TECHNICAL REPORT

Moffett Park Specific Plan Urban Ecology

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San Francisco Estuary Institute

SFEI San Francisco Estuary Institute

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Sunnyvale

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I. ABOUT THIS DOCUMENT

The Bay Area is incredibly biodiverse, meaning it is host to a wide variety of plants, animals, and other life forms. Yet its urban areas are often not designed to benefit from, and contribute to, this rich regional biodiversity. As Sunnyvale's Moffett Park district undergoes large-scale redevelopment, great potential exists for the district to pioneer urban greening interventions that will help support this regional biodiversity while cultivating its own unique sense of place. This urban ecology technical report delineates the key criteria for making a biodiversity-friendly district, explores where Moffett Park currently stands in terms of these criteria, and identifies opportunities and strategies for better supporting biodiversity locally. The opportunities and strategies outlined herein, however, do not constitute formal city policies. Rather, they present an overarching approach to guide Moffett Park towards a greener future using the most up-to-date science-based recommendations.

London Wetlands Centre (Photo courtesy of Jon Aker, CC by 2.0)

II. BIODIVERSITY GOALS AND GUIDING PRINCIPLES

The goal of this document is to identify specific measures through which the City of Sunnyvale can facilitate actions that improve Moffett Park's human experience and support for biodiversity. The urban greening interventions outlined in this document will further several proximate objectives towards this overarching goal. Greening interventions will help Moffett Park mitigate and adapt to climate change through carbon sequestration, urban heat island reduction, air pollution filtration, and stormwater retention — ensuring the district remains habitable into the future. They will likewise create healthier, restorative environments in which people can relax and recreate and wildlife has space to thrive. Through combined efforts to transform Moffett Park into *a green district*, the district can serve as a case study and testing ground for multi-benefit nature-based solutions in urban areas.

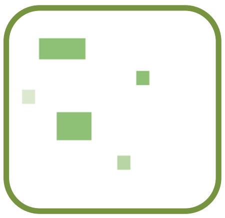
The following guiding principles summarize the basic approaches to improving support for biodiversity and augmenting the human experience in Moffett Park:

- **Protect and enhance existing ecological assets** including patches, wetlands, large site-appropriate trees, and corridors.
- **Create a network of large patches** with high-quality habitat to support biodiversity across Moffett Park.
- **Build ecologically complex and biodiverse spaces** for people to experience the biophysical and psychological benefits of access to nature.
- **Improve the ecological performance of all open spaces**, from civic plazas to natural areas.
- **Promote connectivity** for native flora and fauna: create corridors, fill gaps in existing corridors, reduce barriers to movement, and create stepping-stone habitat patches.
- **Ensure continuous canopy cover along mobility corridors** to increase connectivity between open spaces, improve outdoor thermal comfort, and promote active mobility.
- **Increase tree canopy cover** across Moffett Park to mitigate against the formation of urban heat islands, sequester carbon, avoid stormwater runoff, and reduce air pollution.
- **Maximize softscape and reduce impervious surfaces** to decrease stormwater runoff, mitigate against urban heat islands, and better support flora and fauna.
- Identify **architectural and landscape elements** to better support urban ecology: create new biophilic experiences; use **wildlife-friendly** materials and practices; reduce light and noise pollution.
- Utilize current or restored ecosystem functions for **multiple benefits**.

The next three sections provide a framework for understanding how these principles build support for biodiversity, explain how they relate to existing assets in Moffett Park, and detail how they can specifically be applied in the district.

III. INTRODUCTION TO THE URBAN BIODIVERSITY FRAMEWORK

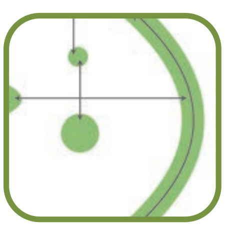
Cities can support both people and biodiversity — if they are designed and managed with ecosystem functions in mind. In recent years, scientific research in urban ecology has provided new insight into the components of urban environments that are most important to promote biodiversity and achieve conservation outcomes. Drawing on this research from cities around the world, the report *Making Nature's City: A Science-Based Framework for Building Urban Biodiversity* (SFEI-ASC 2019) identifies seven key elements for supporting nature in cities. These seven elements work together to encourage healthy, functional ecosystems that support biodiversity and provide a range of benefits to urban residents, including cleaner air and water, temperature moderation, increases in physical and mental health, and improved outdoor experiences.



Element 1: Patch Size

Patch size, or the area of each discrete greenspace in a city, is one of the two main drivers of urban biodiversity (Beninde et al. 2015). In urban settings, terrestrial habitat patches range from smaller neighborhood parks to golf courses, cemeteries, and large city parks. Other urban natural spaces, such as beaches and ponds, can host a variety of species that specialize in riparian, coastal, and aquatic habitats.

Larger patches generally support greater biodiversity because they contain more kinds of habitats and provide more resources than smaller patches. Additionally, patches that are less isolated, have less edge than core area, and mimic locally-native habitats can support more flora, fauna, and fungi. Based on several studies, patches in this document are defined as greenspaces above 2 acres. Biodiversity increases rapidly when greenspaces are above 10 acres in size and large patches (above 130 acres in size) can host species that are area-sensitive and intolerant of urban environments With appropriate habitat components (see following sections: Habitat Diversity, Native Species, Special Resources and Management), networks of habitat patches have been shown to maintain species richness in urban settings, particularly species of small vertebrates (Dickman 1987).



Element 2: Connections

Connections between patches are the second most important element in urban biodiversity support (Beninde et al. 2015). Connections are vegetated features that facilitate the movement of plants or animals across the landscape and through the urban environment (e.g. greenways and riparian corridors). In cities, buildings, roads, fences, and other components of the built environment present barriers to wildlife movement and can lead to isolated and less resilient wildlife populations. Connectivity can be especially important for animals that are wide-roaming, rely on different types of habitat across seasons or life stages, or are less able to cross urban barriers.

Contiguous stretches of vegetation linking wider greenspaces, such as green corridors along waterways and right-of-ways form some of the most effective connections in cities. Waterways can also serve as critical connections between urban and rural populations and aquatic and terrestrial habitats. In the absence of continuous corridors, “stepping stones” of matrix habitat, such as closely-spaced pocket parks or green roofs (see below), can help create connectivity between patches.

Element 3: Matrix Quality

Urban areas surrounding habitat patches and corridors are often referred to as the urban matrix. Matrix quality refers to how well these developed areas support biodiversity. Developed areas integrated with vegetation, such as street trees, bioretention areas, green roofs, and backyard gardens, are better able to support native plants and animals (Goddard et al. 2010; Bateman and Fleming 2012; Ziter 2016). Habitat elements in the matrix are often too small to support large wildlife populations themselves, but can support wildlife movement and foraging in cities (Baum et al. 2004). Improvements to the urban matrix are most valuable in coordination with patches and connections. Matrix quality improvements can be made around patches to increase the effective patch size, along connections to increase the effective corridor width, between patches to increase connectivity, or clustered to form habitat complexes.

Element 4: Habitat Diversity

Natural landscapes contain diverse assemblages of ecosystems. Restoring the scale, complexity, arrangement, and diversity of habitats is key to supporting native species and increasing total resources available. When planning for habitat diversity it is important to both promote coherence and heterogeneity at the city-scale and mimic the spatial complexity, verticular structure, and physical features of individual habitats at the site-scale.

Mimicking native habitat configurations can help support species that rely on multiple adjacent ecosystems across time. Amphibians, for example, lay their eggs in wetlands and then migrate to upland habitats, where they remain until they return to wetlands during the breeding season (Semlitsch and Bodie 2003). Urban areas that replicate this natural habitat diversity and arrangement can therefore support greater overall biodiversity (Fernández-Juricic and Jokimäki 2001; Tews et al. 2004). Protecting and augmenting rare native habitats in cities can be particularly beneficial for habitat specialists, which may be especially vulnerable to habitat loss.

Element 5: Native Vegetation

Native species are those that have long evolved in a particular location and are adapted to the particular conditions present. Over evolutionary history, native species often develop special relationships with one another and with their physical environment. For example, many insects have developed specialized relationships with native host plants. Native plants can bolster the entire food web by supporting the presence of these specialized local insects, which can, in turn, be a food resource for other wildlife. Native plants are also often especially well-suited to local conditions and can support the native wildlife with which they have co-evolved. Thus, in addition to providing wildlife habitat, the use of native species in urban landscaping can also reduce water usage and maintenance costs.

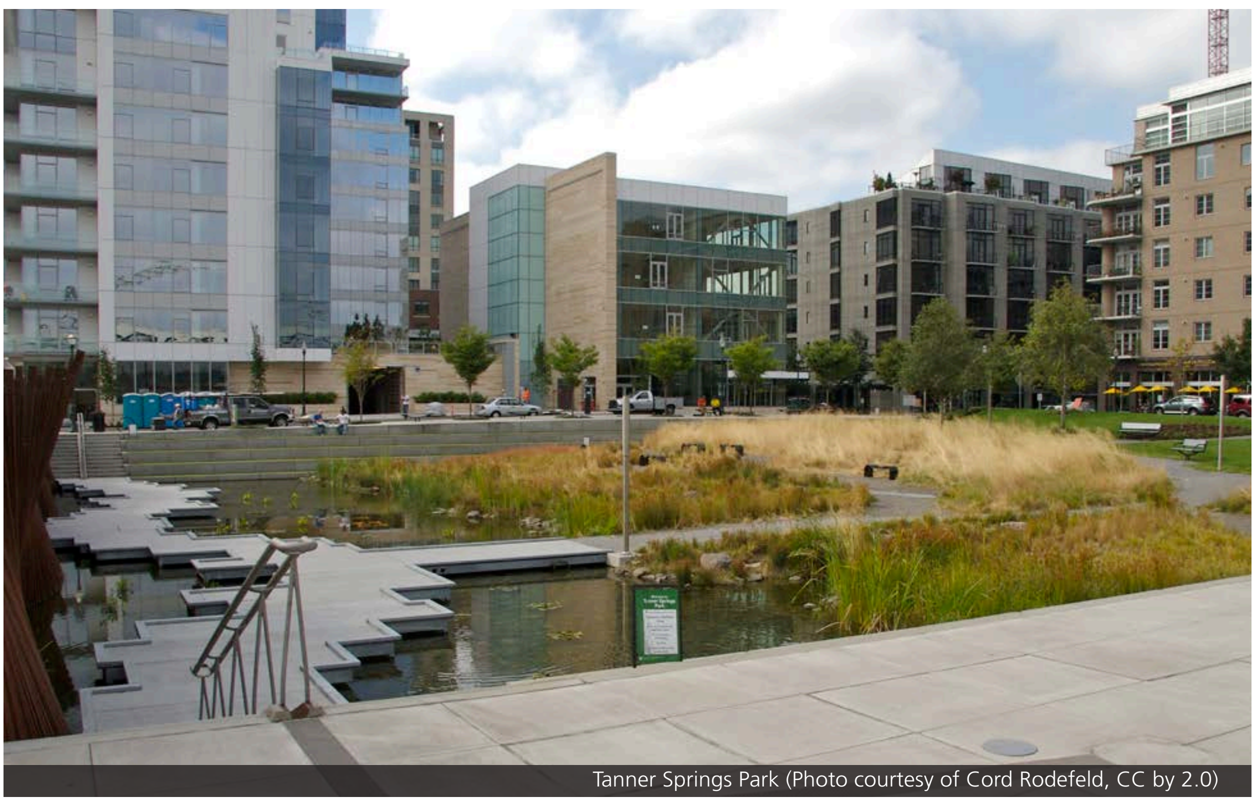
Element 6: Special Resources

Certain physical or biological components of an ecosystem can provide disproportionate benefits to wildlife. These special resources can help animals meet their needs for food, shelter, or water during all or part of the year. Because water is necessary for nearly all species, well-designed urban water bodies serve as hubs for local biodiversity (Hill et al. 2017). Large trees can likewise provide outsized benefits, such as by providing cavities for nesting and fruits as food for wildlife (Stagoll et al. 2012). Some resources important for specialist species, such as older trees with cavities for nesting birds and woody debris piles for reptiles and insects, are typically removed in urban environments. Specifically managing for features like these can support specialists and increase biodiversity in otherwise resource-limited areas.

Element 7: Management

Most urban spaces experience some degree of human management, i.e., interventions in which people manipulate or make changes to the landscape. Land managers can often adopt minor changes to their practices that are both beneficial to biodiversity and are lower in cost. Biodiversity-friendly management actions are many and varied; they include planting native flowers and other plants that provide food for wildlife, providing water through bird baths and ponds, and providing shelter and places to raise young such as nesting boxes and platforms. They also include actions aimed at enhancing the quality of habitat, such as reducing pesticide and herbicide use, minimizing disturbance to sensitive wildlife areas, limiting the impacts of domestic cats and dogs, reducing light and noise pollution, and regulating human activity to reduce conflict with wildlife. Other actions can be incorporated in architecture and urban planning to create a more wildlife-friendly built environment. These include fitting buildings with bird-safe windows and creating wildlife underpasses and overpasses.

