LEBEES

POLLINATOR CONSERVATION AND SERVICES IN THE SAN JOAQUIN DELTA

senior capstone project, 2018
beverly yee

LEBEES

Pollinator Conservation and Services in the San Joaquin Delta

by Beverly Yee

Submited in partial satisfaction of the requirements for the degree of

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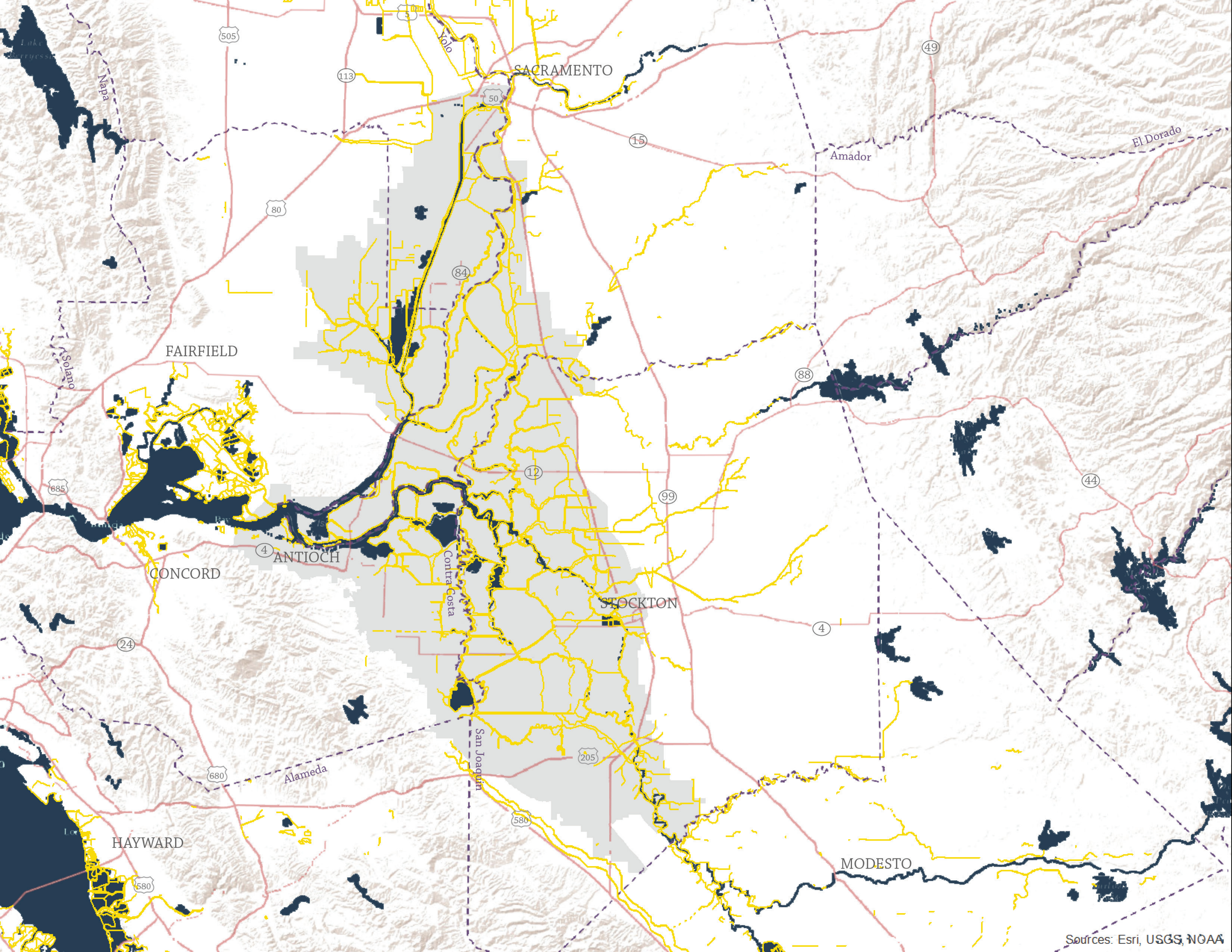
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Sources: Esri, USGS, NOAA

ABSTRACT

The reclamation of land in the San Joaquin Delta brought about drmatic change to people, wildlife and the landscape. What was once acres of habitat for wild bees are now acres of monoculture crop, producing a variety of products for consumption. Many farmers once depended upon free pollination services from wild bees. Now they spend thousands of dollars renting European honeybee hives. With the rise of colony collapse disorder (CCD) threatening entire honeybee colonies, the cost of pollination services will only continue to increase.

This project aims to apply reconciliation ecology upon the existing levee system in the San Joaquin Delta to not only benefit and conserve for wild bees, but to help mitigate agricultural reliance upon managed honeybee hives. By establishing a network of pollinator patches, the design allows wild bees to effectively move and adapt as the agricultural matrix changes. The pollinator patch concept works well in benefiting both farmers and wild bees through utilizing barren land, as well as turning it into a home, a service provider, and an aesthetic break in the agricultural matrix.

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INTRODUCTION

The San Joaquin Delta is unique due to its economic, environmental, historic and cultural significance. Located in Northern California, it is one of the largest inland estuaries in the United States. In 1861, the Board of Reclamation reclaimed land in the Delta for agriculture, and established an extensive levee system to keep the wetland waters at bay. The soil in the Delta consists of peat, an organic material that is considered prime farming soil due to the nutrients. Today, the San Joaquin Delta holds roughly $800 billion in crop value with categories such as deciduous fruits and nuts, field crop, grain and hay, pasture, truck and nursery crops, and vineyard ("Economic Sustainability Plan For the Sacramento-San Joaquin Delta" 2012). Because of the many years of farming on peat soils, the Delta continuously undergoes subsidence. Subsidence is irreversible, and the continuous sinking of Delta land has and will continue to place many areas in the Delta under sea level; many of which are now ten plus feet below the sea level. The ongoing subsidence makes the levee system a permanent necessity in this landscape ("Economic Sustainability Plan For the Sacramento-San Joaquin Delta" 2012).

California alone produces roughly a third of the country's vegetables and two thirds of the country's fruits and nuts, making crop pollination an essential ecosystem service. In 2010, 423,727 acres of cropland was reported in the Sacramento San Joaquin Delta making agriculture the highest form of employment in the area ("Economic Sustainability Plan for the Sacramento-San Joaquin Delta" 2012). Yet the intensive agricultural matrix makes it unsuitable for native bee survival due. Habitat fragmentation, habitat loss and a host of other threats from commercial farming such as pesticides, herbicide, and lack of year round resources threaten native bee ability to flourish in this landscape. Farmers instead, rely upon colonies of managed European honeybees that are imported to their fields to pollinate crops. It is estimated that pollination service is valued at $217 billion globally and $20 billion in the US (Frankie et al. 2014).

How did the honeybee industry grow? In the 17th century, the European honeybee arrived in North America through the assistance of many Europeans fleeing their homes. By 19th century technological advances made it possible to commercially rear the European honeybee, *Apis millifera* for commercial pollination (Horn 2008). Over the years however, the lack of genetic diversity and diseases has subjected European honeybee hives worldwide to colony collapse disorder(CCD). The alarming rate of colony decline and the dependence on honey bees for food production is now a pressing issue for all.

This project identifies two problems and proposes a solution to help ensure pollination security in the San Joaquin Delta. First, the reliance upon farmed European honeybees to pollinate crops. Secondly the decline of native bees in California mainly due to habitat fragmentation and habitat loss. Before, crops were sufficiently pollinated through native bees. Since CCD only affects honey bees in managed hives (Frankie et al. 2014), it is logical to look into how native bees can be reintroduced into the agricultural landscape matrix. The proposed solution is to simply increase native bee populations within the agricultural matrix. Increased native bee populations will ideally help subsidize the pollination services provided by commercial honeybees. With a continuous population of native bees in the area, farmers are guaranteed services and could potentially spend less on renting honeybee hives.

Several research questions are asked to focus the direction of the project:

How can native bee habitat be restored in the San Joaquin Delta to be mutually beneficial to farmers?

What space is available within the agricultural landscape matrix for bee conservation?

This project looks at the existing levee system as an opportunity to create viable habitat for native bees. It aims to use the sloped levee edges proximity to crop fields as a medium to provide pollination services to augment the cost of renting managed honeybees for farmers. The existing levee system is typically stripped of all vegetation, taking away potential habitat, and creating an eye sore in the very structured yet comforting agricultural landscape. The importance of using the existing levee system is its current non-economic value in agriculture and its proximity to the crops. By placing nesting resources in closer proximity to the crops, farmers will also benefit through bee visitation.

NATIVE BEES

Understanding native bee needs, life history and behavior is integral to creating a successful conservation plan. There are over twenty thousand different species of bees in the world, the honeybee being the most well-known, then bumble bees and other solitary bees (Wilson-Rich, 2014). Originally descended from wasps, bees turned from their carnivorous ancestors to feed on pollen and nectar. Their choice of food is vital to the pollination of not only crops but much of the world's plants (Rich, 2014). North America is home to roughly 4,000 different bee species with 1,600 of them native to California. Today, bees hold agricultural, economic and scientific importance.

WHAT'S IT LIKE TO BEE?

Different types of social behavior among different species dictate their way of life. It is believed that bees have four overlapping seasons in which they collect pollen, build nests, and reproduce (Frankie et. al, 2014).

SOLITARY BEES

Univoltine bees have short lifespans and produce a new generation every year. Males emerge first either in early spring or in summer depending on whether they are early-spring-to-summer or summer-to-autumn univoltine bees. The females emerge shortly after the males and immediately begin preparing for mating. Univoltine female bees only have a few weeks to live. They mate, gather pollen to build up their ovaries, and then dig and forage for materials to build a nest. At the end of the season, the adults die leaving behind a pollen ball for the eggs in the nesting chamber. By early summer or autumn, larva emerge and consume the last of the food left from their parents. Once this is complete, they move into the pupa stage. This is where the three adult parts are beginning to become distinguishable. The new generation remains inside the chamber until the beginning of season starts again. Some bees are multivoltine meaning they have more than two generations per year. Most solitary bees fall under either univoltine or multivoltine (Frankie et al. 2014).

SOCIAL BEES

Honey bees, bumble bees and some sweat bees on the other hand are social bees meaning their individual life is a part of a larger picture, the colony. Bumble bee colonies are often annual, meaning they remain active throughout the year and die off at the end of the year (Frankie et al. 2014). Few bumble bee colonies live for more than a year. Queens emerge in spring and are tasked to find a suitable nesting site. When found, she secretes wax to form a thimble-shaped honey pot (Frankie et al. 2014). She then fills the pot and collects pollen to form a lump where she will lay eggs on top of and covers them with wax (Frankie et al. 2014). Female workers are first to emerge. They spend their life constructing the nest and foraging. This allows the queen to focus on reproduction. Near the end of the first year, males and new queen bees are born (Frankie et al. 2014). The new queen bees mate immediately, feed and enter into hibernation. At the end of the year, the old queen, males and worker bees die off and the cycle begins all over again the next spring (Frankie et al. 2014).

BEE SENSES

Bees see the world differently than people do. While people see more yellows and reds, bees tend to see more blues and purples. This is because bees can see ultraviolet light (Rich, 2014). Communication between one another occurs through physical vibrations from body to body. These vibrations are received through receptors from hair on the body as well as the antennae. This form of communication is referred to as "dancing" and is associated with social bees that live in a colony (Rich, 2014).

BEES NEEDS

The attraction and flourishing of bee populations comes down to two main factors: nesting and floral resources.

The pollen and nectar from flowers serve as the main dietary needs of bees. It is important that there not only be an abundance of flowers, but also a diverse amount of flowers. This is because bee abundance and species richness has been seen to be positively associated with diverse floral resources (Black et al. 2009, Kremen et al. 2007). Because of the diverse morphology of bees, the flowers available should be able to cover and create a wider array of foraging niches. In doing so, a larger diversity of bees are able to inhabit the area.

Providing nesting habitat is integral in establishing wild native bees to promote their persistence in the landscape (Black et al. 2009, Kremen et al. 2002). Many species of solitary bees will not stay or even return to an patch if nesting resources are unavailable. Roughly 70% of the 4,000 native bees in North America are ground nesting bees that require direct access to soil surface for their nests (Black et al. 2009). These beesprefer poor quality sandy or loamy soils over rich soils. Other species are wood nesters and prefer to nest in abandoned beetle tunnels, in logs stumps and snags (Black et al. 2009). Among the many species in North America, bumble bees are the only ones that are considered social, meaning they live among other bumble bees similar to honey bee colonies. They prefer to nest in small cavities such as abandoned rodent nests, under grass, hollow stems etc. "Leaving patches of rough undisturbed grass in which rodents can nest will create future nest sites for bumble bees" (Black et al. 2009, 13).

