an ecologist or naturalist who can meet with small conservation groups and teach them how to take population sampling so that people can understand the importance and have the groundwork for improvement.

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Appendix

Table 8: A breakdown of the information found in Figure 12. Information gathered from the Bay Area Air Quality Management District Archived Data from 1999 to 2016. Data was the 1-HR Ozone Max recorded for the year in ppb. Data from 1999 to 2004 was in pphm but then converted to ppb. (Bay Area Air Quality Management District, 2017).

Year	8-HR Ozone Max (ppb)
2017	54
2016	57
2015	67
2014	69
2013	59
2012	48
2011	54
2010	51
2009	72
2008	66
2007	49
2006	46
2005	54
2004	60
2003	60
2002	50
2001	50
2000	40
1999	60

Table 9: A breakdown of the information found in Figure 13. Information gathered from the Bay Area Air Quality Management District Archived Data from 1994 to 2016. Data was the 1-HR Ozone Max recorded for the year in ppb. Data from 1994 to 2004 was in pphm but then converted to ppb. (Bay Area Air Quality Management District, 2017).

Year	1-HR Ozone Max (ppb)
2017	87
2016	70
2015	85
2014	79
2013	69
2012	69
2011	70
2010	79
2009	72
2008	82
2007	60
2006	53
2005	58
2004	90
2003	90
2002	50
2001	80
2000	60
1999	80
1998	50
1997	70
1996	70
1995	90
1994	60

Where to Buy/Find Native Local Plants in San Francisco

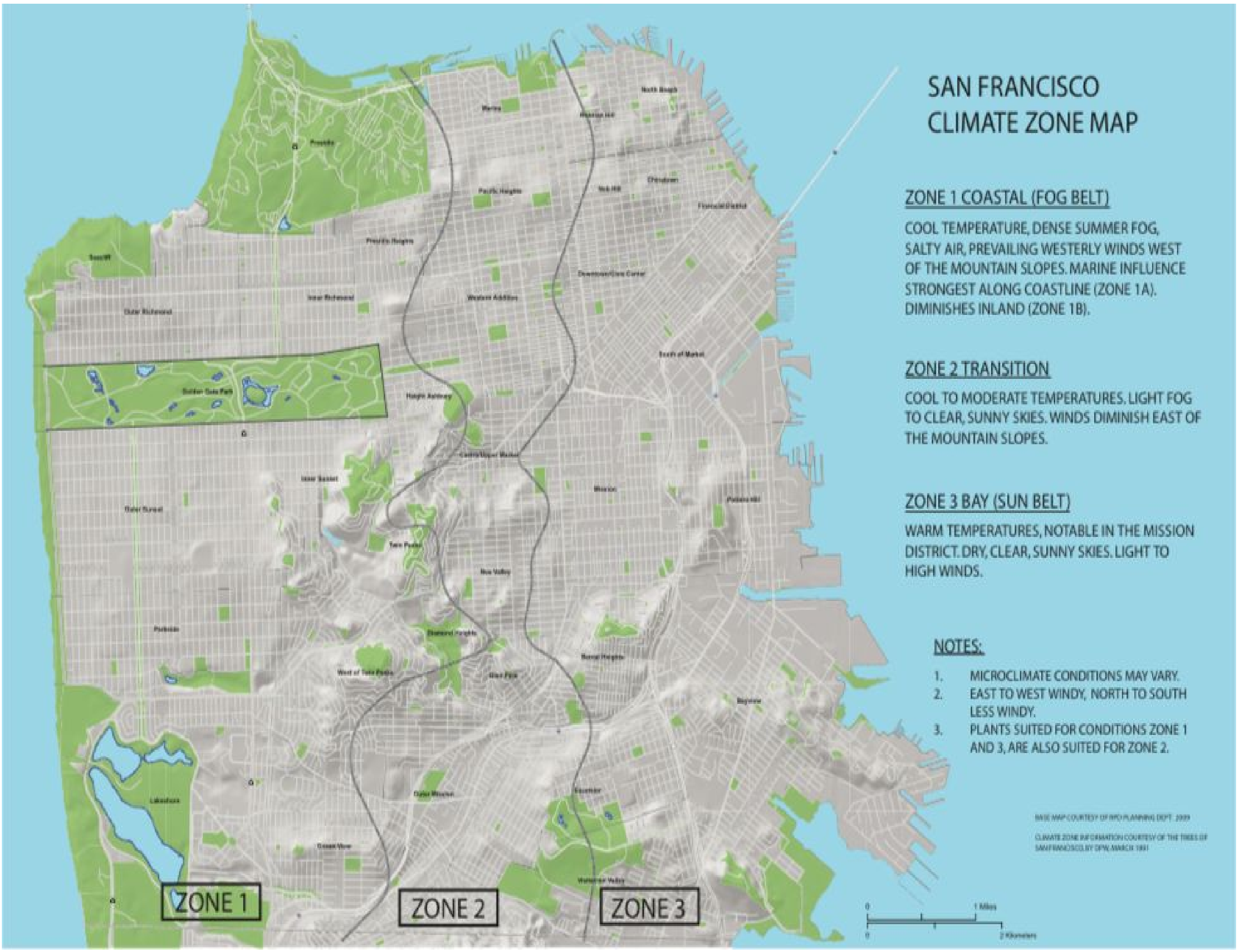
1. Sutro Native Plant Nursery: 456 Johnstone Drive, San Francisco, CA
    a. Offers 180 different native plant species.
    b. Flower availability changes based on season