La Soledad Parkway (Photo courtesy of Felipe Restrepo Acosta, CC by 5A4.0)



Tanner Springs Park (Photo courtesy of Cord Rodefeld, CC by 2.0)

IV. SITE ANALYSIS

Regional Context

Moffett Park lies at the northern edge of Santa Clara Valley, a highly urbanized region in northern California located between two mountain ranges: the Santa Cruz Mountains to the west and the Diablo Range to the east. Protected areas in these ranges preserve vast expanses of forests, oak savanna, grasslands, and various other habitats. These habitats support a wide range of flora and fauna, including several rare and endangered species. To the north of Santa Clara Valley and adjacent to Moffett Park, large expanses of tidal marsh, mudflats, ponds, and open water in South San Francisco Bay provide habitat for diverse wetland and aquatic wildlife.

While there are vast habitat areas neighboring Santa Clara Valley, there are relatively few greenspaces amidst the Valley's office parks, commercial areas, and suburban sprawl. Development in the Valley acts as a barrier separating tidal habitats on the shoreline and upland habitats in the hills. Creeks and riparian corridors constitute the primary connections between these wildlands, terrestrial mammals, and other animals to migrate between the Bay and hills. In some areas, existing urban parks may also act as "stepping stones," particularly for birds and other flying animals traveling between larger greenspaces.

Targeted ecological interventions can improve Santa Clara Valley's ability to support biodiversity and connect adjacent habitat areas. Moffett Park can act as a model for showcasing these interventions. The following sections outline Moffett Park's ecological assets and opportunities for the district to help better support biodiversity throughout the region.

Diablo Range
San Francisco
Bay
Moffett Park
Sunnyvale
Santa Cruz Mountains
N
5 mi

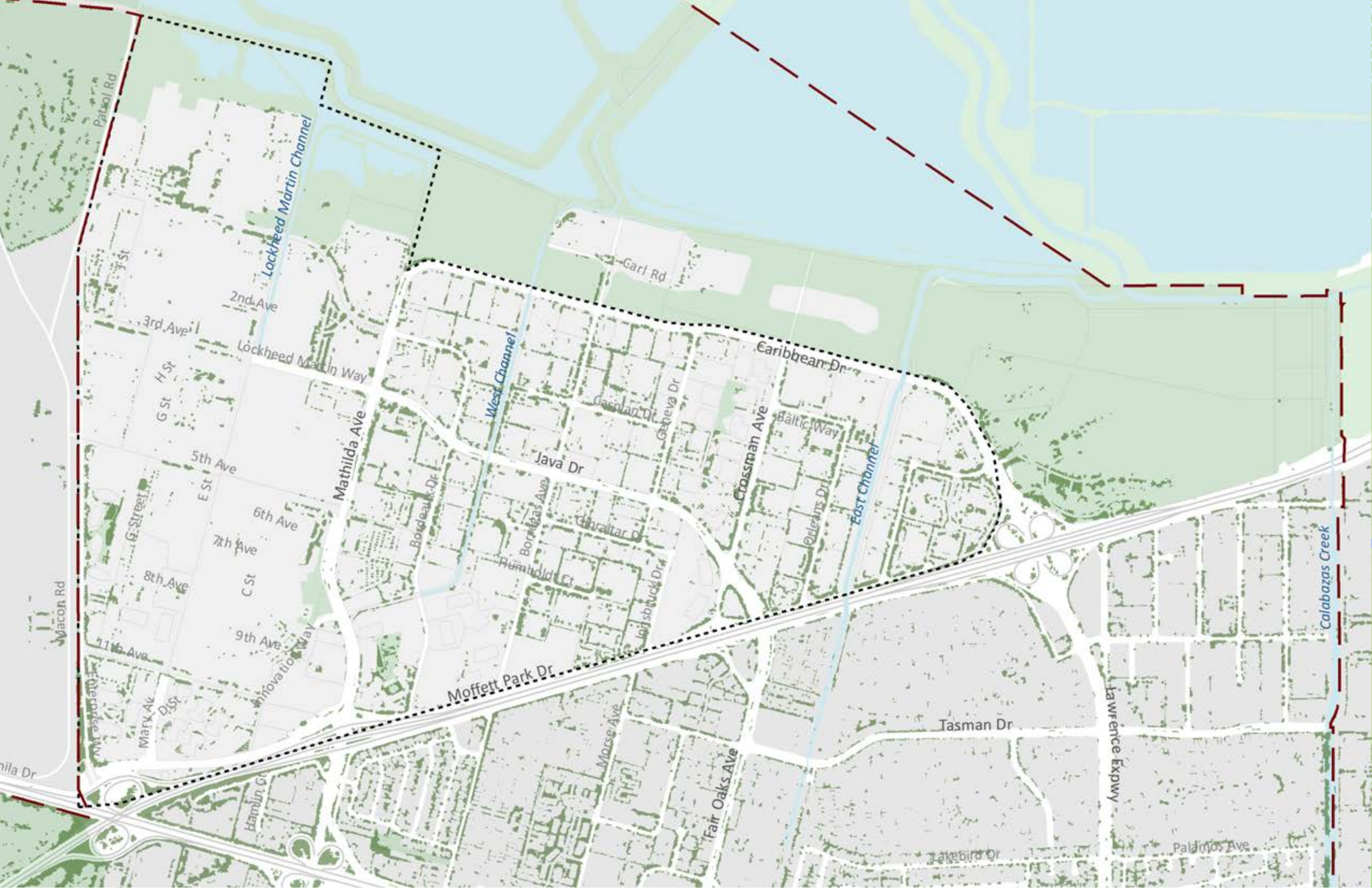
Habitat Patches

Within the Specific Plan boundary, there are small landscape areas in privately held campuses and the wetlands found on Lockheed-Martin's property. Habitat patches around the Specific Plan boundary include the Sunnyvale Municipal Golf Course, Golf Club at Moffett Field, Sunnyvale Landfills, Sunnyvale Baylands Park, and Harvey Marsh.

Sunnyvale Baylands Park and Harvey Marsh are protected open spaces of 223 and 52 acres, respectively. These patches are part of the wider baylands ecosystem, and are characterized by tidal flats, tidal marshes, wetlands, and grasslands. They are home to mammals such as ground squirrels, black-tailed jackrabbits, striped skunks, about 200 bird species, including a great variety of shorebirds and waterbirds (e.g., Ruddy Ducks, American Coots, American Avocets). These patches are popular destinations for outdoor recreation and are equipped with trails, picnic tables, and an outdoor amphitheater. The Golf Club at Moffett Field and the Sunnyvale Municipal Golf Course are predominantly composed of manicured lawns with relatively low habitat value. The Sunnyvale Landfill is 116 acres of mainly annual grasslands and barren areas with a small amount of ornamental woodlands on the perimeter. Endangered Burrowing Owls overwinter on the landfills and were known to once breed there; otherwise, the landfills provide little habitat for native plants and animal species.

Connectivity

There are three existing corridors within the plan boundary: Sunnyvale East, Sunnyvale West, and Lockheed-Martin Channels. These are man-made channels built to protect local homes and businesses against flooding by increasing drainage to the Bay. The channels are six, three, and half a mile long, respectively, and are largely unvegetated except for non-native ruderal grasslands along levees. Unlike natural streams in the region, the channels do not provide connections to hillside terrestrial animal populations. However, with improvements to the riparian vegetation, they have the potential to support important wildlife habitat and movement within the district. Given its relative length, the East Channel has the strongest potential to act as a conduit for wildlife.



Matrix Quality

Matrix quality in Moffett Park is notably low. Moffett Park is characterized by extensive impervious surfaces with surface parking covering ~33% of the entire Specific Plan area. Overall tree canopy cover is very low, at 8.9%, and mostly composed of non-native species that provide little biodiversity support and shade. Landscaped areas are primarily located along roads and the perimeter of buildings, planted primarily by a variable mix of mostly non-native grases, shrubs, and trees.