Figure 1 |Variety of bee nesting materials

Figure 2 | Field with variety of floral resource

Figure 3 | Ground nesting bee

Figure 4 | Apidae bee collecting pollen

Figure 5 | Halictidae bee collecting pollen

Figure 6 | Alfalfa leafcutting bee

FORAGING

Once a bee settles down and builds a nest, they are fixed in the location for all other activities (collection of food, transport, reproduction). This means that "The foraging distance of a bee limits its capacity to move between nesting and foraging habitat" (Black et al. 2009, 14), making it a key component to determine whether or not certain areas in the landscape will receive pollination services. Crop fields farther away from nesting will contribute less resource compared to those nearby (Londsorf et al. 2009) simply because they are outside the maximum range of a bees foraging distance. Scientific studies and literature shows that the general foraging range for solitary bees range from 150-600 meters (Greenleaf et al. 2007). Bumble bees on the other hand have a larger range, between 800-1000 meters (Greenleaf et al. 2007). Investigation of proximity relationships between nesting and forage sites showed that there is a significantly higher chance that a nesting site would be inhabited if there are foraging resources within 150 meters from the site (Black et al. 2009).

CALIFORNIA NATIVE BEE FAMILIES

ANDRENIDAE

APIDAE

COLLETIDAE

HALICTIDAE

MEGACHILIDAE

ANDRENIDAE

This is a large family of bees with short tongues that receive their common name from their preferred nesting type simple soil burrows. They are found in temperate, arid and warm climates and are among the first bees to emerge and visit flowers in the spring (Wilson-Rich 2014, Frankie et al.2014)

APIDAE

The Apidae family is large and contains a very diverse group of bees. These long tongued bees range from solitary to eusocial and even some that are parasitic such as cuckoo bees that invade other bees nests (Wilson-Rich 2014, Frankie et al. 2014). The well known honey bee as well as all bumble bees fall in this family. Honey bees are originally from Europe, and was brought over to North America for managed hives for commercial pollination.

COLLETIDAE

Another short tongued bee, "Colletidae is known for the membranous cellophane-like secretion females use to line burrows they excavate in the soil or construct in tubular cavities" (Frankie et al. 2014, 77). Their unique two part tongue allows them to line their burrows (Wilson-Rich 2014).

Figure 7| Andrenidae

Figure 8| Apidae bee

Figure 9| Colletidae bee

HALICTIDAE

One of the medium tongued bees,the Halictidae family perspirate and tend to be specialists. They are known for their striking colors such as the "Ultra Green Sweat Bee" and range from highly social to solitary (Frankie et al. 2014) These bees are known to sting and prefer to nest underground in soil or sand (Wilson-Rich 2014).

MEGACHILIDAE

One of the most researched family, second to the Apidae family, Megachilidae carry pollen in a special structure on their belly instead of their hind legs like other bees, lowering their pollen transfer per trip (Wilson-Rich, 2014). Because of this, these bees tend to make more frequent trips making them more effective pollinators. They nest in preformed tubular cavities such as tunnels of wood-boring beetles, hollow plant stems or even abandoned snail shells (Frankie et al. 2014).

Figure 10| Halictidae (sweat bee)

figure 11| Megachilidae bee

SAN JOAQUIN DELTA LEVEE SYSTEM

In 1861, the Board of Reclamation reclaimed the Delta for agriculture and established an extensive levee system to keep the wetland waters at bay. There are several classifications of levees within the Delta. Each are managed by a different entity. Project levees were initially set up by the federal government. It was later handed over to the state for management. All other levees fall under the "Non-Project Levee" category and are then split into urban or non-urban. A majority of non-project levees are maintained by local reclamation districts (See Appendix A). Currently, the San Joaquin Delta contains 1,115 miles of levee. All levees are built to the Habitat Mitigation Plan standard requiring sufficient structural integrity to withstand a 100-year flood. Public Law 84-99 recommends new levee standards (figure 12) to improve structural integrity to be able to better withstand 100-year floods.

The existing levee system is identified as an integral part of the Delta to help solve the two problems identified in this study. The proximity of the levees to crop fields make it ideal for bee habitat. Much of the existing projects that aim to increase native bee populations utilize unused space near crop fields as well (see case studies in Appendix B). For the purpose of this project, the Hazard Mitigation Plan standard will be used for design and calculations.

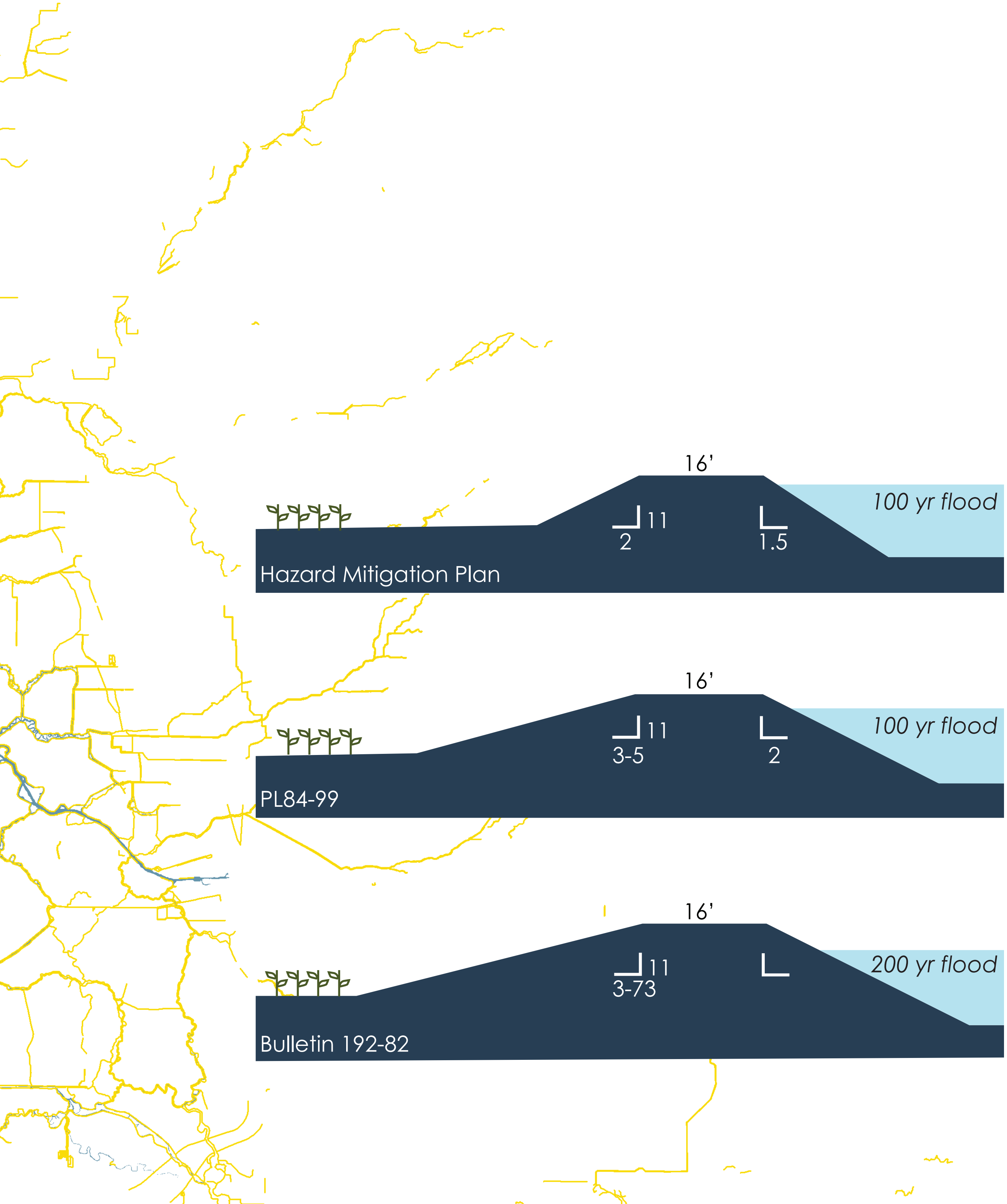


Figure 12| Levee structural standards

SAN JOAQUIN COUNTY

The most current agricultural report for the San Joaquin County that is made available to the public revealed that the gross value of agricultural production was $2,337,922,000. In 2016 the top ten crops with highest gross value were grapes, milk almonds walnuts, cattle and calves, tomatoes, cherries, hay, potatoes and melons. Of these ten crops, half of them require pollination services as well as many others that are grown but not indicated in the top ten list (San Joaquin County Agriculture Report 2016.

One of the fastest growing industries is the apiary industry. It includes honey production, pollination services and miscellaneous products (pollen, bees, queens, nucleus, colonies and beeswax). In 2016, pollination services alone accounted for $23,338,000 of the gross value. Figure 13 shows the cost per hive and number of hives managed from 2006 to 2016. The table indicates an upward trend of honey bee hive rentals. This could be correlated with the impacts of CCD which was first detected in 2006. Another factor could be that crop production is continuously growing. This results in increasing the demand and needs for pollination services.
(Delucchi 2017).

AGRICULTURE INDUSTRY

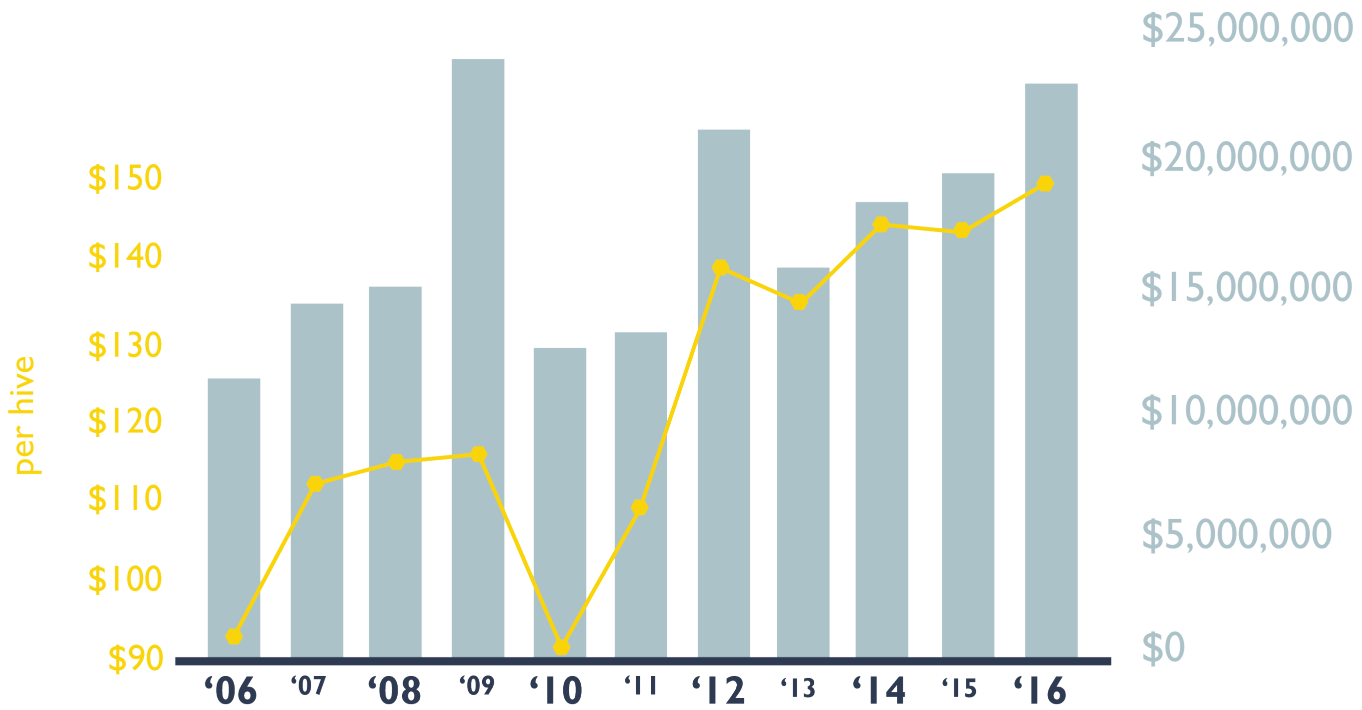


Figure 13| Cost per hive and total gross value of apirary industry from 2006-2016 in the San Joaquin County

RESEARCH

CROP POLLINATION

LANDSCAPE ECOLOGY & EFFECTS OF LANDSCAPE STRUCTURE

HABITAT SIZE

CROP POLLINATION

The pollination of any plant requires interaction of several parties. Bees transfer pollen from the anther to the stigma of the same or different flower. The more pollen grains transferred between flights develop more seeds in a flower.

Wild bees can help contribute to crop pollination in four ways. First, they can replace the services provided by commercially-managed honey bees. Second, they can enhance the services already provided. Studies of wild bee interaction with honeybees show an increase in pollination efficiency of honeybees (Kremen 2008). Third, wild bees can provide services to plants that are otherwise not provided by honeybees such as buzz pollination (Kremen 2008). Fourth, "they can enhance productivity in plants that self-pollinate and for which pollination is consequently rarely managed" (Kremen 2008).

Pollination is more efficient when pollinators are able to travel quickly to flowers. When they encounter a patch of profitable flowers, they tend to travel in a straight line, limiting " the chance of a bee revisitng a flower recently emptied of nectar" (Delaplane and Mayer 1992, 13). Studies have also shown that bees tend to linger longer at poor quality flower

Figure 14 | Sweat bee pollinating melon crop

Figure 15 | Alfalfa leafcutting bee pollinating alfalfa

Figure 16 | Blue orchard mason bee pollinating blackberry patches (Delaplane and Mayer 1992). This tells us that the quality of flower patches can influence the efficiency of foraging activity.