2. Bay Natives Nursery: Pier 96 10 Cargo Way, San Francisco, CA
    a. Offers over 200 native California plant species specifically for urban landscaping
    b. Carries the three lupine species needed for *I. icarioides missionensis*

3. California Native Plants Society, Yerba Buena Chapter: 99 Ellsworth St., San Francisco, CA
    a. Several plant sales per year, usually spring and fall
    b. Work to maintain a local gene pool by propagating plants from seeds, cutting or divisions from around the area
    c. Specifically mentions the Green Hairstreak Butterfly in benefits of native plant gardening

San Francisco Climate Zone Map

Provided by SF Public works to help determine the best plants to put in the sidewalk gardens



How to Guide for designing an SF sidewalk garden

Provided by SF Public Works. Notice under examples of material to use they do not mention leaving soil bare, affecting the ability to host ground nesting species. They also mention using mediterranean plants, which are non-native, and mixing them with native plants. This might inadvertently cause competition between the natives and non-natives, which might lead to a decrease in native plant species.

Information to Gather:

1. In what climate zone are you located in San Francisco (Fog belt versus Sun belt)?
2. Is your sidewalk sunny (south or west facing) or shady (north facing) most of the day?
3. Which plant palette option is most appropriate for your location and what do you prefer aesthetically? (Refer to SFDPW Suggested Plants on website)
4. Do you have 'Parking' or 'No Parking' adjacent proposed sidewalk landscape? Do you have parallel, perpendicular or diagonal parking? (Refer to SFDPW sample plans for different sidewalk conditions on website)
5. Measure distance of proposed landscape area width and length to calculate total square feet for planting area and paving areas. Do not include driveway, curb ramps, and proper clearances required for above-ground utilities. (Refer to SFDPW Sidewalk Landscape Permit Plan Template on website)
6. Select preferred material option for accessible path from curbside parking, courtesy strip at curbside parking and mulch for planting beds. (See below examples and refer to SFDPW Suggested Sidewalk Landscape Materials on website for more choices)

Examples of Materials to Choose:

Mulch: shredded bark chips, stone or decomposed granite

Access Path: brick or pavers, concrete

Courtesy Strip: brick or pavers, concrete or decomposed granite

Examples of Sidewalk Landscaping Planting:

DPW has selected a number of combinations of mixes including Native California Plants, Succulents from various arid climates, and Mediterranean Plants. (Refer to SFDPW Suggested Plants on website)