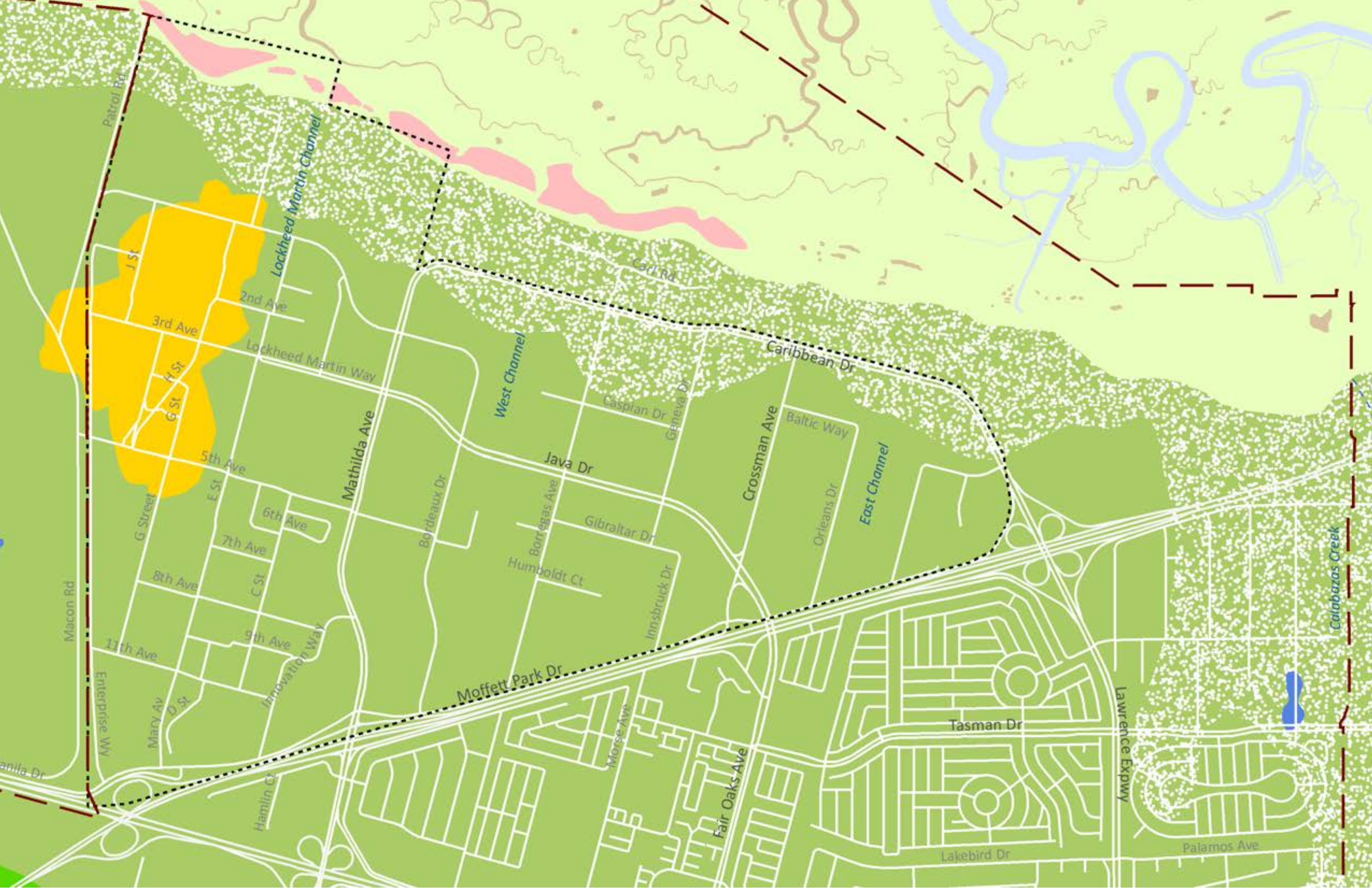
Tree Canopy

Habitat Patches

MPSP Boundary

N

0.5 mi



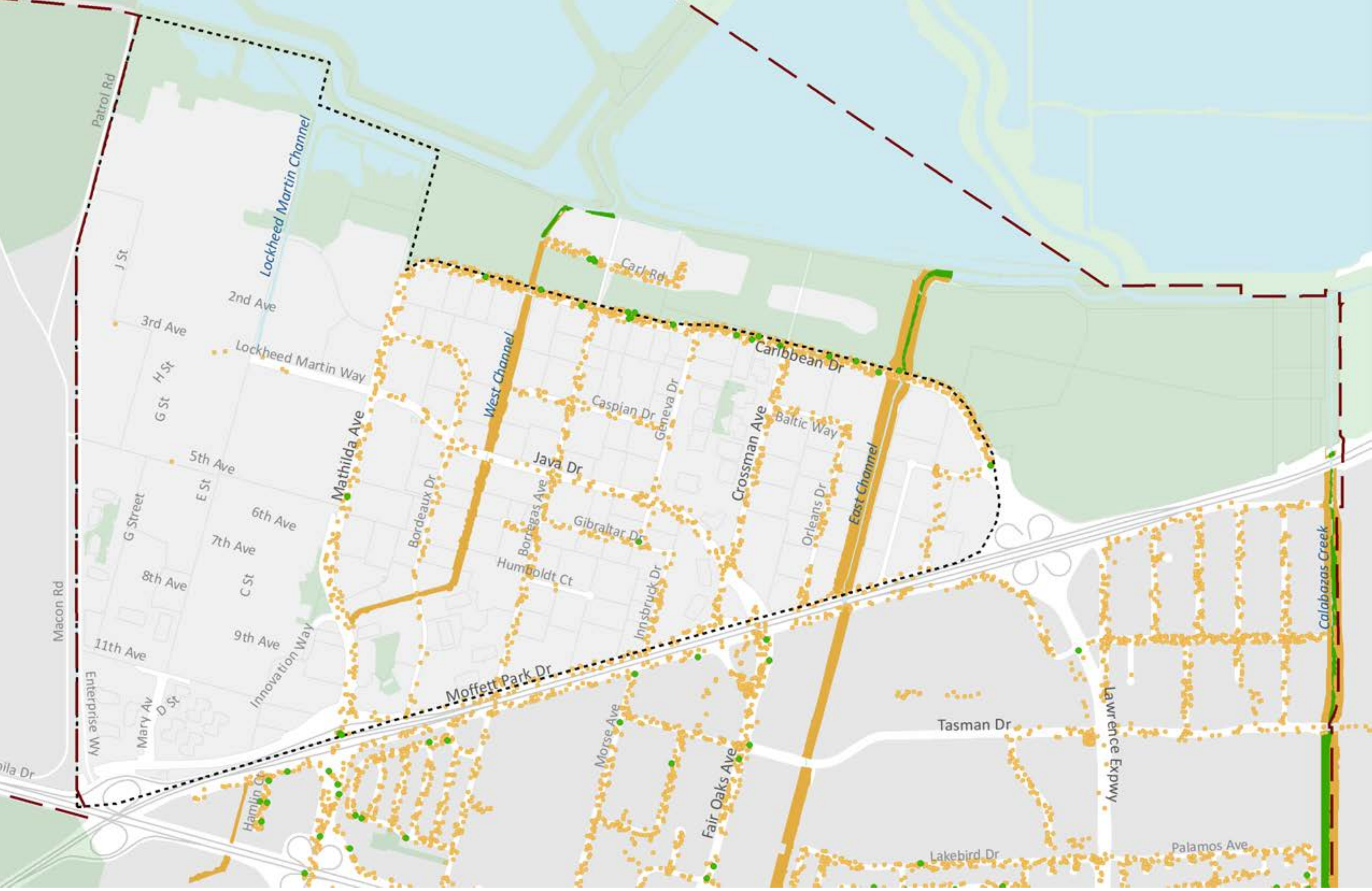
Habitat Diversity

Moffett Park was historically located at the edge of the Bay and was home to oak savannas, wet meadows, alkali wet meadows, tidal marshes, and salt flats. These habitats were almost entirely cleared for development with the exception of small patches of aquatic habitat found along the Bay.

Salt Flats
Alkali Wet Meadow
Wet Meadow
Oak Savanna
MPSP Boundary

N

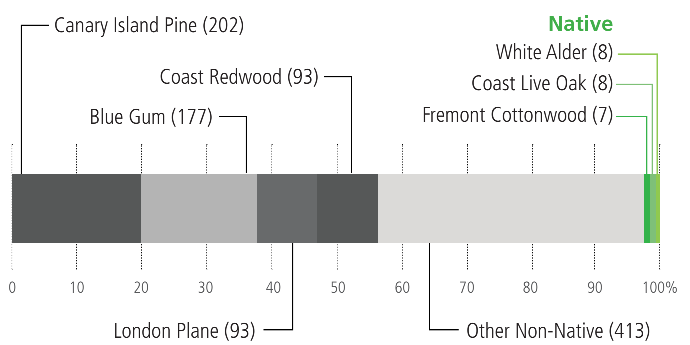
0.5 mi



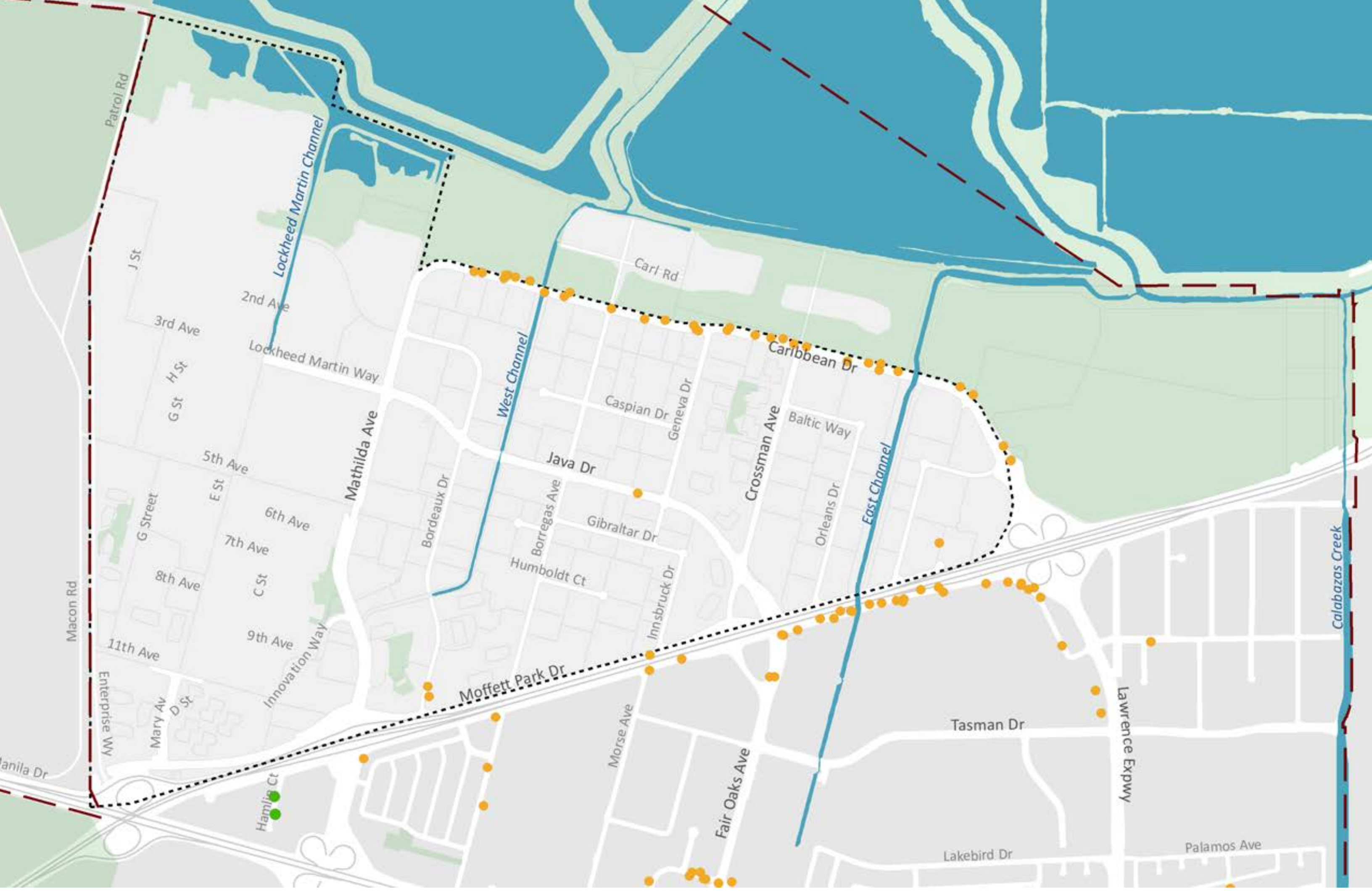
Native Vegetation

Moffett Park's landscape is dominated by non-native vegetation. The district's municipally-owned trees are overwhelmingly non-native species (97.7%). Only three native species are present in the street tree inventory: coast live oak (*Quercus agrifolia*), white alder (*Alnus rhombifolia*), and Fremont cottonwood (*Populus fremontii*). Native vegetation is also limited along the channels. There is no comprehensive inventory of plant composition in privately owned lands; however, field visits indicate that, with some recent exceptions, these too are predominantly planted with non-native species.

Non-native Tree and Native Tree composition



Number in parentheses after tree type represents specific number of trees found in survey.



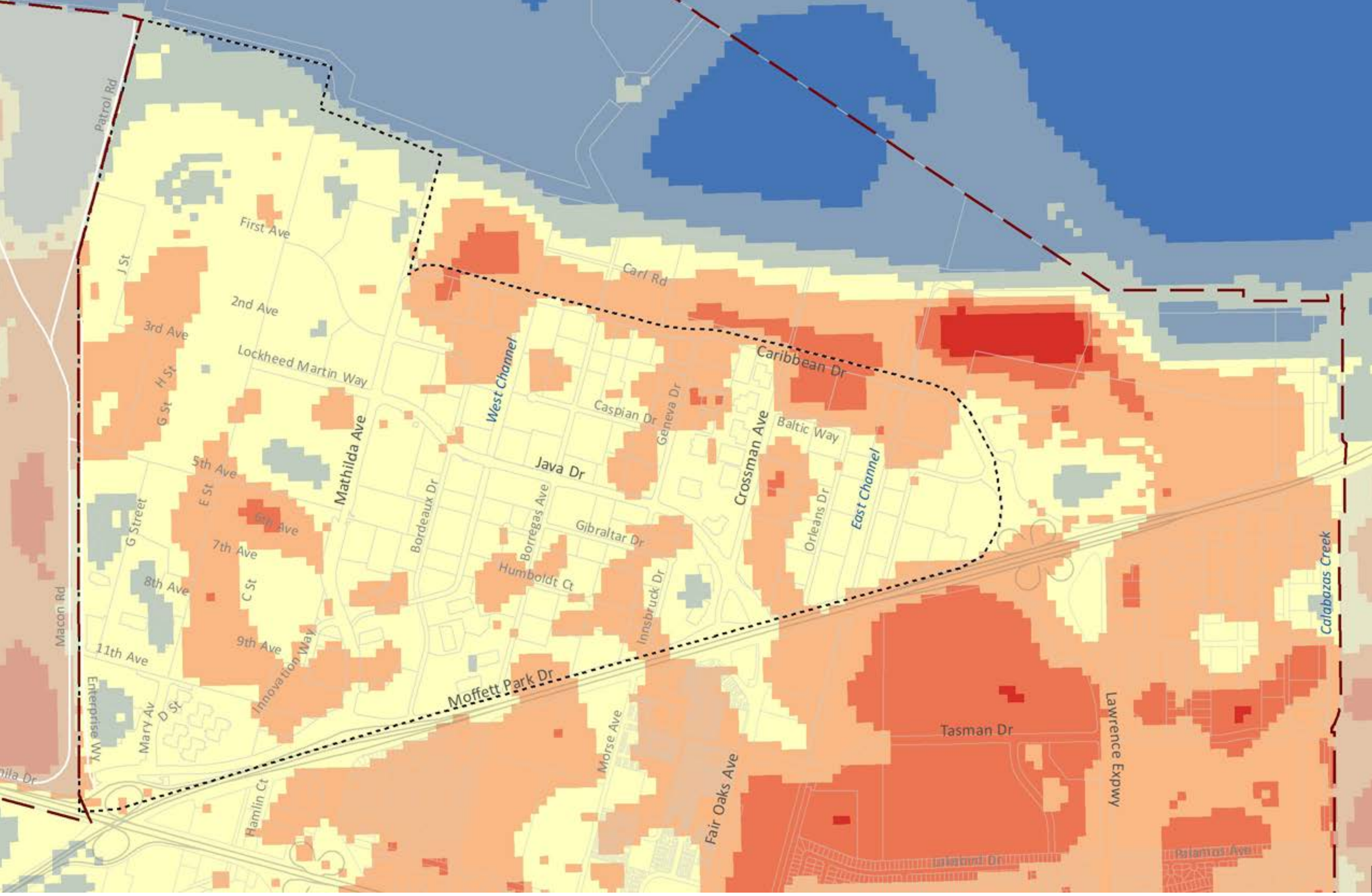
Special Resources

Moffett Park is located at the confluence of aquatic and terrestrial habitats. Within the Specific Plan boundary, the freshwater wetlands in Lockheed-Martin's property are of particular importance to local biodiversity and help detain stormwater flows. A number of tidal wetlands and managed ponds lie just outside of the Specific Plan area and serve as special resources to migratory and resident waterfowl. Plans for the restoration of the former South Bay Salt Ponds further enhance the potential ecological value of Moffett Park's adjacent landscapes and in turn urban greening efforts. A single large tree can be meaningful habitat for species; there are a few (n = 26) large trees surveyed in the municipal tree inventory.