The optimal foraging theory "predicts that foraging animals will forage efficiently, moving between food patches and lingering in focal patches in such a way as to get the most return for their effort" (Delaplane and Mayer 1992, 12). Ideally, the suitable crop for pollination will act as these focal patches. Proximity of crops to bee habitat will also greatly increase the chance of bees nesting and foraging in crop fields. However, nesting in fields could be impacted by ploughing and other agricultural field activities.

Some bees employ a technique called buzz pollination to release pollen. This technique is commonly used on species of plants that have smaller pores. Most bumble bees are able to utilize this technique, providing them an upper hand at obtaining more food (*Wilson-Rich* 2014). Commercial crops in the genus *Solanum* (eggplants, tomatoes, and potatoes) and *Vaccinium* (blueberries/ cranberries) require buzz pollination. Because of the diverse physiology of bees that affects their ability to extract pollen, it is important to provide a diverse array of flowers.

Figure 17 | Bumble bee pollinating tomato

Figure 18 | Native bee pollinating blueberry

Figure 19 | Carpenter bee pollinating chives

LANDSCAPE ECOLOGY & EFFECTS OF LANDSCAPE STRUCTURE

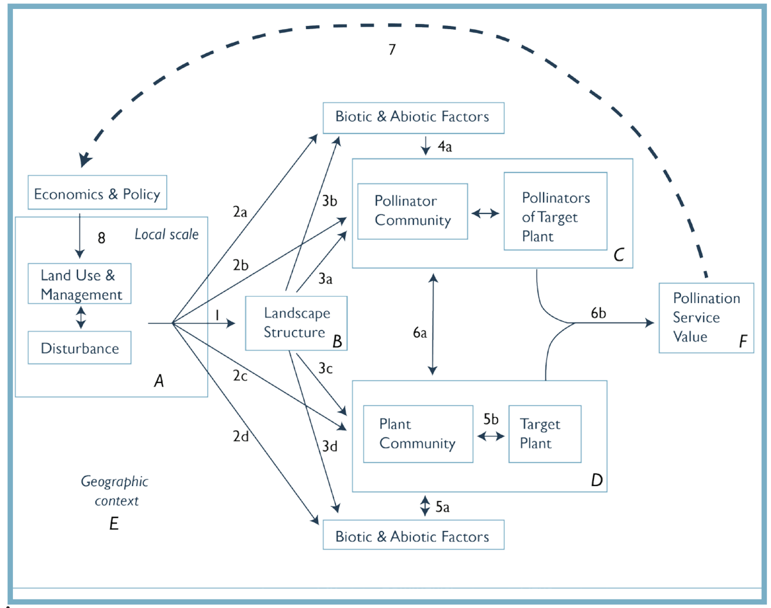


Figure 20| Conceptual model for pollination services (Kremen, 2007)

Landscape structure has profound effects on mobility, species richness and crop visitation. This project looks at Claire Kremen's conceptual model (Kremen 2007) that was developed for understanding the impacts of land use change on pollination services as well as other research to understand the effects of landscape structure (figure 20).

Box A in figure 20 shows how land-use and management practices affect the local plant community, its pollinators, and the biotic and abiotic factors that affect both groups (2a-d). These site-scale effects then add up to create landscape structure; the spatial configuration of different natural, semi-natural and developed habitat (3a-d). Target plants in Box D are those that require pollination services (Kremen et al. 2007). These target plants are only visited by a certain number and species of bees from the pollinator community (Kremen et. a 2007). "The abundances of pollinators in the wild are influenced by abiotic and biotic factors (4a,b) and the availability of critical resources (2a,3a and 6a)" (Kremen et al. 2007, 21). Similarly, the plant communities are also influenced by abiotic factors and by the distribution of resources and habitat (5a,b, 2c, and 3c). Box F indicates pollination service value. This is dependent upon Box E, the geographical context in which this model is being used, and in turn may influence the environment, policy and economics as is the case in the San Joaquin Delta (Kremen et al. 2007)

Studies on farm management reveal that organically managed farms tend to experience a higher abundance and richness of bees in crops, compared to conventionally managed farms. The higher abundance and richness is however, not related to management type but the occurrence of more natural habitat, stressing the importance of having habitat near farms (Kennedy 2006, Black et al. 2009). The study unfortunately did not look at the types of plants found within the natural habitat, but it is assumed that it contained plants that are favored by bees. These studies concluded that "as fields become increasingly simplified (large monocultures), the amount and diversity of habitats for wild bees in the surrounding landscape become even more important" (Kennedy 2006, 597) reinforcing the idea that land use will affect pollinators (Kennedy 2006, Kremen 2007).

For bees, landscape structure will affect the spatial availability of nesting, food and overwintering sites (Kremen et al. 2007). Habitat conversion from natural habitat into monoculture crop has drastically affected wild bee ability to thrive within agricultural matrices due to the lack of natural habitat and diversity of floral resources. In addition to conversion, the remaining natural habitat is fragmented. This makes it difficult for native bees to move around. A continuous corridor with the species habitat type is ideal for mobility across landscape. However, if there are patches of suitable habitat within a species travel range, they are still able to move, movring from one patch to another like stepping stones.

Figure 21| California land cover classified into 6 types with nesting and floral suitability

13 original land cover types	6 simplified land cover types	Nesting type				Floral Resources		
		Ground	Wood	Stem	Cavity	Spring	Summer	Autumn
Bare Cropland Cut grass Fallow Oarchard	Agriculture	0.25	0	0	0.05	0.05	0.15	0
Organic farm	Oraganic ag	0.5	0.5	0.5	0.5	0.75	0.5	0.25
Grass	Pasture	1	0	0.25	0.5	0.75	0.5	0.1
Riparian	Riparian	1	1	1	1	1	0.25	0
Chaparral Mixed oak Oak	Scrub forest	1	1	0.5	1	0.75	0.25	0.25
Rice Water Unclassified	Water	0	0	0	0	0	0	0

LINEAR FEATURES	Ground	Wood	Stem	Cavity	Spring	Summer	Autumn
Roadside	1	0.1	0	0.5	0.75	0.75	0
Ditchside	1	0.25	1	1	0.5	0.5	0
Residential-suburban	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Agricultural parcel edge	1	0	0	0.5	0	0.25	0

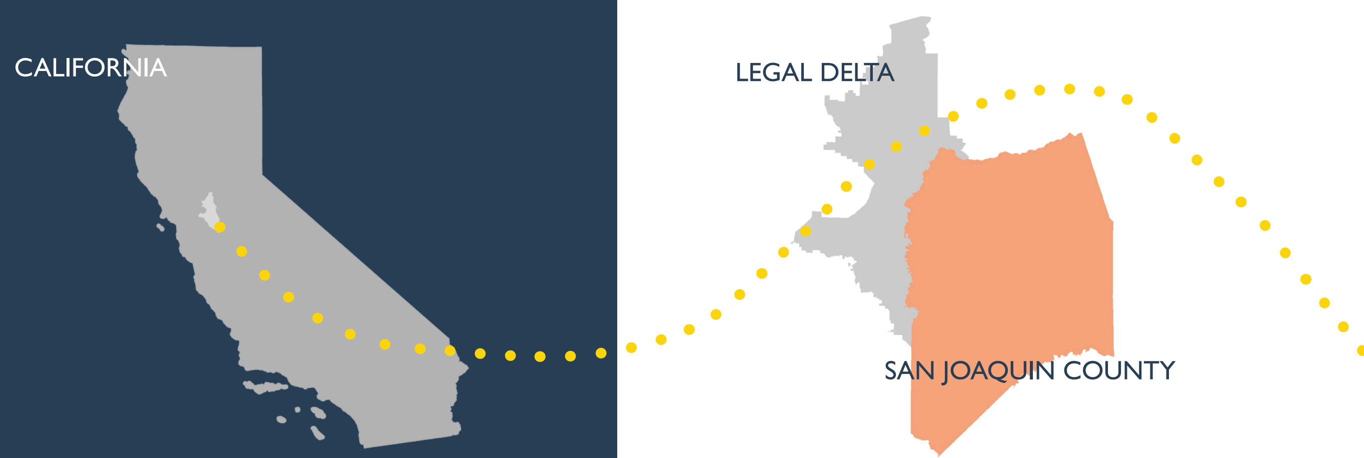
Not only is the diversity and abundance of natural habitats important, but the proximity and quality of these habitats to crops will also impact the efficiency and number of visits to the crops. One study observed native bee visits to watermelon sites, found that the services provided are strongly dependent on the proportion of natural upland habitat within 1-2.5 km (0.6-1.5 miles) of the farm (Kremen et al. 2004). The data indicated that an increase of proportional area of upland habitat increases both the amount and stability of pollination services from native bees (Kremen et al. 2004) . The current levees of the San Joaquin Delta act as upland areas, indicating its potential to be beneficial habitat for native bees that will pollinate crops.

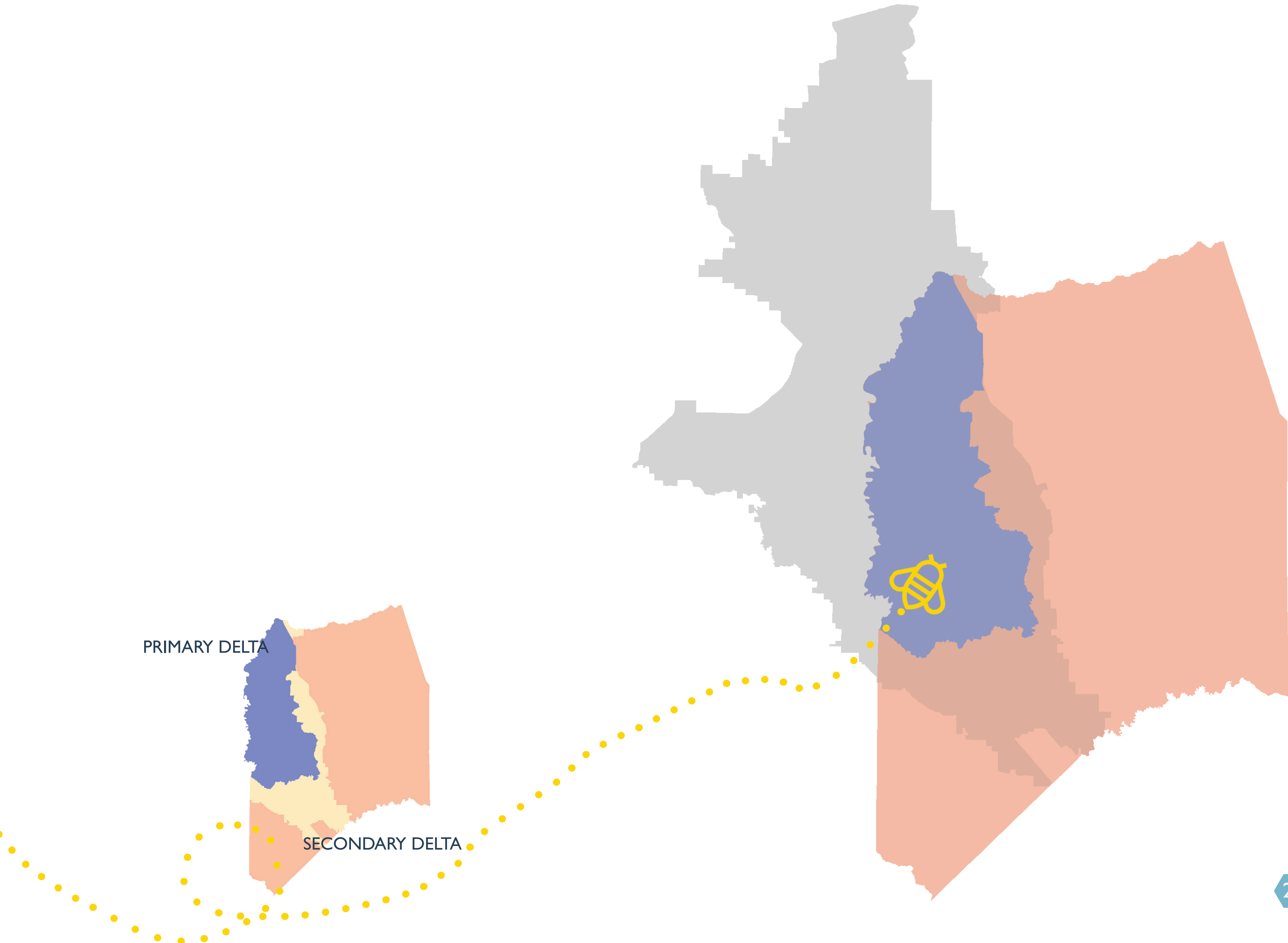
HABITAT SIZE

In terms of habitat size, studies show that larger-contiguous areas that minimize edge effects are better. More edge increases the risk of competition, invasion, predators, and decreases available habitat. In one study, it was recommended that the area of crop fields not exceed 75% of total area and that the remaining 25% should be for bee conservation (Banaszak 1992). Others recommend 10% to 30% of a farm should be natural habitat to support pollinators (*100 Plants to Feed the Bees* 2016). This is a generalization for bees, and conservation area may differ based on specialization and needs of individual species. On a finer scale, plants are recommended to be grown with similar plants in patches of at least 1 square meter (4sq ft)(*100 Plants to Feed the Bees* 2016).