Native Large Tree
Non-native Large Tree
Wetlands & Ponds
Channels
Habitat Patches
MPSP Boundary

N

0.5 mi



Surface Temperature (°F)

- 73 -81
- 73 - 90
- 90 - 99
- 99 - 102
- 102 - 108
- 108 - 111
- 111 - 138

MPSP Boundary

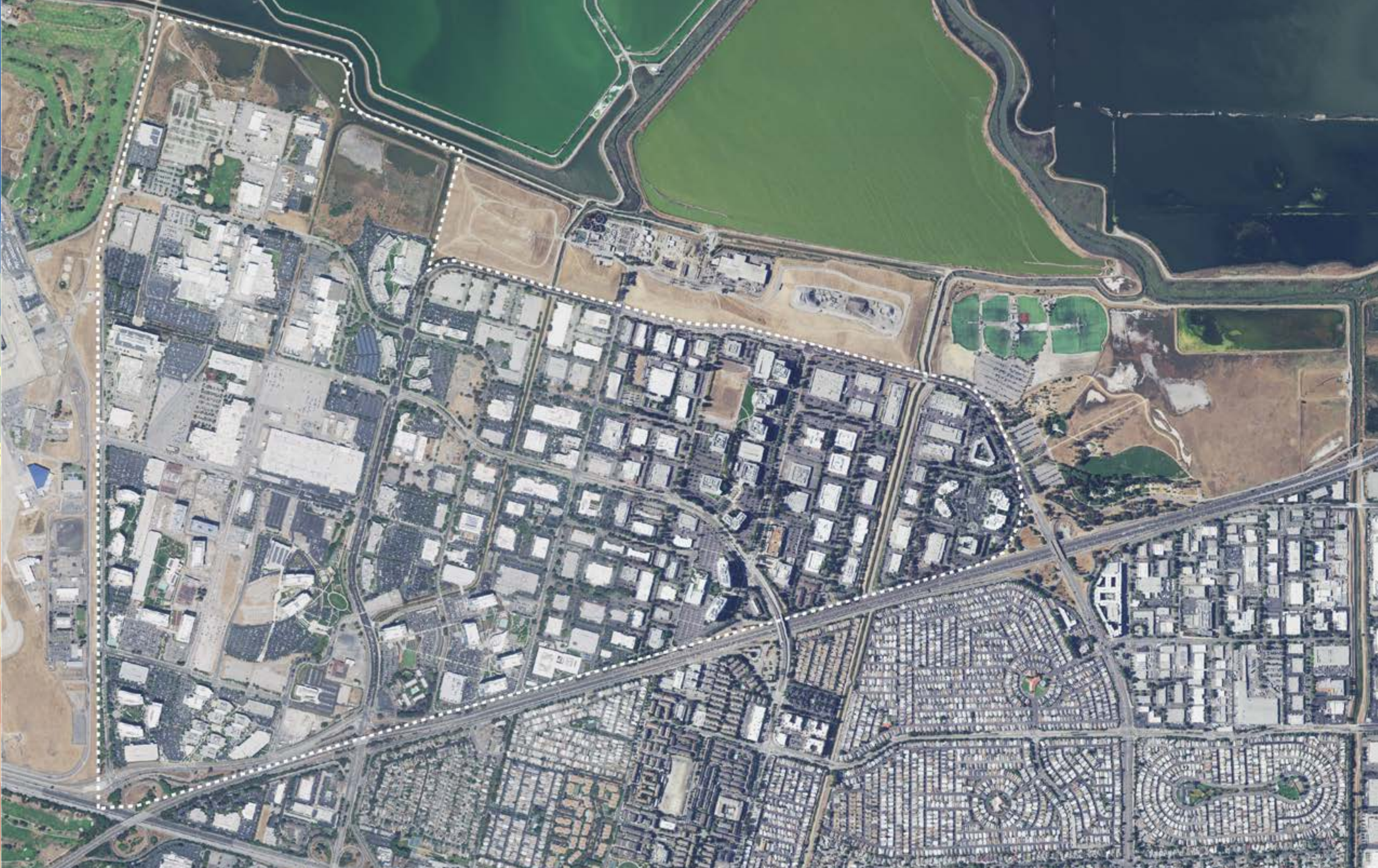
N

0.5 mi

Urban Heat Island Effect

Moffett Park's landscape is highly vulnerable to the formation of urban heat islands. Extensive impervious areas, lack of vegetative cover, and low albedo surfaces exacerbate heat stress during summer and extreme heat events. This is of particular concern given Cal-Adapt's climate projections. Average summer temperatures are expected to increase in Santa Clara County by ~4°F by 2050 and up to more than 6°F by 2100 (Maizlish et al. 2017), while the number of extreme heat events will double by 2050 and triple by the end of the century[1].

1 Cal-Adapt defines extreme heat days as above the 98th percentile of the computed maximum temperature for each location using 1961-1990 data for the May to October warm season. https://cal-adapt.org/tools/extreme-heat/


Moffett Park aerial view (Imagery courtesy of USDA, NAIP)

Heat stress can exacerbate a number of medical conditions, including cardiovascular risk, respiratory diseases, mental health illnesses, stroke, organ damage, and can even lead to death[2]. The heat wave that struck California in 2006 killed more than 600 people and resulted in 16,000 excess hospitalizations (Gershunov and Guirguis 2012). In Santa Clara County, a study found a 1.28% increase in mortality rate per 2°F increase in air temperature (Basu et al. 2008).

The map above left shows remotely-sensed surface temperatures captured by Landsat 8 during the heatwave of September 2, 2017 at 10:40 am. At this time, hours before air temperature peaked (108°F) at 5:00 pm, the synthetic turf fields at Twin Creeks Sports Complex (upper right quadrant) registered the highest surface temperatures (138°F). Most areas in Moffett Park ranged from 99-108°F. The Baylands, Lockheed-Martin wetlands and patches of irrigated landscape are relatively cooler (73-90°F).

It is important to note that surface temperature is one of a number of variables that lead to the urban heat island effect, including air temperature, wind velocity, humidity, solar radiation, and anthropogenic heat generation.

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2 Children, seniors, pregnant women, and others with a lower capacity to thermoregulate are at greater risk of developing heat related medical conditions (Hajat and Kosatky 2010).

V. OPPORTUNITIES AND STRATEGIES TO ENHANCE THE ECOLOGY OF MOFFETT PARK

Goal 1: Create greenspaces that provide urban cooling, stormwater capture, immersive nature experience, and local biodiversity.

Strategy 1: Enhance existing patches

There are a number of existing patches within or immediately adjacent to the Specific Plan boundary with the potential for ecological improvements. These include the wetlands on Lockheed-Martin's property and private greenspaces in corporate campuses. Greenspaces on most corporate campuses are predominantly composed of lawns and non-native ornamental species, which are of low ecological value. Ecological improvement projects need to emphasize native plantings that take into consideration the historical ecology of the area, current conditions, climate projections, and functional and recreational needs. Invasive species removal and the adoption of wildlife-friendly management actions is crucial to the enhancement of existing greenspaces.

A number of regional patches lie just outside of the Specific Plan boundary including the Sunnyvale Landfills, Twin Creeks Sport Complex, and Baylands Park. These large existing green and bluespaces support a wide range of species. However, there are opportunities to improve the ecological value of these patches by replacing exotic and invasive species with native vegetation, and considering long-term habitat trajectories (SFEI-ASC 2018).

Sunnyvale Landfills (Photo courtesy of Stanislav Sedov, CC by 2.0)

Recommendations:

- Consolidate vegetated areas to create large and connected planting areas.
- Design ecological features in relation to surrounding ecological assets.
- Create coherent plant assemblages drawn from local native ecosystems that mimic their spatial complexity and function (*see Goal 3, Strategy 1*).
- When possible, integrate water features, downed logs, bird and bat houses.
- Adopt wildlife-friendly management practices to reduce environmental impact.
- Limit active programming along ecologically sensitive areas.
- Reduce impervious cover.
- Incorporate educational programming to showcase multi-benefit urban greening strategy.
- The Sunnyvale Landfills provide habitat for Burrowing Owls, a California Species of Special Concern. Any enhancements to the Landfills will need to further protect and improve this species' habitat requirements.
- Set standards and guidelines for open space design and maintenance.

Strategy 2: Expand wetland area and create a terrestrial buffer

Wetlands are rare and unique features on the landscape that serve many essential functions, such as retaining flood water, providing habitat for wildlife, and improving water quality (e.g., through removal of pollutants, nutrients, and sediment; Mitsch and Gosselink 2015). Moffett Park can capitalize upon its bayfront location to create a unique aesthetic identity while simultaneously reaping the ecological and recreational benefits of wetlands. Currently, the district's visual and ecological connections to the Bay are limited by the presence of a capped landfill running along the northern edge, disconnecting the district from the Bay. A set of significant wetlands (~89.75 acres in area) currently exist on Lockheed Martin's property on the northwest corner of the district. These brackish wetlands are former tidal marshland and tidal-terrestrial ecotone habitat, now filled by stormwater detention and groundwater rather than tidal flows. Expansion of the wetland area could occur through the retreat of buildings and parking surfaces that currently encroach into the wetland's profile, which would increase the wetland area's width and the connectivity within the local wetland system[1]. Expanding and enhancing the ecological value of these wetlands provides an opportunity to redefine Moffett Park as a bayfront district, particularly given the lack of current or planned tidal wetlands in the former salt ponds immediately adjacent to the district (Sunnyvale Treatment Ponds and Pond A8). The location of these wetlands along the Bay Trail makes them easily accessible and a prime nature-based destination within the district, which is currently lacking in natural character.

Wetlands require terrestrial buffers (i.e., strips of land that buffer the transition from upland to aquatic habitats) for several reasons: (*i*) they are important for maintaining the quality and function of the wetland through nutrient, pollutant, and sediment removal, which also protects the water quality of other hydrologically connected waterways; (*ii*) a majority of wetland-dependent species use terrestrial buffers as an essential part of their life cycle[2]; and (*iii*) they help support functional ecological communities and higher levels of wetland biodiversity[3]. Wetland buffers can be implemented through municipal zoning ordinances, such as a habitat overlay zone. The terrestrial buffer around the Lockheed-Martin wetlands varies from 90 to 650 feet in width.

Recommendations:

- Create a vegetated terrestrial buffer around the wetlands
    - For nutrient and pollutant removal, a minimum buffer width of 100 feet is needed[4]
    - To maintain both wetland water quality and to provide functional habitat for a diverse subset of wetland species, 330 feet is recommended[5].

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1 The amount of wetland habitat in a region can greatly improve how each wetland in the network individually functions for wildlife (Fairbairn and Dinsmore 2001). The Lockheed-Martin wetlands are well situated to improve connectivity in the broader regional wetland network. The Lockheed-Martin wetlands are fed by freshwater inundation and only small areas of freshwater wetlands are present in the South Bay, two of which are located nearby: Palo Alto Baylands Nature Preserve is ~3.5 miles to the northwest and the wetlands at Baylands Park are ~1.6 miles to the east. Further, this marsh will be a part of a vast future network resulting from the South San Francisco Bay Shoreline Project, which will restore 2,900 acres of tidal marsh.

2 Species require terrestrial buffers for nesting, breeding, foraging and shelter (Boyd 2001; Semlitsch and Bodie 2003). For example, in Massachusetts, 76% of wetland-dependent species used terrestrial buffers to some extent, with more than half (52%) using habitat >200 feet from the wetland edge(Boyd 2001).

3 In urban wetlands, wider wetland buffers are related to higher levels of breeding bird richness and abundance (Milligan 1985).

4 In a review of more than 100 papers, most buffers that demonstrated significant removal of nutrients were >30 m (~100 feet) in width (Hickey and Doran 2004).

5 The Environmental Law Institute (2003) recommends a 100 m (~330 foot) width based on the synthesis of 156 studies of riparian and wetland terrestrial buffers.

- For more comprehensive support for wildlife and plants, 650 feet is recommended[6].
- Implement a habitat overlay zone or offer transferable development rights for parcels abutting the wetland to create terrestrial buffers and to protect wetland species by requiring raptor perch deterrents on building roofs and taller structures.

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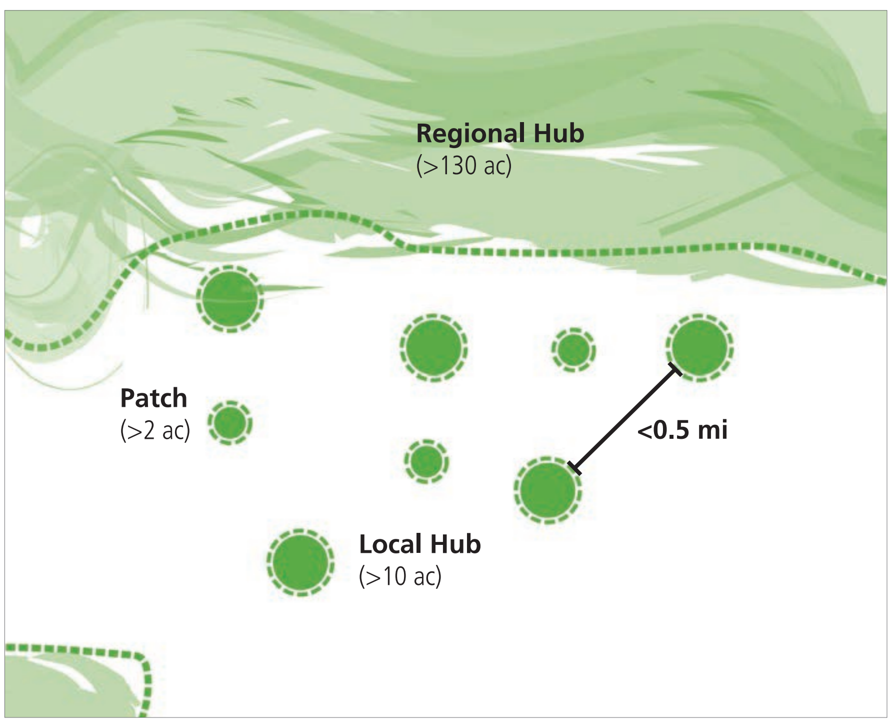
6 In general, the wider a terrestrial buffer is, the more ecological function it will support. No specific standard minimum width exists for fully capturing ecological function and conserving biodiversity, however, a 200 m (~650 foot) buffer has the potential to additionally capture: (*i*) the minimum core habitat requirements for amphibian and reptilian species (65 species;Semlitsch and Bodie 2003); (*ii*) habitat needs for space-restricted birds (Stauffer and Best 1980); (*iii*) support local avian species richness (widths of 250 feet to 575 feet were needed to support 90% of bird species; Spackman and Hughes 1995).

Wetland Terrestrial Buffers for Lockheed-Martin detention ponds. Scientifically-based, recommended buffer widths provide different essential functions for wetlands: (a) 100 feet for nutrient and pollutant removal, (b) 330 feet for support of a subset of wetland species, (c) 650 feet for comprehensive support of biodiversity.

Strategy 3: Create new patches distributed throughout the district

Habitat loss and fragmentation are the two principal threats to terrestrial biodiversity (Rogan and Lacher 2018). These processes occur as humans modify natural landscapes, reducing the amount of natural habitat in the landscape and relegating the remaining habitat to small patches isolated from one another (Pardini et al. 2018). Habitat fragmentation most significantly limits the amount of biodiversity and across urban landscapes globally, intact vegetation is the strongest predictor of biodiversity(Aronson et al. 2014).

While Moffett Park borders large expanses of aquatic habitat, the district itself contains few habitat patches and thus contributes to habitat fragmentation at a regional scale. Creating new habitat patches across Moffett Park can allow the district to act as a network of "stepping stones" to support local, regional, and migratory species (Saura et al. 2014). Currently, patches (greenspaces >2 ac) cover 8.3% of Moffett Park adding up to 107 acres. However, as noted above, most of this patch area is of low ecological value and located within privately-held office campuses. The southwest region of Moffett Park is currently devoid of habitat patches and more than 0.5 miles away from existing patches (>0.5 miles), which limits greenspace accessibility for people, district cooling, biodiversity support, and plant and wildlife movement. The upcoming redevelopment of Moffett Park presents a rare opportunity to increase greenspace area to meet the city's and regional targets as well as improve the district's publically accessible greenspace. New patches can be created as part of new community parks, stormwater features (especially at the lower northern district margin), or nature-based wastewater treatment approaches.



Distribution of Open Space. Patches of open space greater than 2 acres in size should be distributed no more than 0.5 miles apart across the landscape.

Recommendations:

- Create an additional 44 acres (minimum) of high habitat value greenspaces are recommended for Moffett Park[7].
- To minimally support some wildlife species, patches should be > 2 acres[8]. Individual patches should be >10 acres[9] in order for them to serve as local hubs[10] for biodiversity.
- Patches should be square or circular in shape, rather than long and skinny, in order to contain more core habitat and be more suitable for edge-sensitive species.
- Distributing habitat patches spaced within a half mile will allow native species to reside in and disperse across Moffett Park[11]. This distribution of greenspace likewise ensures that parks are accessible within a short walk of all locations in Moffett Park — an outcome associated with mental and physical health benefits for people working and living in the area (Han et al. 2013; Sturm and Cohen 2014).
- New patches should be located, as much as possible, in relation to existing ecological assets, such as along existing and proposed corridors or adjacent to existing habitat.
- Set open space overlay zones and incentive zoning to promote the creation of coordinated patches in private land.

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7 This recommendation is in line with urban areas that support levels of high biodiversity as identified by The UN's Cities and Biodiversity Outlook (2012). The proportion of open space for these cities, as derived from the Trust for Public Land (2019) and the World Cities Culture Forum's World Culture Report (2018), was 28%. A 20-30% threshold of available habitat is recommended at the landscape level. 20% is based on a report synthesizing values from 27 papers reporting extinction or habitat fragmentation thresholds (ELI 2003). Twenty percent captures the threshold values reported in half of the studies. The recommendation of habitat coverage refers to the amount of habitat at the regional scale, which justifies the inclusion of adjacent open spaces in this calculation. This recommendation has additionally been corroborated through various recent studies (Estavillo et al. 2013; Rigueira et al. 2013; Banks-Leite et al. 2014)

8 From a review of 80 studies that reported minimum area requirements of 216 terrestrial species (Pe'er et al. 2014), 1 hectare (~2.47 acres) includes the minimum average area required for one third of species studied. All species contained in this group are birds or insects. As a caveat concerning this threshold, minimum area requirements were calculated using a variety of methods across studies, which to some extent limits their comparability across species and studies.

9 4.4 hectares (10.6 acres) is the patch size threshold where even urban-adapted species begin to decline rapidly (Beninde et al. 2015).

10 For regional biodiversity hubs, patches of >130 acres are recommended. This threshold represents the average patch size necessary to support area-sensitive or forest-interior species 53.3 hectares or 132 acres (Beninde et al. 2015).

11 Germaine (1995; 1998) recommends patches be no more than 0.5 km (0.31 miles) apart to conserve desert-specialist birds in Tucson, Arizona. In New Zealand, van Heezik et al. (2008) found a negative exponential relationship between native bird species richness in urban parks and the distance to the nearest 2 acre patch of remnant habitat, with an apparent threshold at 1 km (~0.5 mi).

Goal 2: Create ecological corridors that facilitate ecological movement, active mobility, urban cooling and stormwater resilience.

Strategy 1: Enhance channels as ecological corridors

The Sunnyvale East and West Channels that run through Moffett Park provide an opportunity to combine flood management needs with the enhancement of ecological and recreational corridors. The channels are currently minimally vegetated and have planted banks as narrow as 5 feet wide in many areas. Providing adequate building setbacks and space for native vegetation around the channels can help create riparian habitat that can serve many functions for Moffett Park, such as biodiversity support, regional connectivity for wildlife and people, urban heat island mitigation, and pollution and runoff management.

Even though riparian ecosystems generally occupy small proportions of the landscape, they are biodiversity hotspots for flora and fauna[12]. Riparian habitats also provide an array of essential ecological functions: stabilization of stream banks, erosion reduction, and modulation of water temperature, and provision of nutrients and organic matter for aquatic wildlife.

Recommendations:

- The more extensive the protection and restoration of riparian habitat, the better for ecology and ecosystem services. To provide the following functions, the following minimum thresholds for riparian widths (as measured from the top of the bank at each side) are recommended in the scientific literature[13]:
    - >80 ft (25 m) for pollutant removal
    - >100 ft (30 m) for temperature regulation and sediment removal
    - >160 ft (50 m) for bank stabilization.
- In general, a width of at least 330 feet (100 m) is considered optimal for creating quality riparian habitat for multiple species of wildlife, however, wider areas are needed to support some communities[14].

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12 Riparian zones in the western United States comprise <1% of the total land area, yet these areas are used by more breeding bird species than any other habitat combined (Knopf et al. 1988). Further, they are areas of unusually high plant diversity (Naiman et al. 1993). Riparian areas provide areas for shelter, breeding, nesting, and foraging for wildlife and serve as important movement corridors for birds and small mammals in developed landscapes (Hilty and Merenlender 2004).

13 Values are based on the recommendations of The Environmental Law Institute (2003) which are based on the synthesis of 156 studies of riparian and wetland terrestrial buffers.

14 In some regions, riparian areas over >1600 ft wide are needed to support all species in bird communities (*see* Fischer 2000; May 2003).

Channel Terrestrial Buffers. Scientifically-based, recommended buffer widths provide different essential functions for riparian areas: (a) 80 feet for pollutant removal, (b) 100 feet for temperature regulation and sediment removal, (c) 160 feet for biodiversity support and bank stabilization. A 330-foot buffer (not shown) is considered optimal for biodiversity.

- Narrower corridors can still be beneficial for wildlife, particularly for movement, however, value of this habitat diminishes as width decreases and a secondary threshold at 160 feet (50 m) appears to exist below which habitat suitability tends to decline sharply[15].
- Buffers can vary in width where needed, but should be continuous along the length of the feature.
- Implement a habitat overlay zone or offer transferable development rights for parcels along the channel to create terrestrial buffers.

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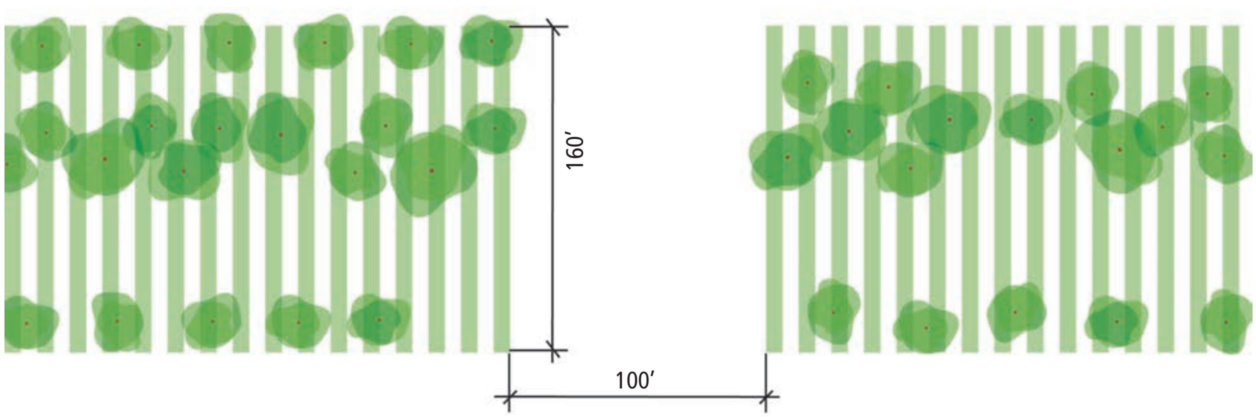
15 For example, many long-distance migratory birds will not nest in riparian areas less than 160 feet wide, and widths more than 330 feet supported more of these migrants than narrower areas (Fischer 2000).

Strategy 2: Connect existing and new patches with greenways

The East and West channels link Moffett Park's urban matrix to the Baylands. However, additional corridors are needed to create lateral connections and link proposed greenspaces across the district and city. Greenways enhance the movement of plants and wildlife and increase connectivity between habitat patches, improving each patch's ecological value and the biodiversity of the district as a whole. Wildlife are known to avoid crossing expanses of inhospitable terrain, particularly areas of low vegetation cover such as parking lots and wide roads (Tremblay and Clair 2011). Because surface parking lots and wide roads cover much (~33%) of Moffett Park, the current landscape is highly impermeable to wildlife and plant movement which makes establishing corridors a necessity. Greenways can also enhance pedestrian and bike mobility, providing safer and more beautiful ways of moving around the district. Planting strips and bioretention areas can be designed to separate bike lanes from vehicular and pedestrian traffic while supporting biodiversity functions.

The width and length of corridors, as well as their continuity determines their ecological benefit. Generally, the wider the corridor the more effective it is for increasing animal movement(Haddad 1999), and greater corridor widths tend to have greater diversity and abundance of mammals, birds, and insects (Lindenmayer and Franklin 2002). Few studies have tested minimum corridor widths, particularly in urban areas.

There are a number of opportunities for new greenway corridors in Moffett Park. Protected bike lanes along green streets can support continuous landscape and tree corridors. Private landscaping and streetscape improvements can be coordinated along multiple blocks to create broad, walkable promenades with improved mobility for people and nature. Along the northern margin, new open space with stormwater retention wetlands could be created adjacent to Caribbean Drive to form a valuable wildlife corridor providing movement and refuge from high water and sea level rise.