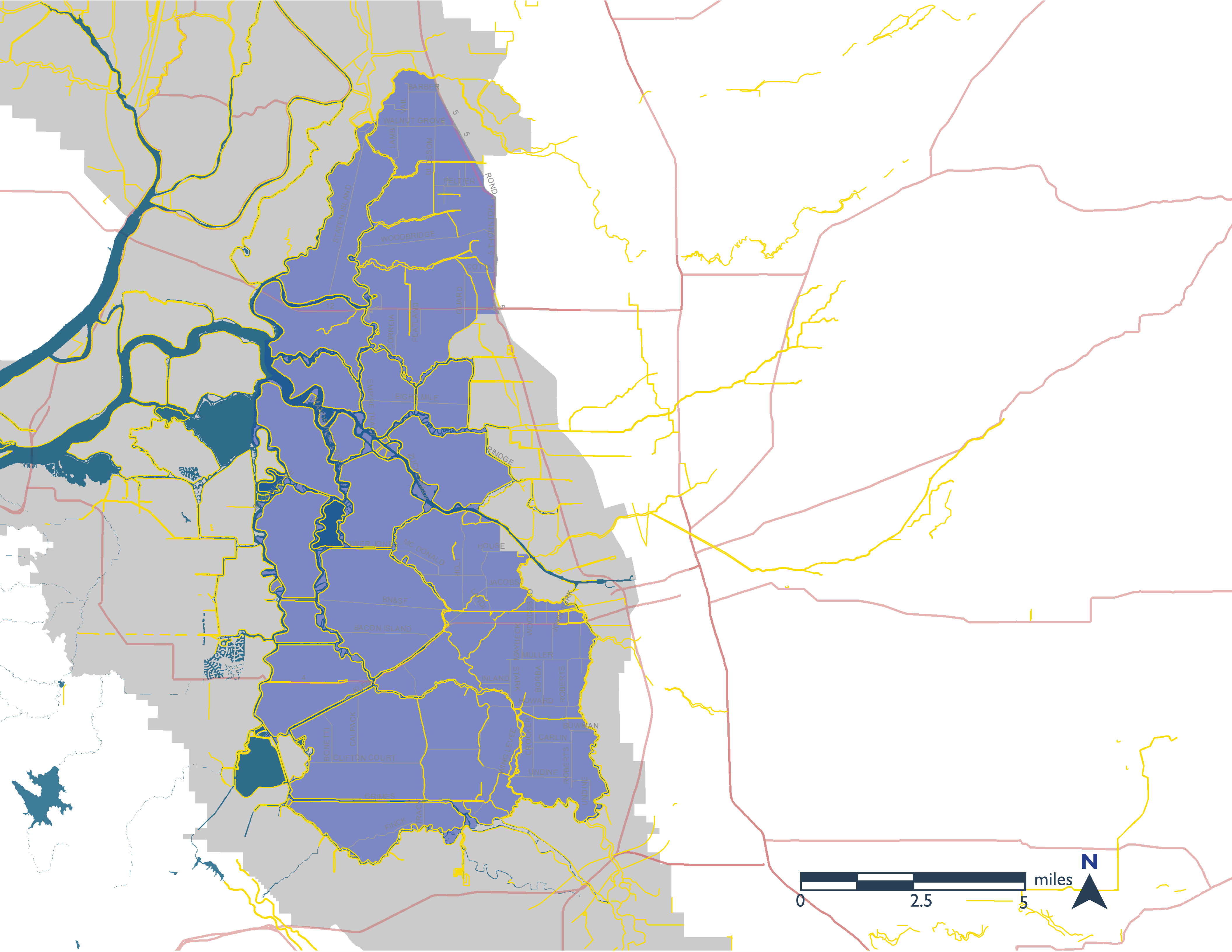
PROJECT SITE

The estimated area of levee space is roughly 11,000 acres. This number was calculated by creating a 100-foot buffer along the existing levees, calculating the area and then summarizing the sum of the area in acres through GIS. Most levees are barren with little to no vegetation (figure 34-39).



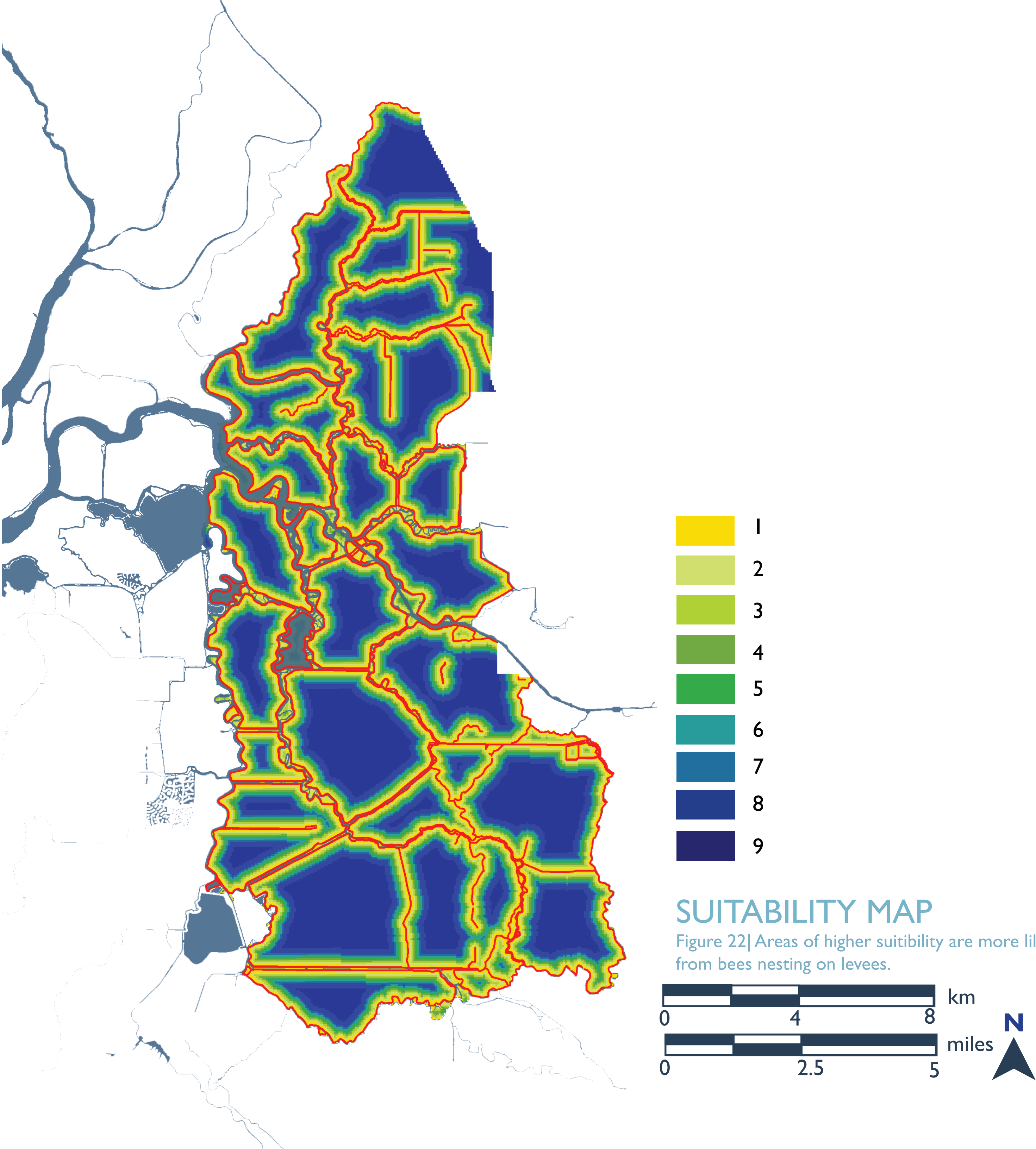

PRIMARY DELTA
SECONDARY DELTA

REGIONAL SCALE


N
miles
0
2.5
5

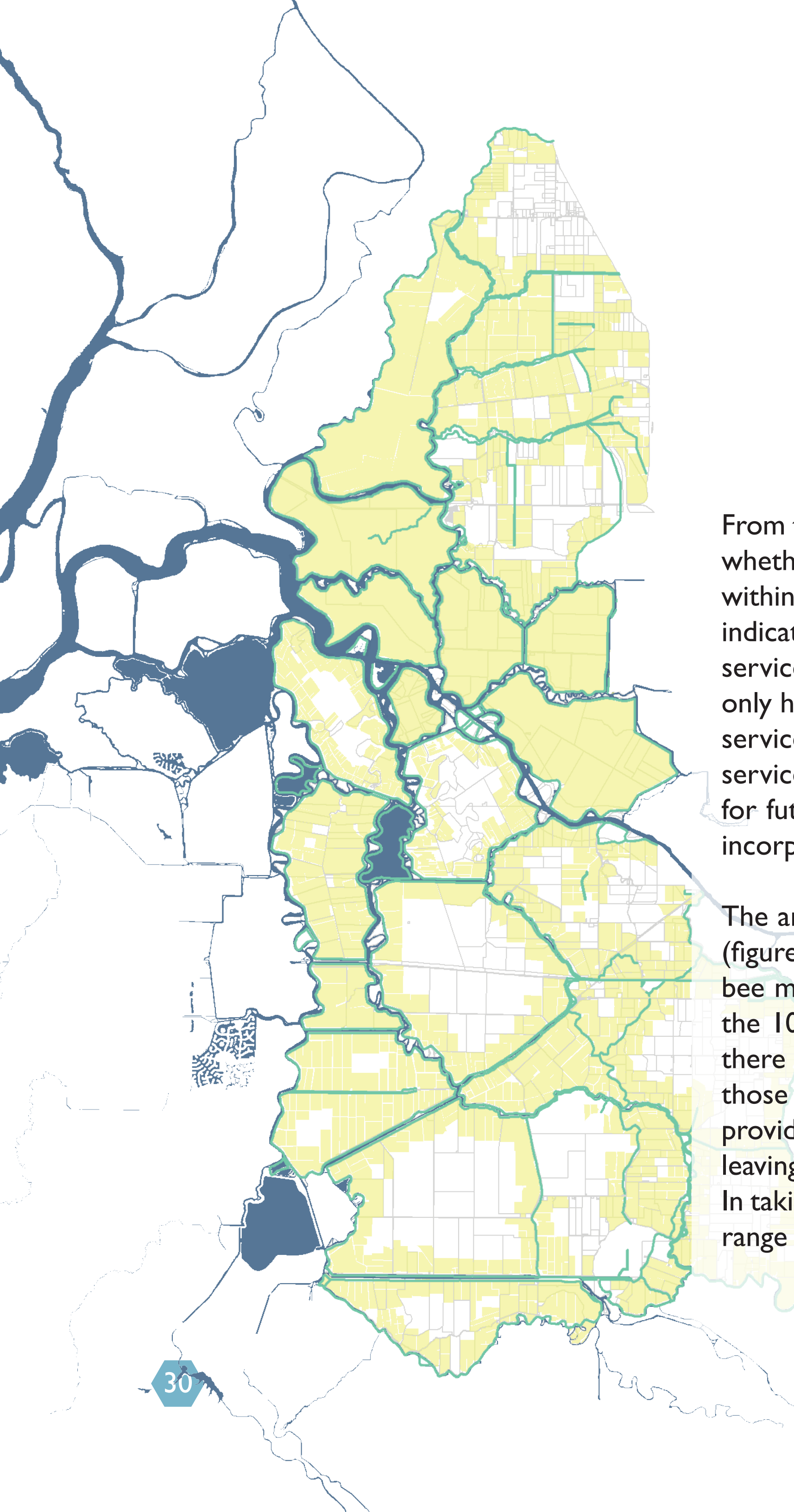
FEASIBILITY

The general range for foraging distances discussed in the research range from 100-600m for native solitary/ burrowing bees, and somewhat farther (800-1000m) for native bumble bees (Black, 2009). Feasibility of the project depends on whether or not crop fields fall within this range. It is important that there are not only crops within this range, but are also "suitable" (requiring pollination). Since bees tend to travel in a straight line, the use of the Euclidean distance tool in GIS helped calculate and classify the distance of fields from the levees. A reclassification of this map provides a suitability map that indicates area of high and low suitability. A suitability of 1 indicates most suitable and 9 being not suitable at all



SUITABILITY MAP

Figure 22| Areas of higher suitibility are more likely to recieve pollination services from bees nesting on levees.



From the suitability map (figure 22), new pieces of information are revealed. First, it shows whether there are crop fields within foraging distance from the levees. Crops fields within foraging distance will be more likely to receive pollination service. Secondly, it will indicate the extent of which an area in an individual field that would receive pollination services from bees nesting on the levees. Some fields may be larger than others and only have a portion of the field within the range. If this is the case, the gaps in pollination services from resident levee bees will require alternative solutions for providing pollinator services. This issue is beyond the scope of this project, but has the potential to become for future research. Based on case studies (Appendix B), farm edges are prime areas to incorporate wildlife/pollinator habitat.