Urban Greenways. Linear vegetated corridors promote local movements and connect patches. Greenways should ideally be mostly vegetated, have a minimum 160 foot width and should be continuous, with gaps less than 100 feet wide.

Recommendations:

- Green corridors should ideally have a minimum width of 160 ft[16].
- Corridors >325 feet in width have the potential to support most wildlife and plant connectivity[17].
- Where space constraints limit the establishment of wider corridors, narrower corridors — such as continuous rows of street trees[18] and shrubs[19] — can also promote connectivity.
- Corridors should be designed to have the most direct route between habitat patches and as few gaps and barriers along their length as possible[20].
- Gaps in vegetation along green corridors should be no larger than 100 feet[21].
- Corridors with higher proportion of native species (White et al. 2005), higher diversity of plants (Murgui 2007), more vertical complexity[22] (Tzilkowski et al. 1986), and lower amounts of management (e.g., mowing; Mason et al. 2007) provide greater connectivity.
- Implement habitat overlay zoning, open space zoning, or offer transferable development rights to create corridors. Open space configuration and landscaping requirements can be added to promote connectivity across the landscape.

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16 (Mason, et al. 2007) found no forest-interior bird species in suburban greenways <50m (164 ft) wide.

17 This recommendation is based on a report synthesizing >40 studies on the effective width of riparian corridors that support plants and wildlife in different landscapes (ELI 2003).

18 Treed streets that connect parks have been found to increase the number of species present in those parks (Fernández-Juricic 2000; Fernández-Juricic and Jokimäki 2001).

19 Narrow (<20 feet) strips of shrubs have been found to provide connectivity for small mammals in agricultural lands (Silva and Prince 2008) and bird species in chaparral habitats (Soulé et al. 1988).

20 Gaps in vegetation and barriers, such as busy roads, tend to reduce the effectiveness of corridors.

21 In urban areas, birds were much less likely to move across 30 m (~100 foot) gaps in vegetation than 25 m (~80 foot) gaps (Tremblay and St. Clair 2009). Smaller gaps may be needed to ensure connectivity for other species. For example, bats may avoid crossing gaps of 10 m (32 ft; Entwistle 2001).

22 Vertical complexity refers to multilayered vegetation structure and includes layers of vegetation: groundcover, understory, midstory, and canopy.

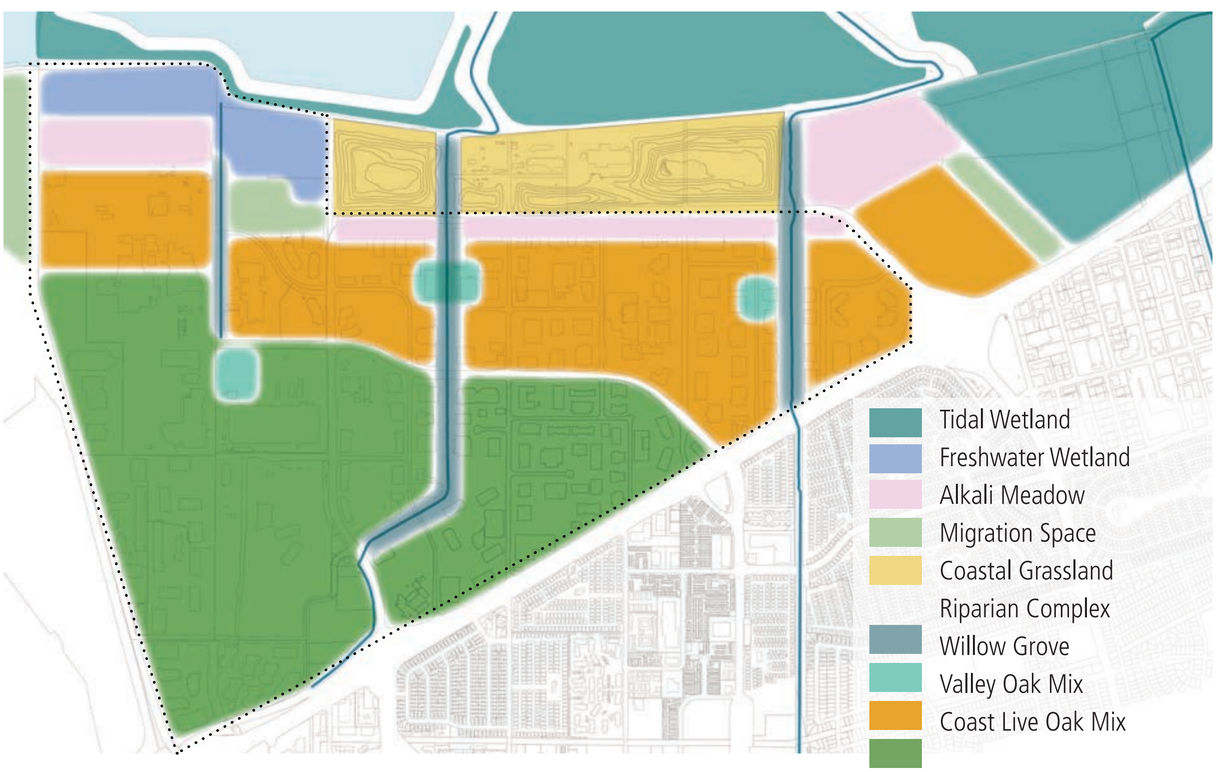
Goal 3: Incorporate nature throughout the urban matrix to deliver cooling, stormwater retention, and nature benefits.

Strategy 1: Restore native habitat types and create native habitat zones

Moffett Park's limited and predominantly non-native vegetation constitutes a hindrance to biodiversity. Several studies have shown that native vegetation patches in urban greenspaces support significantly more species richness and abundance across all taxa than non-native vegetation both at the regional (Threlfall et al. 2017) and site scale (Burghardt et al. 2009).

To increase habitat suitability in Moffett Park, ongoing greening efforts should give priority to native vegetation by incorporating a diverse native plant palette in all components of urban greenspaces, including habitat patches, connections, and matrix elements such as plazas, stormwater features, and street trees. The positive effect of native vegetation on urban biodiversity also applies to the vertical structure, from the understory vegetation to the tree canopy. Therefore, to have positive biodiversity impacts, representation of native vegetation in greenspaces' vertical complexity should also be taken into account. A number of recent development projects have demonstrated the potential of native landscaping to create attractive and drought-tolerant habitats.

Habitat Zones. Habitat types have been selected based on a combination of historical and contemporary data, and future projections, representing what species are most likely to succeed and support local ecology.



Historically, wet meadows of short flowering plants dominated the Moffett Park inland area, with patches of willow grove and tidal marshes occupying its shoreline. However, land development, including grading, soil compaction, fill, and some reduction of groundwater levels (from formerly artesian conditions) has profoundly altered the landscape, making it now more suitable for oak woodland habitats, valley oak groves, willow groves, riparian habitat, or freshwater marsh. At the district scale, new habitat zones representing the currently appropriate habitat types have been determined, based on a combination of historical, contemporary and future projections. These include: freshwater marsh & willows, riparian forest, valley oak woodlands, coast live oak woodlands, and other local native trees for biodiversity and aesthetics as appropriate. Because Moffett Park retains relatively high groundwater, it has the potential to support healthy and fast-growing communities of native trees of high ecological, cultural, and aesthetic value, such as arroyo willow, valley oak, Fremont cottonwood, white alder, box elder, and western sycamore.

At the parcel scale, planting efforts must consider individual species' habitat requirements for shade, water, soil, and aesthetic needs. For example, shade tolerant trees can be planted on the north and east side of tall buildings, while high water-demanding plants can be planted along riparian buffers and high-groundwater areas. Tree location and height must also be carefully considered to avoid conflict with infrastructure such as overhead and underground utilities.

Recommendations:

- Create plant assemblages drawn from local native ecosystems (see Appendix C):
    - Freshwater marsh
    - Alkali wet meadow
    - Wet meadow
    - Willow grove
    - Oak savanna
    - Oak woodland
- Prioritize site-appropriate native species. Select plant palettes with >80% native species.
- Create ecological memes. Mimic the complexity, structure, and composition of native habitat types, as well as transition between habitat types.
- Design a multi-layered landscape (groundcover, understory, midstory, and canopy) with an overlap of 2-3 native layers present for >75% of the habitat area.
- Introduce ecology zoning requirements which provide incentives for the use of native plants.

Bee and ceanothus (Photo courtesy of Shira Bezalel, SFEI)

Native landscaping (Photo courtesy of Shira Bezalel, SFEI)

Strategy 2: Increase canopy cover and native species in the urban forest

Higher canopy cover increases ecological benefits in urban areas. Increasing canopy cover has been found to be the most valuable action for conserving species (Hennings and Edge 2003). Canopy cover provides habitat for shelter, cover, foraging, and nesting. Tree-lined streets also help connect greenspaces for wildlife, improving the biodiversity support of the streetscape, greenspaces, and the district as a whole (Fernández-Juricic 2000; Fernández-Juricic and Jokimäki 2001).

Beyond providing habitat, urban trees have numerous benefits to cities, most of which are directly associated with the number of trees and percentage of tree canopy cover. Urban trees can provide immense economic benefits through provisioning services[23], such as reducing stormwater runoff by intercepting rainfall (Xiao et al. 1998), muffling traffic noise[24], removing pollutants and dirt from the air[25], improving both mental and physical health of residents (Kuo and Sullivan 2001), providing carbon sequestration, and reducing cooling costs through direct shading of buildings[26]. Increasing canopy cover can greatly improve the thermal comfort of outdoor spaces and reduce heat stress during extreme weather events and hot summer days, which are associated with health outcomes and active mobility.

Canopy Cover Recommendations:

- Higher tree cover tends to enable greater biodiversity support (Beninde et al. 2015). For local biodiversity support, a minimum of 25% canopy cover[27] is recommended based on the historic cover of Silicon Valley's oak woodlands[28] (Beller et al. 2010). However, levels of canopy cover will vary depending on the habitat type that is most appropriate for each site.

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23 In 2008, Sunnyvale's street trees provided more than $1 million dollars in annual net benefits (Bernhardt et al. 2014).

24 Strips of trees can reduce perceived loudness by as much as 50% (Dwyer et al. 1992).

25 Street trees can help remove ambient carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide and particulate matter. For example, Sacramento's urban forest removes ~1,400 tons of pollutants annually(Scott et al. 1998).

26 In Sunnyvale, shading of the western exposure of homes was estimated to reduce annual cooling needs through air conditioning by shading of the western exposure of homes was estimated to reduce annual cooling needs through air conditioning by 52% (Simpson and McPherson 1996).

27 For reference, as of 2007, Sunnyvale had a citywide canopy cover of 18%. In the City of Sunnyvale Urban Forest Management Plan, a citywide canopy cover target has been set at 20.5%(Bernhardt et al. 2014). This target was deemed achievable through new planting levels that could occur without changes to existing designs. A redesign of Moffett Park and changes to impervious surface and landscaping requirements can make higher levels of canopy cover attainable.

28 For extensive recommendations on approaches to re-oaking in communities in South San Francisco Bay, *see* SFEI-ASC (2017).

- Canopy cover targets should be implemented at the block-scale, when possible, because this is the spatial scale shown to have the greatest impact on conserving biodiversity (Chong et al. 2019).
- Achieving ≥40% canopy cover across the district[29] and ≥42% canopy cover within parks[30] is recommended for heat island mitigation.
- Establishing continuous canopy cover along walkways and bike corridors can promote active mobility in the summer and reduce heat stress during extreme heat events.
- Preserving larger trees should be done where conditions allow[31].
- Redesign of streets and public right-of-ways should maximize planting strips and medians, tree wells, and building setbacks to ensure adequate growspaces for trees.
- Creating policy incentives for private tree plantings and establishing codes for minimum open space requirements can help achieve canopy cover goals through participation of private landholders.

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29 Ziter et al.(2019) observed a threshold in the cooling effect of tree canopy cover. Blocks with ≥40% tree canopy cover reported substantially lower air temperatures.

30 Parks with high tree cover have the largest cooling intensity (Cao et al. 2010). Parks with less than 42% of canopy cover showed insignificant reductions in day-time urban heat island intensity (Lin et al. 2017).

31 Larger trees provide greater benefits for biodiversity conservation (Murgui 2007) and for humans. For example, a single large tree with a crown 70 feet in diameter provides as much canopy cover as forty six 10-foot-diameter trees (Bernhardt et al. 2014).