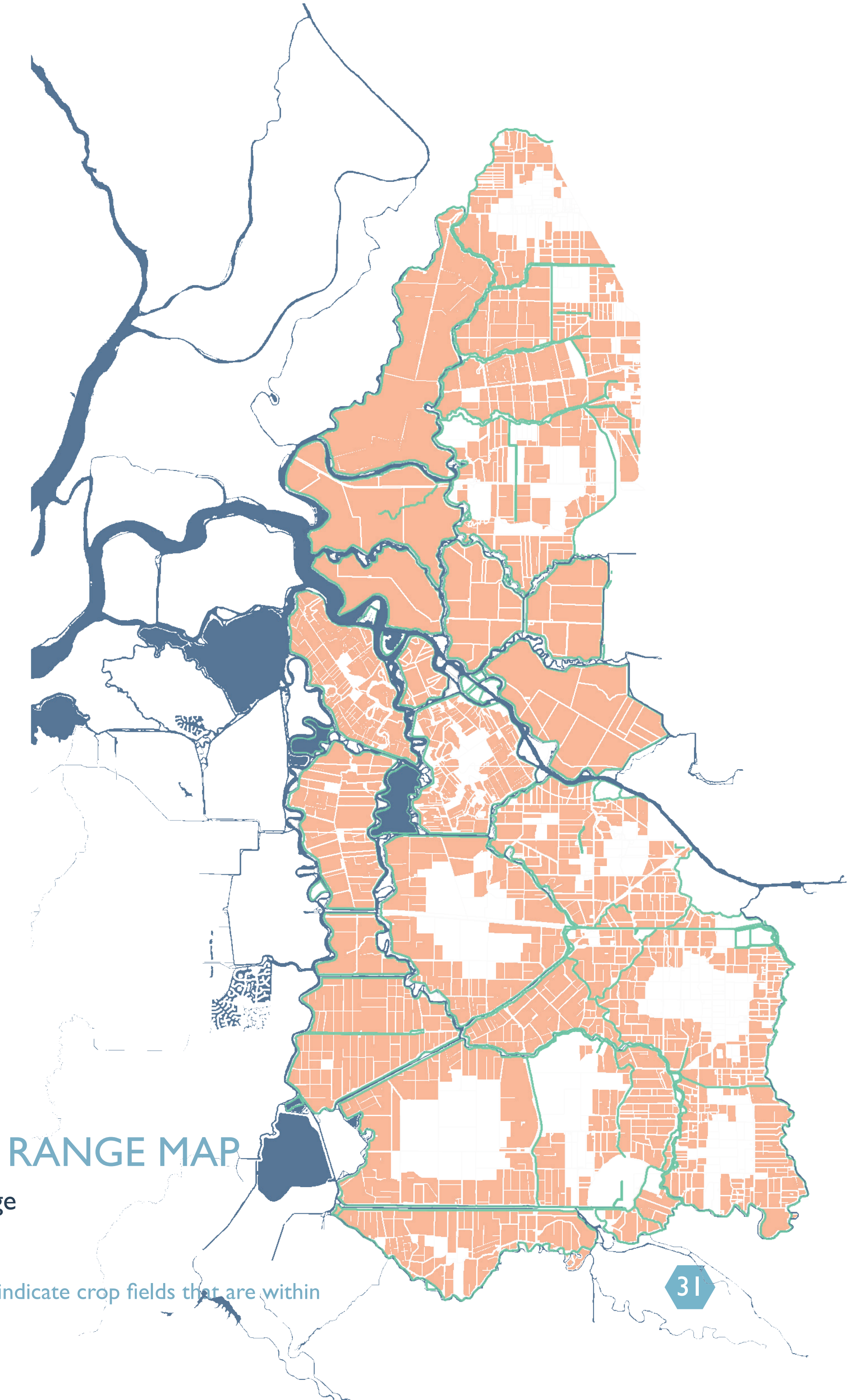
The areas of high suitability are translated into a 600-meter (figure 23) and 1000-meter (figure 24) range map. All fields in yellow in figure 23 indicate crop fields within native bee maximum foraging range of 600-meters. Figure 24 indicates all crop fields within in the 1000-meter maximum foraging range. Based on these two maps, it is apparent that there are gaps in the landscape that fall outside of the foraging ranges. This means that those areas will require an alternative source of pollination. The 1000-meter range map provides much better coverage, serving most of the northern portion of the site, and leaving smaller and fewer gaps in the southern portion compared to the 600m range map. In taking a more conservative approach, the 600-meter range map will be used as the base range for the project.

600M(~0.5 miles) RANGE MAP

600m (~0.5 mile) range

levee

Figure 23| Areas highlighted in yellow indicate crop fields that are within 600meters(~0.5)miles of levees. These crops are withing the foraging distance of most native bees.



1000M (~0.75 miles) RANGE MAP

1000m (~0.75 mile) range

levee

km

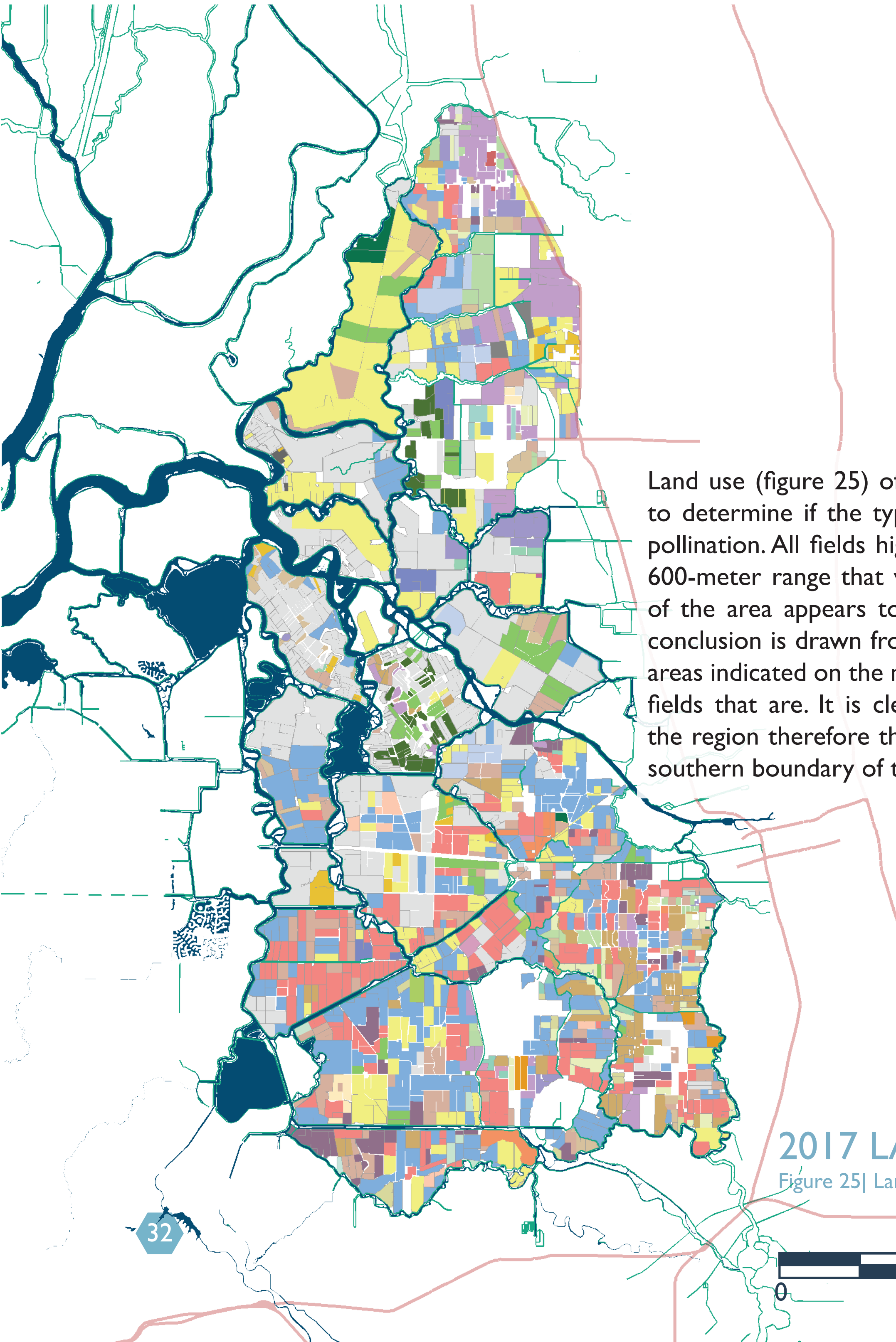
0 4 8

miles

0 2.5 5

N

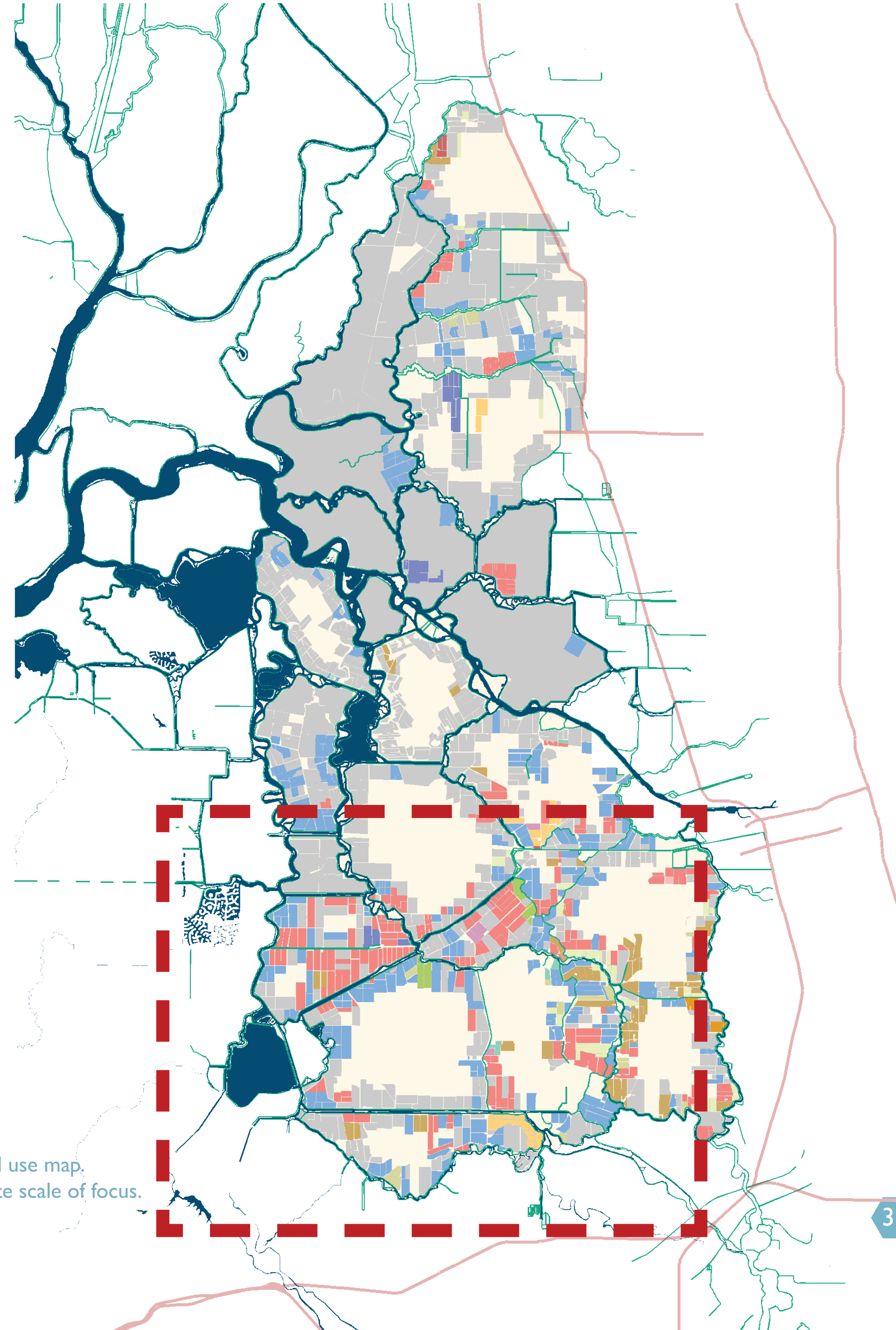
figure 24| Areas highlighted in yellow indicate crop fields that are within 100meters(~0.75)miles of levees.



Land use (figure 25) of each crop field within the 600-meter range must be identified to determine if the type of crop grown in the location will require and benefit from pollination. All fields highlighted with color in figure 26 represent all crop fields in the 600-meter range that will require and benefit from the project. The southern portion of the area appears to have the most potential for the success of the project. This conclusion is drawn from visual observations of the suitable crop map (figure 26). Grey areas indicated on the map represent crop fields unsuitable, and those in color represent fields that are. It is clear that there are significantly more fields in the lower half of the region therefore the next area of focus for the project will be from Holt St to the southern boundary of the Primary Delta.

2017 LAND USE MAP

Figure 25| Land use map of the regional scale based on 2017 data.



SUITABLE CROP MAP

Figure 26| 600m range map overlaid ontop of the 2017 land use map. Area within the red box have been identified as intermediate scale of focus.

INTERMEDIATE SCALE

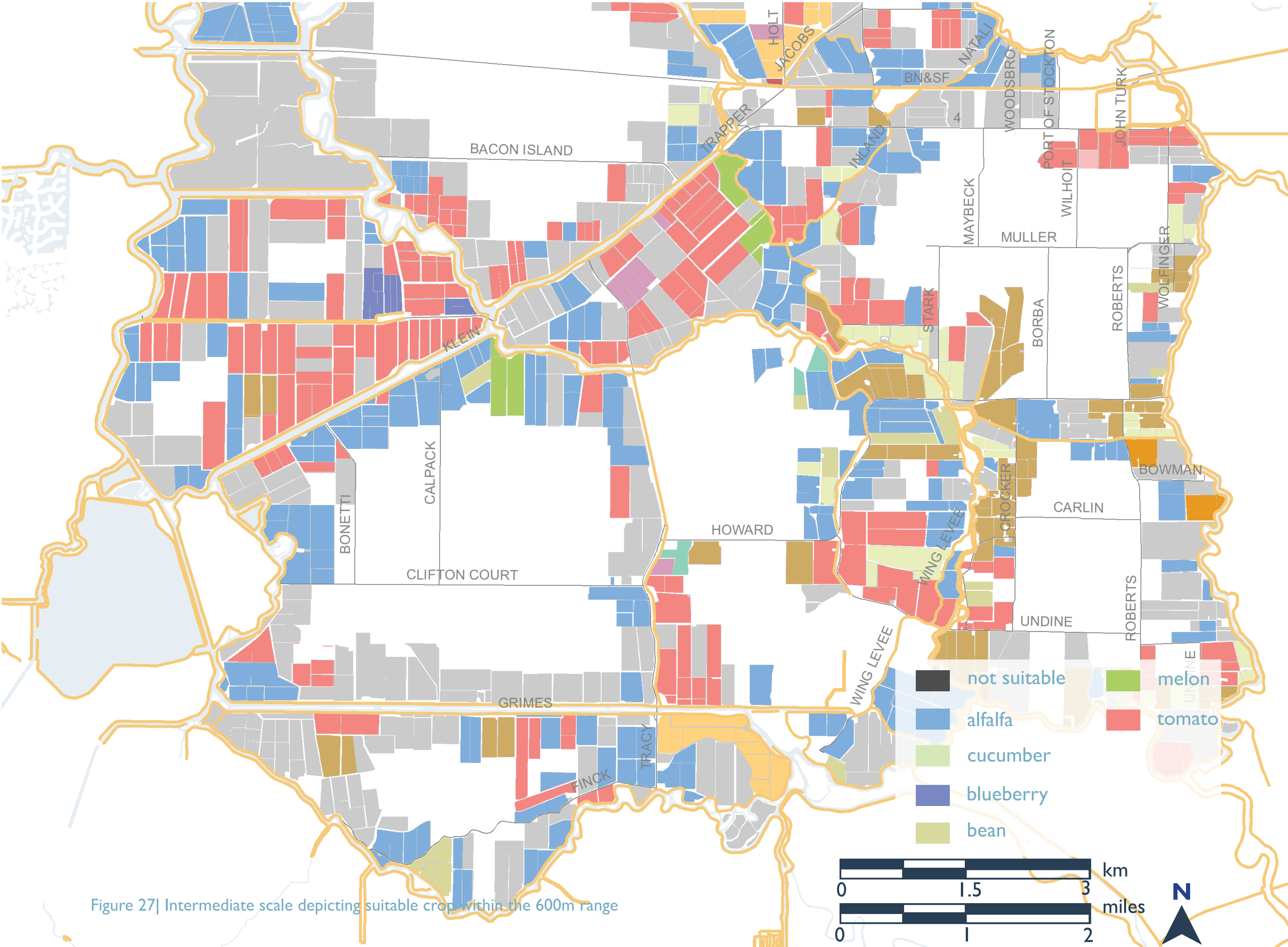


Figure 27| Intermediate scale depicting suitable crop within the 600m range

CROP ROTATION

ALFALFA
3-4 years
(harvested 5-6 times a year)

BLUEBERRY
~25 years

MELON
every year

BEAN
3 years

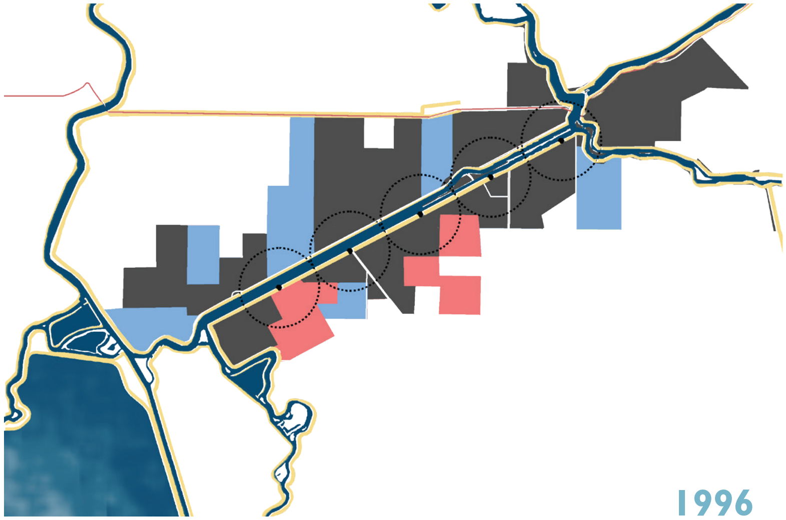
CUCUMBER
every year

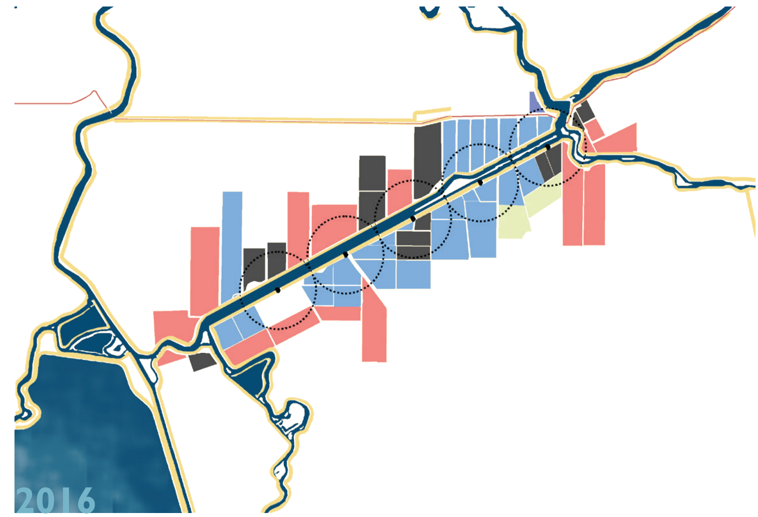
TOMATO
every other year

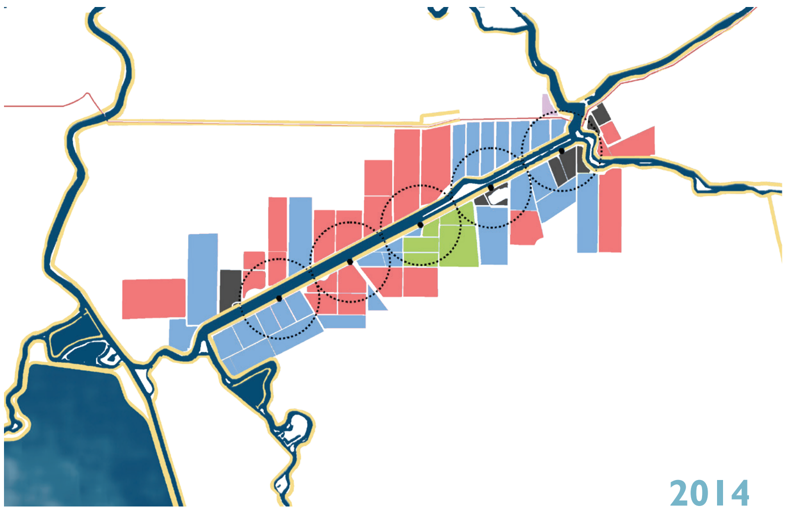
TEMPORAL ANALYSIS

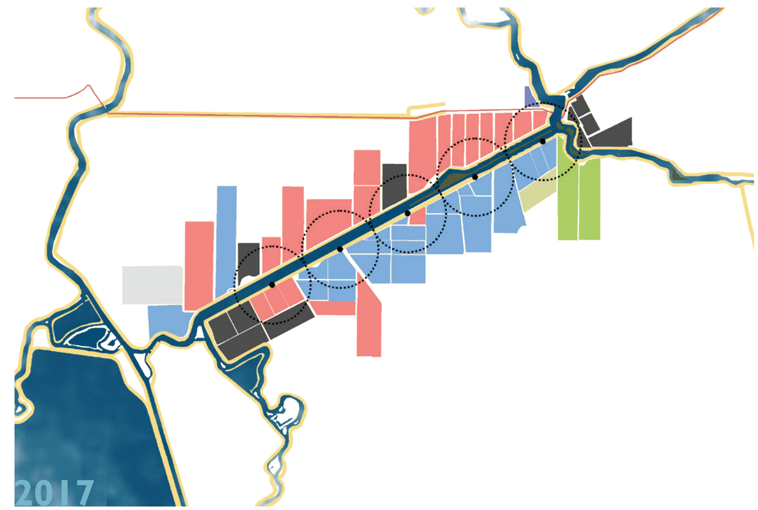
The agricultural matrix is constantly changing due to the seasonality of crops and maintenance of soil quality. Depending on the crop, a single crop parcel may support two to three different crops within a year or several years (figure 28). Crop rotation will greatly affect the ability for resident levee bees to pollinate crops effectively, as well as affect the amount of forage available. If the adjacent crop does not require pollination, then the farmers do not require the service.

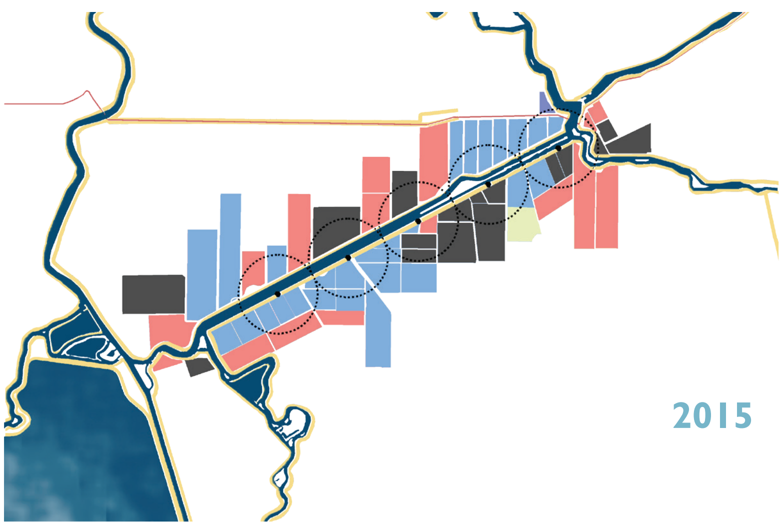
To better understand how the agricultural matrix changes, land use maps from 1996, 2014, 2015, 2016 and 2017 were analyzed (California Department of Water Resources). The analysis resulted in the creation the pollinator patch concept, a continuous corridor along the levees that provides nesting and foraging resources for bees and allows for bee mobility. This will allow bees to move across the landscape as it changes.











not suitable
melon
alfalfa
tomato
cucumber
blueberry
bean

Figure 28| Land use maps depicting suitable crop along Victorian Channal from 1996, 2014 to 2017.