California sycamore (Photo courtesy of Milheco, CC by SA)

- Hardscaped open spaces with ground-level vegetation restrictions should prioritize native tree canopy cover to better support biodiversity and provide shade.
- Implement performance zoning requirements for tree density standards on private developments. For model municipal code, see Portland, Oregon's Tree Code[32].
- Require permits for removal of large diameter trees and reduction of disturbance to trees both above and below ground during development. For model municipal code, see Toronto, Ontario's Tree Protection Zone standards[33].

Species Composition Recommendations:

- Trees selected for new plantings should be chosen from locally-adapted, site-appropriate, native species. Planting native trees that are adapted to local environmental and climate conditions provides better support to native wildlife[34] and greater economic benefits[35].

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32 Portland, Oregon, Municipal Code Title 11, 2015 (http://www.portlandoregon.gov/bps/article/331401)

33 Toronto Department of Parks, Forestry & Recreation, Tree Protection Policy And Specifications For Construction Near Trees 2-3, 2013

34 Native vegetation can support a greater abundance and diversity of native wildlife(Burghardt et al. 2009; Goddard et al. 2010; Raupp et al. 2010).

35 Economic benefits occur through lower maintenance, irrigation, and replacement costs as native trees are more suited for local conditions and disturbances when they occur (e.g., fire, drought, pests, and extreme temperatures; Kawecki and Ebert 2004; Meineke et al. 2013).

Coast live oak street trees (Photo courtesy of Shira Bezalel, SFEI)

- Native trees should be planted as a default, with recommended tree composition of 100% native species[36]. Tree canopy should minimally be composed of 80% native species[37].
- Selected tree species should match native habitat zones (see Goal 3, Strategy 1 and Appendix C) and site-specific conditions (shading, water availability, aesthetic requirements, and appropriate branching structure).
- Link stormwater basins and landscaping along Caribbean Drive and the Lockheed wetlands to create ecological connectivity and flood resilience along the Baylands.

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36 Currently, only 2.3% of street trees in Moffett Park are native. Increased proportion of native species will need to be achieved through new plantings, and strategic replantings of existing trees.

37 Eighty percent composition is inline with recommendations of the City of Sunnyvale's Urban Forest Management Plan (Bernhardt et al. 2014) and with biodiversity thresholds. For example, a >70% native plant cover threshold was found to be related to greater reproductive success in birds(Narango et al. 2018). Also, steep increases in native biodiversity (i.e., bats, birds, bees, beetles and bugs) have been found to occur from 30% and continuing steady increases to 60%, with likely continuing increases at higher percentages (Threlfall et al. 2017).


Blue elderberry (Photo courtesy of Franz Xaver, CC by 2.0)

Strategy 3: Design stormwater features to function ecologically

If designed properly, smaller constructed habitats (e.g., bioswales[38], bioretention basins[39], greenroofs, and rain gardens) can help manage stormwater – through minimization of runoff and removal of pollutants – and benefit biodiversity[40]. Green infrastructure can enhance local ecology by using native plant species and including multiple layers of vegetation (i.e. shrubs and trees in addition to low groundcover). Where not limited by hydrologic or water quality concerns, bioretention features without liners can have greater ability to support natural vegetation, particularly in Moffett Park, where naturally high water tables have the potential to support high-value trees such as willows, cottonwoods, and valley oaks. Bioretention basins can be combined with restoration to re-create locally rare habitat types, such as willow thickets, wildflower meadow patches, and wetlands. Municipal green infrastructure plans can be one method for encouraging the creation of these features across the district, which will soften the urban landscape by providing stepping-stone habitat for insects and wildlife.

Recommendations:

- When possible, include trees in bioretention areas to increase evapotranspiration during the rainy season and shade in the summer.
- Select local native plant palettes from:
    - Alkali wet meadow and wet meadow species for tree-less bioretention areas.
    - Riparian plant species for bioretention areas suitable for trees.
    - Freshwater marsh and willow groves for larger features, such as detention and retention basins.
- Maximize width (>6 feet) of linear bioretention features to ensure gradual slopes, increase soil volume, and support trees where possible.
- Incentivize the creation of ecological stormwater bioretention features by having these features count more towards open space requirements (e.g., through an area multiplier), or through tax credits to be applied towards the reduction of stormwater utility fees.

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38 Bioswales are landscaped, shallow, gently sloping, linear depressions or channels in the ground used to direct, slow, and promote infiltration of groundwater.

39 Bioretention basins are similar to bioswales, however, they are shallow landscaped basins that allow for temporary ponding areas.

40 Built green infrastructure is known to support a variety of insects and birds (Oberndorfer et al. 2007).

Strategy 4: Create on-structure greening

The ecological footprint of the district can be extended vertically through on-structure greening. Greenwalls, greenroofs, and terraces can provide additional space for native plants, pollinators, and birds (Oberndorfer et al. 2007; Chiquet et al. 2013). On-structure greening elements can also help reduce stormwater runoff and improve building energy performance. Green roofs are more effective on lower-profile buildings where they are more easily accessible to plant and animal species and can enhance the ecological value of ground-level interventions (Maclvor 2016). Improved tax incentives and permit expediting can help encourage installation of on-structure greening.

Recommendations:

- Prioritize ground-level habitat creation.
- Prioritize green roofs on lower-profile buildings.
- Design on-structure features in coordination with ground-level habitat to increase their effective size and connectivity.
- Add green balconies or terraces to the lower building levels to create ecological ladders that lead to green roofs that are at higher levels.
- Select native flowering species to create pollinator habitat on extensive green roof systems.
- Incorporate native trees on intensive green roofs to improve thermal comfort, stormwater runoff reduction, and habitat provision.

Green wall (Photo courtesy of Mark Hogan, CC by SA)

- Prioritize the addition of greenwalls along narrow streets to reduce air pollution.[41]
- Implement incentives for on-structure greening. Incentives could be implemented through building density bonuses (aka, floor area ratio bonuses), tax credits to be applied towards the reduction of stormwater fees, or allowing built green features to meet open space requirements.

Strategy 5: Use wildlife-friendly building and lighting designs

Building codes and guidelines can be implemented to incentivize the adoption of wildlife friendly design practices. For example, building collisions are a major source of mortality for birds[42]. Recently developed materials (e.g., ultra-violet window coatings) and simple design considerations (e.g., etched glass and window panel angles) can make building windows safer for birds. Bird-safe window design has been recently incorporated in the building codes of many cities, such as San Jose, New York City, Minneapolis, San Francisco and Oakland.

Light pollution can cause barriers for urban bats during their foraging bouts and can disorient nocturnal species and migrating birds (Longcore and Rich 2004; Hale et al. 2015). Design consideration can also be taken to minimize the amount of light pollution from street and building lights, adoption of which can also be incentivized through building codes and guidelines.

Recommendations:

- Require bird-safe window glazing techniques and facades on new and upgraded buildings.
- Shield street lights.
- Prohibit flood lighting and vehicle-rated light fixtures in open spaces.
- Ban uplighting near ecologically sensitive areas.
- Dim or turn off unnecessary lights at night, or use green/blue night lighting which is less likely to disorient migrating and foraging animals (Ogden 1996; Poot et al. 2008).

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41 Greenwalls can reduce street-level NO2 and PM10 levels by as much as 40% and 60% respectively (Pugh et al. 2012).

42 Nationally, between 365 and 988 million birds are estimated to be killed by building strikes each year (Loss et al. 2014).

Flax and California poppies (Photo courtesy of Shira Bezalel, SFEI)

VI. CONCLUSION

Moffett Park has the potential to set a precedent for the ecologically-friendly redevelopment of office parks. By integrating nature throughout the urban landscape, Moffett Park can become a truly liveable district for people, native plants, and animals. Building ecologically complex and biodiverse spaces will provide a multitude of benefits for the people that live and work in Moffett Park. Biodiverse spaces will improve outdoor thermal comfort; promote active mobility; reduce stormwater runoff, pollution and noise sequester carbon; and lower cooling costs through direct shading of buildings. Improving people's everyday access and contact with nature can also confer a variety of physical and psychological health benefits.

Innovative use of regulatory and incentive structures can encourage the integration of nature and ecology throughout the district. Property owners in Moffett Park have already shown interest in ecological master planning that can be integrated into a coordinated strategy to address problems that are multifaceted and require a holistic and collaborative effort. Following the example that Moffett Park sets, office parks across the Bay Area can together transform the landscape into one that is vastly more habitable for people and native wildlife as they redevelop.

VII. APPENDIX

Appendix A: Site Analysis

Patch size

Green spaces depicted in the patch size map primarily comprise areas mapped in the California Protected Area Database (CPAD), which represents lands protected for open space purposes by public agencies or non-profits (CPAD 2017). Privately held green spaces, such as the Lockheed Martin wetlands and landscaped areas on corporate campuses, were manually mapped based on aerial imagery. In some cases, adjacent parcels were merged so that parks bordering one another were considered a single habitat patch.

Connections

The connections map relied on Bay Area Aquatic Resources Inventory (BAARI), version 2.1 2017 (SFEI). Waterways were classified as underground or above-ground based on BAARI data. Waterways within BAARI classifications "fluvial channel", "fluvial ditch", and "fluvial engineered channel" were categorized as above-ground, while "fluvial subsurface drainages" were categorized as underground. Points were manually added to the map in locations where waterways pass through culverts, under bridges, or past other man-made obstructions.

Matrix quality

The matrix quality map displays fine-scale canopy cover data from Earthdefine's SpatialCover Tree Canopy data set (2013). EarthDefine describes the data set as "derived from LIDAR (Light Detection and Ranging) data where available. The LIDAR data is typically used along with 1 meter or better resolution, 4 band color infrared imagery that is flown as part of the National Agriculture Imagery Program (NAIP) or other imagery available through a state orthoimagery acquisition project. NAIP data is used as the primary data source in areas where there is no usable LIDAR. This product provides a cost-effective solution where tree canopy is the primary land cover class of interest for your application."

Habitat diversity

The habitat diversity map depicts the historical ecology of the Moffett Park area, based on a combination of mapping efforts from multiple San Francisco Estuary Institute historical ecology reports (Grossinger et al. 2006, Grossinger et al. 2008, Beller et al. 2010). Some habitat types were grouped for simplicity. For example, "Alkali meadow" includes high and low concentration alkali meadow types; "Shallow Water" includes shallow bay and shallow tidal channel; "Tidal flat" includes tidal flat / channel and tidal marsh panne.

Native vegetation

The map of native vegetation is based on Sunnyvale's street tree inventory data and riparian stream surveys from SCVWD (AIS 2010).

Street tree inventory data

Sunnyvale's street tree inventory includes species, diameter, height, and other data for municipally owned and managed trees, but excludes all privately owned trees. Therefore, the inventory does not fully represent the population of trees in the urban landscape and underestimates the overall tree density in the area. Vacant sites and incomplete records were excised from the dataset.

Identifying native trees. Trees were considered native if they were historically native to the Santa Clara Valley floor. Note that because the emphasis was on trees native to the valley floor, this list does not include other common street trees native to the region at a higher elevation or in a moister climate, such as Sequoia sempervirens, or trees native likely to other parts of California, such as Cercis occidentalis. Native trees were identified using a variety of sources, including Terrestrial Vegetation of California (Barbour et al. 2007); the Holland Classifications from the Manual of California Vegetation (Sawyer et al. 2009); historical ecology data (Grossinger et al. 2006, Grossinger et al. 2008, Beller et al. 2010); The Distribution of Forest Trees in California (Griffin and Critchfield 1972); CalFlora (https://www. calflora.org/); and the California Native Plant Society's CalScape tool (https:// calscape.org/).

Classified as native: Acer macrophyllum, Acer negundo, Aesculus californica, Alnus rhombifolia, Heteromeles arbutifolia, Platanus racemosa, Populus fremontii, Prunus ilicifolia, Quercus agrifolia, Quercus douglasii, Quercus kelloggii, Quercus lobata, Sambucus caerulea, Sambucus mexicana, and Umbellularia californica.

Riparian stream surveys.

Vegetation types from SCVWD were classified into native and non-native classes. All built and water classifications were excluded from the analysis, including built/urban, channels, reservoirs, rivers and streambeds, and roads. Vegetation was classified as follows:

Classified as native: Acer negundo, Aesculus californica, Alnus rhombifolia, Areas of Little or No Vegetation Group, Arid Freshwater Emergent Marsh Group (Marsh vegetation), Artemisia californica, Baccharis pilularis, Bulrush - Cattail mapping unit, California Perennial & Annual Grasslands Mapping

Unit Group (Native component), Chord Grass, Fresh or brackish Bulrush spp. mapping unit, Juglans hindsii Semi-Natural Stands, Platanus racemosa, Populus fremontii, Quercus agrifolia, Quercus lobata, Salicornia - Salt Grass - Jaumea, Salix exigua, Salix laevigata, Sambucus nigra (lumped with Mexican elderberry), Serpentine Component Mapping Unit, Southwestern North American Riparian Evergreen & Deciduous Woodlands Group.