POLLINATOR PATCH CONCEPT

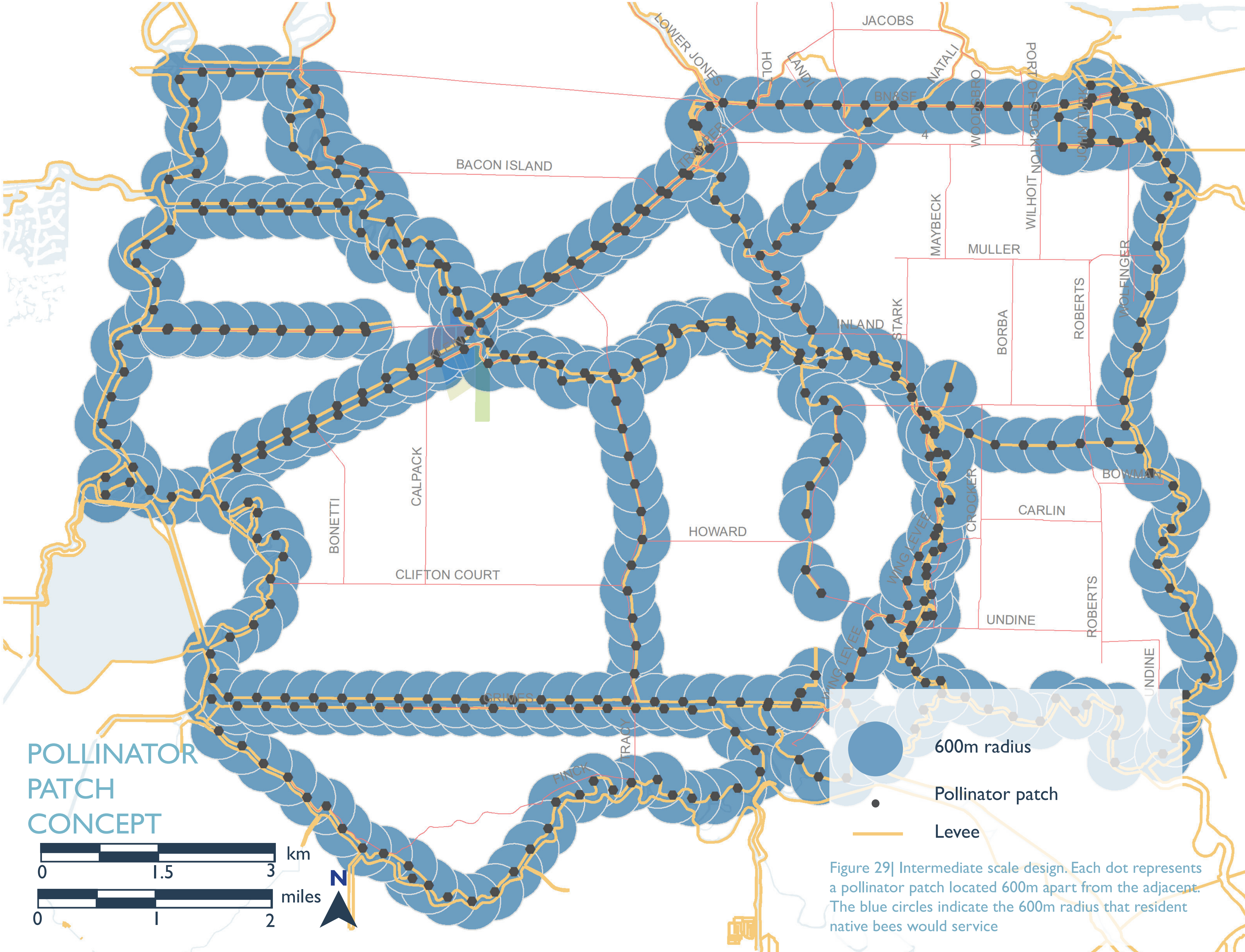
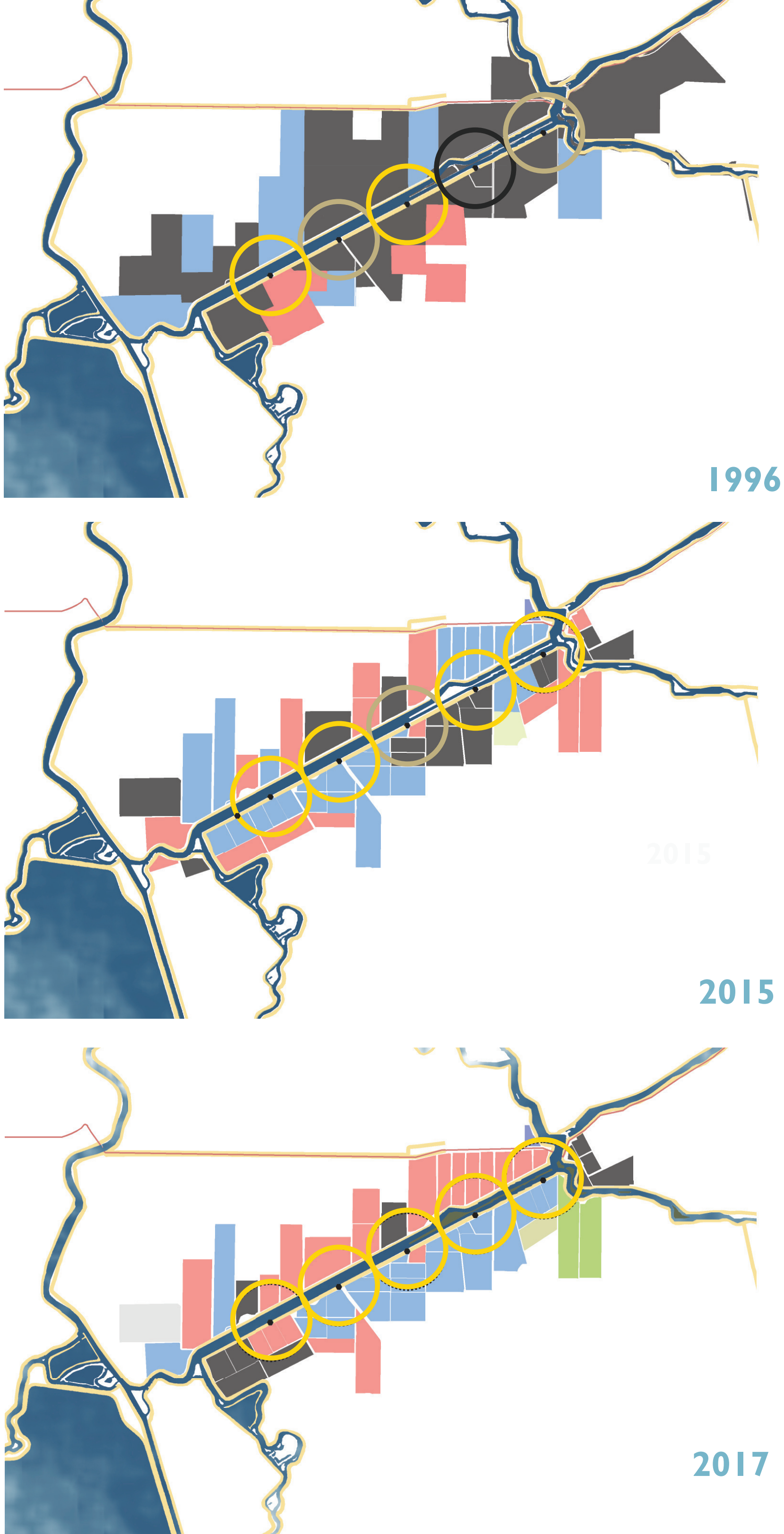


Figure 29| Intermediate scale design. Each dot represents a pollinator patch located 600m apart from the adjacent. The blue circles indicate the 600m radius that resident native bees would service



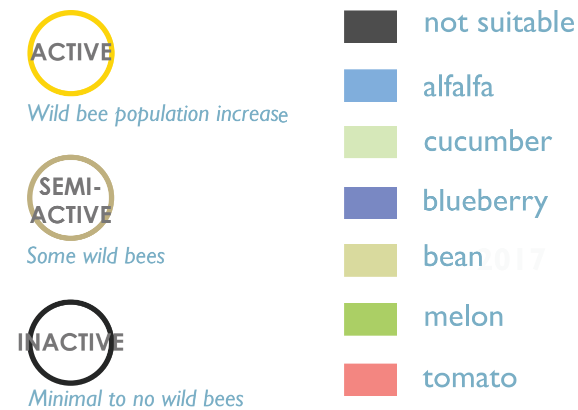
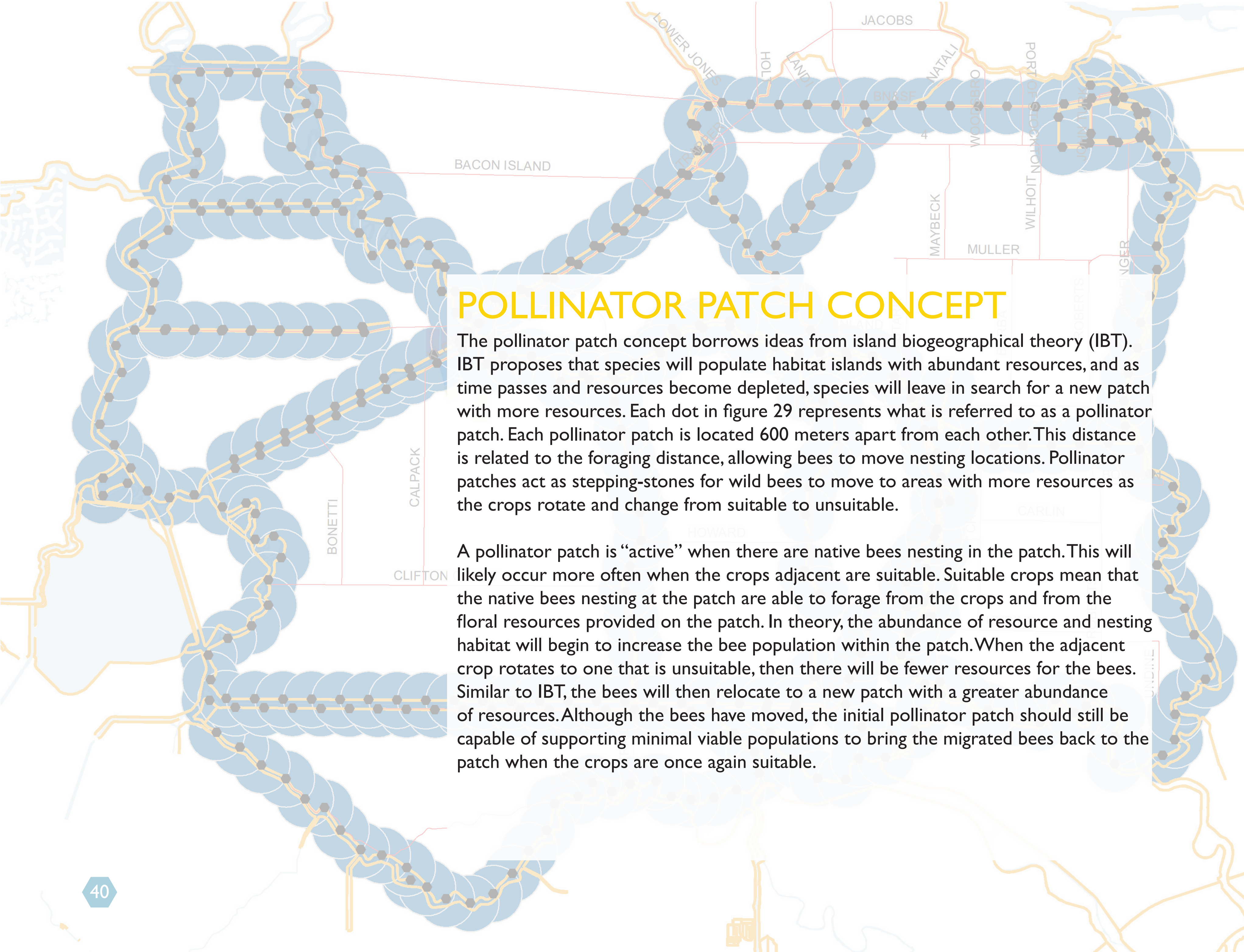


Figure 30| Depiction of how each pollinator patch would change in activity as the crops rotate from year to year.



POLLINATOR PATCH CONCEPT

The pollinator patch concept borrows ideas from island biogeographical theory (IBT). IBT proposes that species will populate habitat islands with abundant resources, and as time passes and resources become depleted, species will leave in search for a new patch with more resources. Each dot in figure 29 represents what is referred to as a pollinator patch. Each pollinator patch is located 600 meters apart from each other. This distance is related to the foraging distance, allowing bees to move nesting locations. Pollinator patches act as stepping-stones for wild bees to move to areas with more resources as the crops rotate and change from suitable to unsuitable.

A pollinator patch is "active" when there are native bees nesting in the patch. This will likely occur more often when the crops adjacent are suitable. Suitable crops mean that the native bees nesting at the patch are able to forage from the crops and from the floral resources provided on the patch. In theory, the abundance of resource and nesting habitat will begin to increase the bee population within the patch. When the adjacent crop rotates to one that is unsuitable, then there will be fewer resources for the bees. Similar to IBT, the bees will then relocate to a new patch with a greater abundance of resources. Although the bees have moved, the initial pollinator patch should still be capable of supporting minimal viable populations to bring the migrated bees back to the patch when the crops are once again suitable.