Classified as non-native: Arundo donax, Conium-Foeniculum patches, Eucalyptus, Exotic Trees (Canopy Height <2 Meters), Exotic Trees (Canopy Height >15 Meters), Exotic Trees, (Canopy Height 2-15 Meters), Lepidium latifolium, Mediterranean California Naturalized Annual & Perennial Grassland Group (Weedy grasslands with no native component - Ruderal), Orchards, Rubus discolor, Sequoia sempervirens

Special resources

The map of special resources was based on street tree inventories (used to identify large trees) and the Bay Area Aquatic Resources Inventory (used to identify the locations and sizes of wetlands and streams [BAARI version 2.1, SFEI 2017]). Trees were designated as "large" if they exceeded 32 inches in diameter. See the Native Vegetation section for a description on native/non-native designations. BAARI wetlands include tidal wetlands, salt ponds, freshwater marshes, creeks, and other wetland habitat types.

Other basemaps

Other spatial data included throughout this report include parcel boundaries from Santa Clara County (2019), the Sunnyvale city boundary from the Metropolitan Transportation Commission (2014), TIGER/Line shapefile roads courtesy of the US Census Bureau (2016), and aerial world imagery from Esri (Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community 2020).

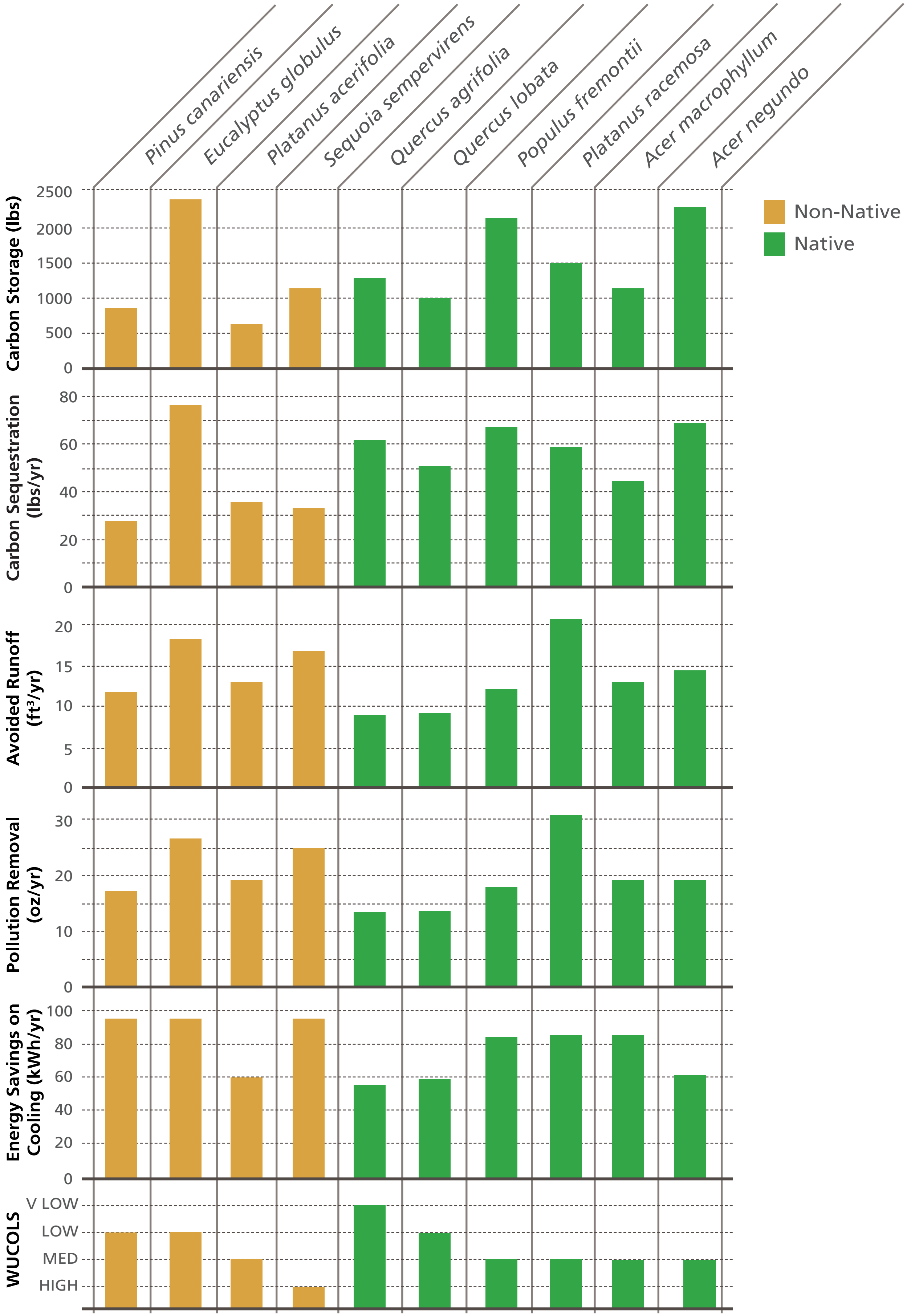
Appendix B: Street Tree Species

Trees along urban and suburban streets provide various benefits to people. Their canopies trap rainfall and help slow urban runoff, and their shade provides shelter from urban heat. They remove pollutants from the air through direct deposition on and uptake through their leaves, and sequester and store carbon dioxide to help regulate the global climate (Silvera Seamans 2013). Different tree species provide these services to differing degrees and require differing amounts of inputs (e.g. water, light, and soil nutrients) to do so. The following charts are intended to inform future tree planting efforts in Moffett Park by comparing the degrees to which ten tree species provide these ecosystem services and the species' respective water requirements. The four non-native species included are the most common trees currently growing along Moffett Park's streets, while the six native species included were common in Silicon Valley's oak and riparian woodland ecosystems historically (Beller et al. 2010).

To quantify ecosystem services for these species, this analysis used allometric equations from the US Forest Service's Urban Tree Database (McPherson et al. 2016) in combination with iTree Eco v6.x86. The Urban Tree Database provides species-specific allometric equations that relate tree age to diameter at breast height (DBH), and DBH to tree height and canopy diameter. Equations are available for the twenty most common trees growing at sixteen study sites in urban environments across the United States. The allometric equations used in this analysis come from the Forest Service's study site in Berkeley, CA, where available. Where equations were not available from Berkeley, those from the nearest available study site to Sunnyvale were used. This analysis used tree diameter and height at age 25 as inputs for iTree Eco. For iTree Eco to calculate the cooling benefits of trees, all trees were assumed to be twelve feet to the west of the nearest building. Charts on the following page display the iTree Eco outputs for carbon storage, carbon sequestration, avoided runoff, pollution removal, and energy savings on cooling.

The Water Use Classification of Landscape Species (WUCOLS IV) system classifies landscaping tree species based on their water requirements. WUCOLS classifications vary depending on where a tree is growing in California. The final chart on the following page reports WUCOLS values for each species, assuming they are growing in Sunnyvale.

It is important to note that the ecosystem services reported here are not the only factor to consider when planting trees for landscaping. Certain trees excel at providing these ecosystem services but can be detrimental landscaping trees for other reasons. Eucalyptus globulus, for example, sequesters relatively large amounts of carbon, yet the trees constitute major fire hazards and their leaf and bark litter have allelopathic effects that prevent understory plant growth (Agee et al. 1973; May and Ash 1990). For these reasons, Eucalyptus is inadvisable for future plantings and should be replaced with the native species shown on the following page.



Pinus canariensis
Eucalyptus globulus
Platanus acerifolia
Sequoia sempervirens
Quercus agrifolia
Quercus lobata
Populus fremontii
Platanus racemosa
Acer macrophyllum
Acer negundo
Non-Native
Native
Carbon Storage (lbs)
2500
2000
1500
1000
500
0
Carbon Sequestration (lbs/yr)
80
60
40
20
0
Avoided Runoff (ft³/yr)
20
15
10
5
0
Pollution Removal (oz/yr)
30
20
10
0
Energy Savings on Cooling (kWh/yr)
100
80
60
40
20
0
WUCOLS
V LOW
LOW
MED
HIGH

Appendix C: Plant Palettes

ALKALI WET MEADOW		
Trees	*Salix laevigata*	Red willow
	Salix lasiolepis	Arroyo willow
Shrubs/ Small trees	*Baccharis pilularis*	Coyote bush
	Frankenia salina	Alkali heath
	Limonium californicum	Marsh rosemary
	Bacharris douglasii	Marsh baccaris
Herbaceous understory	*Distichilis spicata*	Salt grass
	Hordeum depressum	Alkali barley
	Jaumea carnosa	Jaumea
	Limonium californicum	Marsh rosemary

WET MEADOW/BIOSWALE		
Trees	*Acer macrophylum*	Bigleaf maple
	Salix laevigata	Red willow
	Acer negundo	Boxelder maple
	Alnus rhombifolia	White alder
	Platanus racemosa	California sycamore
	Populus fremontii	Fremont cottonwood
Shrubs/ Small trees	*Baccharis pilularis*	Coyote bush
	Morella californica	Pacific wax myrtle
	Sambucus nigra ssp. caerulea	Blue elderberry
	Baccharis salicifolia	Mulefat
	Cornus sericea	Redosier dogwood
Herbaceous understory	*Agrostis pallens*	Diego bent grass
	Deschampsia cespitosa ssp. holciformis	Pacific hairgrass
	Elymus triticoides	Beardless wildrye
	Festuca rubra	Red fescue
	Leymus triticoides	Creeping wildrye
	Juncus patens	Common rush
	Danthonia californica	California oatgrass
	Asclepias fascicularis	Narrowleaf milkweed

RIPARIAN COMPLEX, WILLOW GROVE				
	A. Riparian Complex		**B. Willow Grove**	
Trees	*Acer macrophylum*	Bigleaf maple	See A.	
	Acer negundo	Boxelder maple		
	Alnus rhombifolia	White alder		
	Platanus racemosa	California sycamore		
	Populus fremontii	Fremont cottonwood		
	*Salix laevigata**	Red willow*		
	*Salix lasiolepis**	Arroyo willow*		
Shrubs/ Small trees	*Sambucus nigra ssp. caerulea*	Blue elderberry	*Sambucus nigra ssp. caerulea*	Blue elderberry
	Cornus sericea	Red osier dogwood	*Cornus sericea*	Red osier dogwood
	Vitis californica	California grape	*Vitis californica*	California grape
	Rosa californica	California rose	*Rosa californica*	California rose
	Symphoricarpos albus	Common snowberry	*Baccharis pilularis*	Coyote bush
	Corylus cornata var. californica	Hazelnut	*Solanum umbelliferum*	Blue witch
Herbaceous understory	*Rubus ursinus*	California blackberry	*Rubus ursinus*	California blackberry
	Juncus patens	Common rush	*Juncus patens*	Common rush
	Cyperus eragrostis	Tall flatsedge	*Artemesia douglaiana*	Mugwort
	Clematis ligusticfolia	Virgin's Bower	*Baccharis salicifolia*	Mulefat
	Mimulus guttatus	Seep monkeyflower		

* Dominant tree species in willow grove

COASTAL GRASSLAND		
Shrubs/ Small trees	*Eriogonum fasciculatum*	California buckwheat
	Salvia sonomensis	Sonoma sage
	Trichostema lanatum	Wooly blue curls
	Lupinus albifrons	Silver bush lupine
Herbaceous understory	*Deschampsia caespitosa*	Hairgrass
	Festuca rubra	Red fescue
	Elymus triticoides	Creeping wildrye
	Sisyrinchium bellum	Blue eyed grass
	Stipa pulchra	Purple needlegrass
	Eschscholzia californica	California poppy

COAST LIVE OAK MIX, VALLEY OAK MIX		
Trees	*Quercus lobata**	Valley oak*
	*Quercus agrifolia***	Coast live oak**
	Aesculus californica	California buckeye
	Quercus kelloggii	California black oak
	*Umbellularia californica****	Bay laurel***
Shrubs/ Small trees	*Corylus cornata ssp. californica*****	Hazelnut****
	Heteromeles arbutifolia	Toyon
	Mimulus aurantiacus	Sticky monkeyflower
	Symphoricarpos albus	Common snowberry
	Frangula claifornica	Coffeeberry
	Lupinus albifrons	Silver lupine
	Artemesia californica	California sage
Herbaceous understory	*Stipa pulchra*	Purple needle grass
	Elymus glaucus	Blue wild rye
	Eschscholzia californica	California poppy
	Sisyrinchium bellum	Blue-eyed grass
	Nemophila menziesii	Baby blue eyes
	Lupinus bicolor	Minature lupine
	Clarkia purpurea	Purple clarkia
	Archillea millefolium	Yarrow
	Symphyotrichum chilense	California aster

* Dominant tree species in Valley oak mix

** Dominant tree species in Coast live oak mix

*** Do not plant within 50 ft of oak as precaution for Sudden Oak Death.

**** Plant upslope of immediate riparian area.

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