SITE-DESIGN SCALE

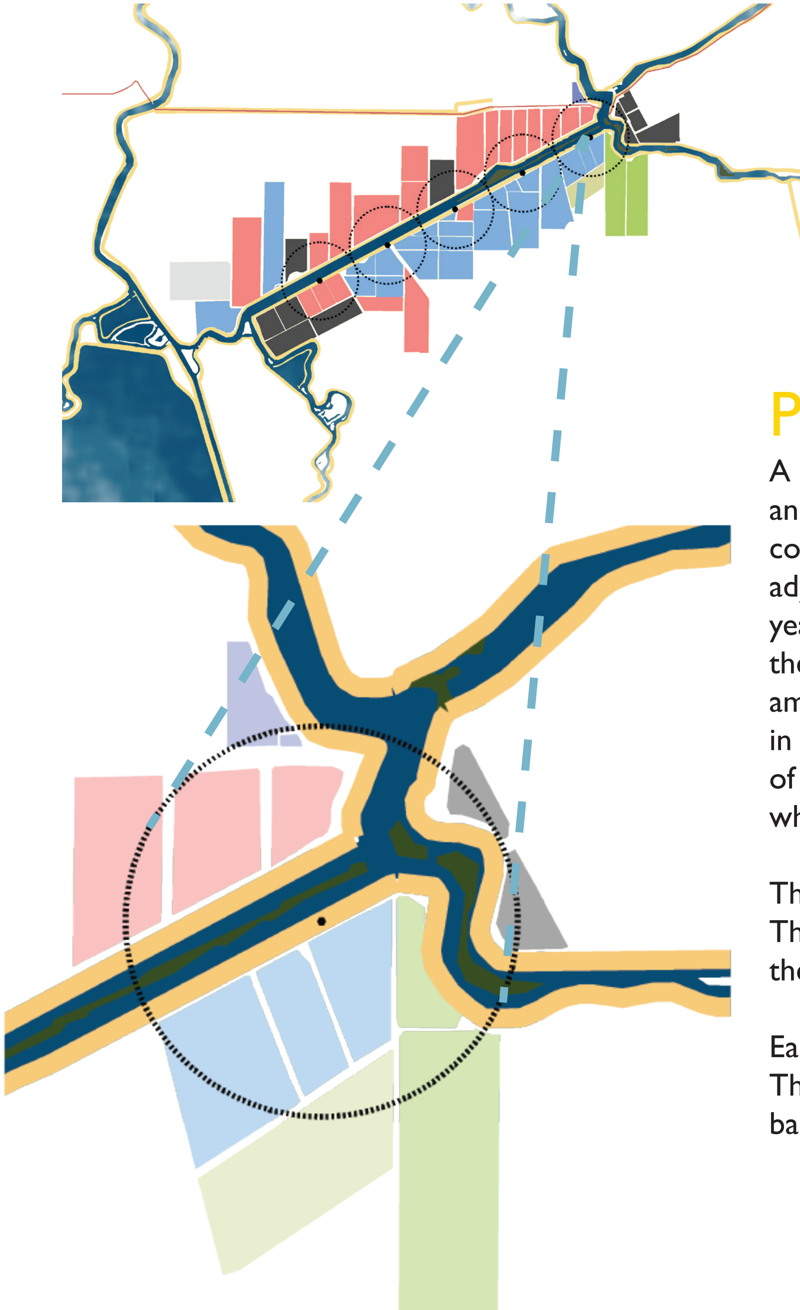


Figure 31| Site-Design Context Map

POLLINATOR PATCH

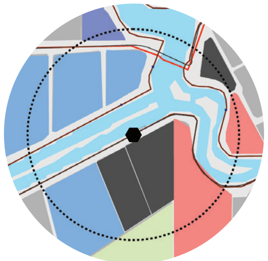
A single patch was selected to better depict how the pollinator patch concept works, and what it would look like on a finer scale. The patch selected was chosen based on its consistency of crop suitability throughout the years (figure 32). It is located on Klein Road adjacent to North Canal (figure 31). By comparing when each of the crops bloom in each year, you can see where there are gaps in floral resources. It is important to know where there these gaps are because those are instances when native bees will lose a significant amount of floral resource for food. Looking at figure 33, it is clear that most crops bloom in late spring and throughout summer. Fall and winter months have the least amount of crops blooming. These two time periods are cruicial to native bee life because this is when they hibernate or provide food for the next generation.

The recommended size for pollinator patch habitat site is 5,000 square feet (~0.5km). These patches can be replicated alongside each other or in a linear pattern as long as there is one located within 600 meters of each other.

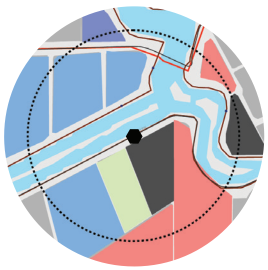
Each individual pollinator patch must contain two components. First, nesting resources. This includes, but are not limited to, bee hotels with various tunnel sizes, piles of twigs, and bare dirt. Secondly, incorporate adequate floral resources for feeding and reproduction.

Figure 32| Temporal analysis of site-design scale site.

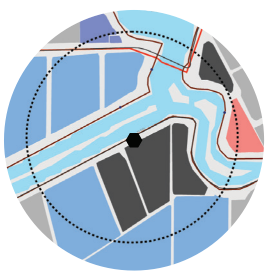
2017



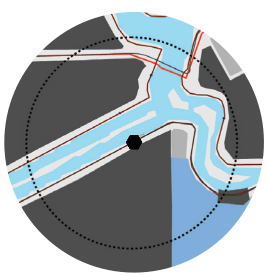
2016



2015



2014



1996

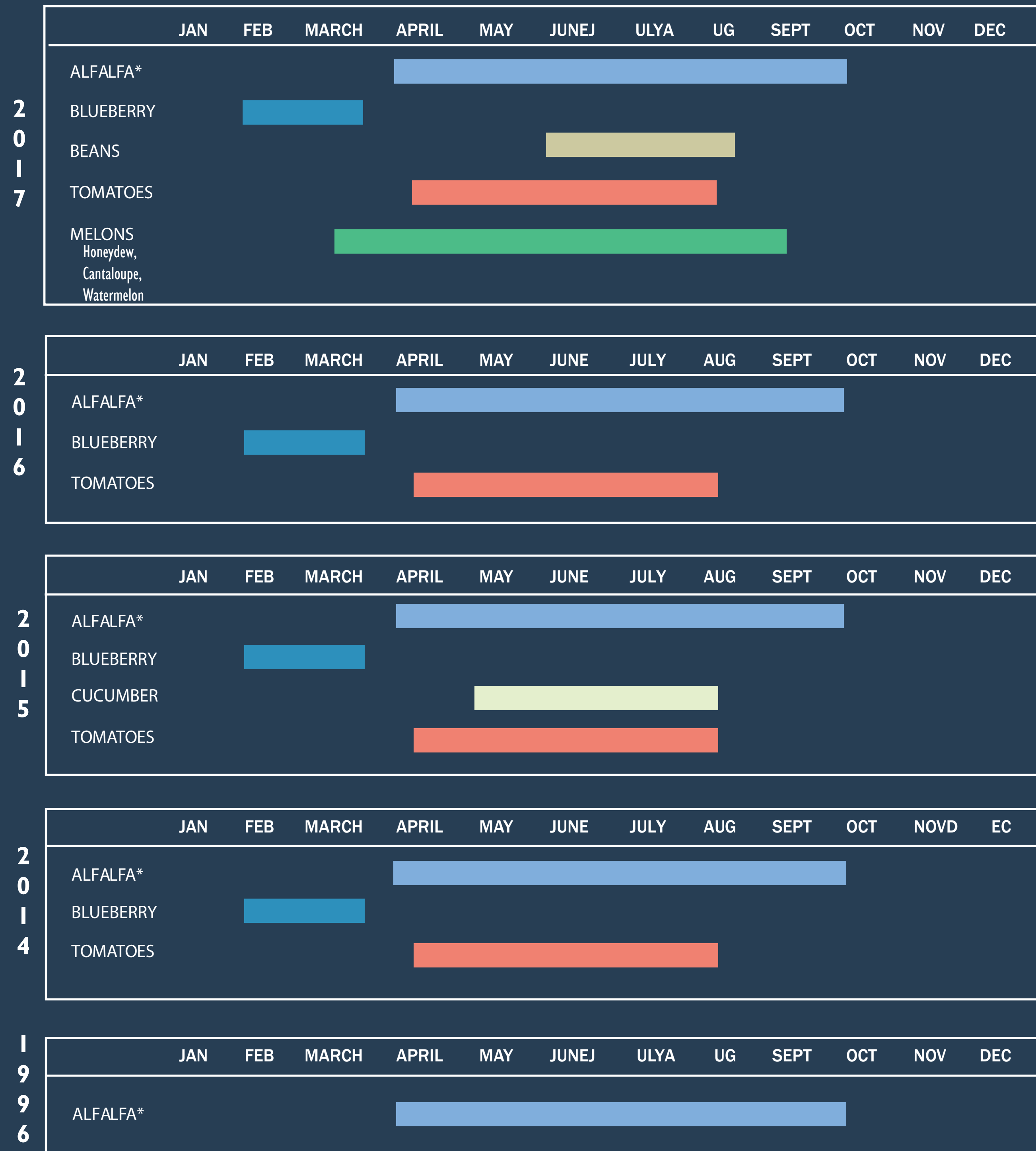


Figure 33| Crop bloom timeline.
(Putnam, et. al., 2007, "Cucumbers", Schrader, et. al., 2002, Mussen and Thorp, 2014, "How to Grow Blueberries-Gardening Tips and Advice"., Davis et. al., 2012, "Asparagus Commodity Fact Sheet, 2017)


Figure 34


Figure 35 | Holes from burrowing animals living on the levee


Figure 36

EXISTING CONDITIONS AT SITE

A visit to the site helped clarify the existing conditions of the levees. At the top of the levee is a two lane road with no shoulder (figure 34). Although some levees have more vegetation than others, the plants currently residing there are weeds. The levees are for the most part barren as seen in figure 35,37 and 38. This is most likely due to spraying herbicides. There is no habitat for wildlife except for burrowing animals (figure 35) which would be beneficial for native bees since some utilize abandoned holes of burrowing animals as nesting grounds.

Figure 37

Figure 38

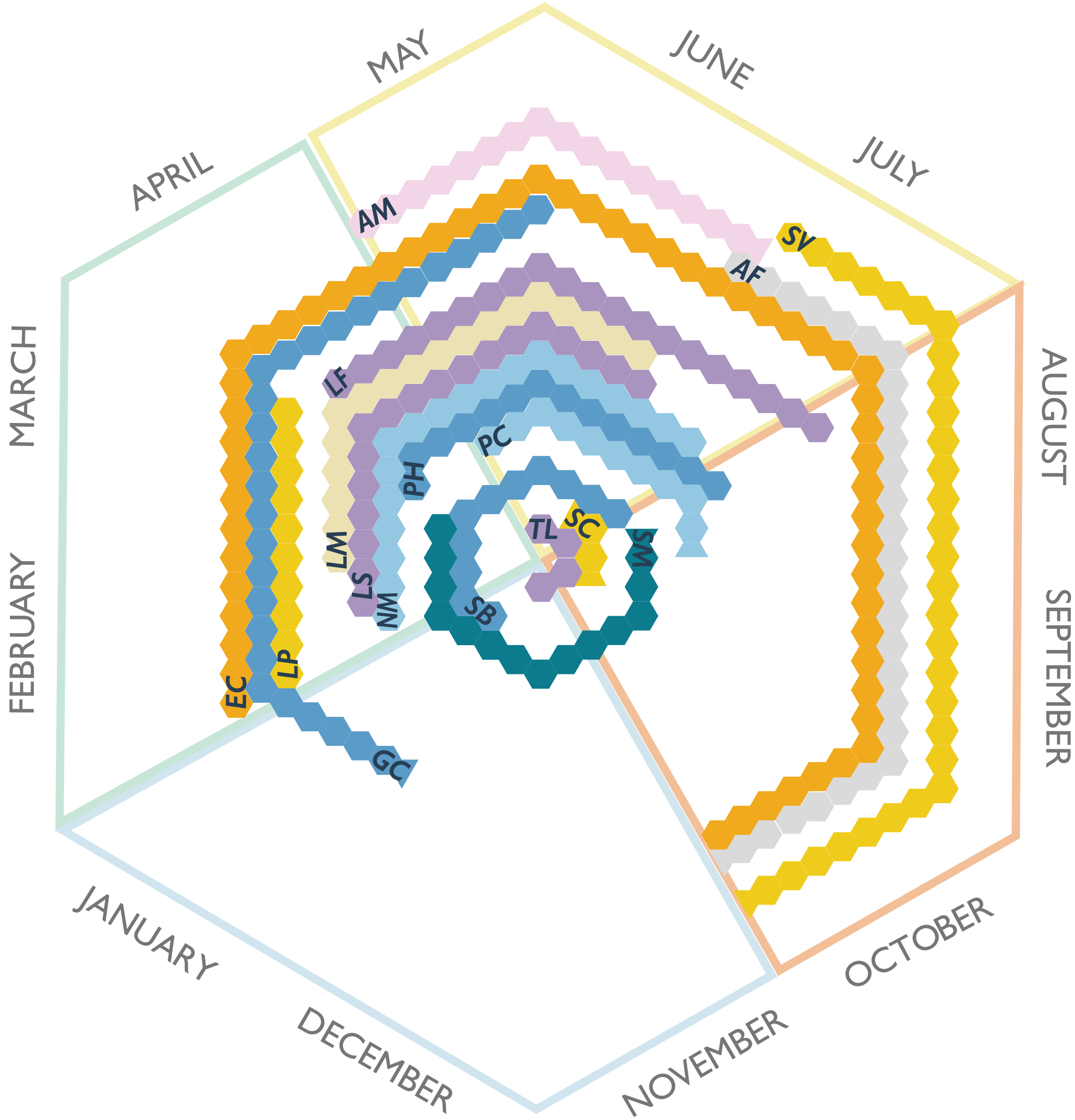
Figure 39 | Image of drainage ditches at edge of crop fields.

PLANTING PLAN

PLANT SELECTION

Areas should consider planting an array of flowering plants that bloom throughout the season to provide food year round. Bee nesting and foraging activities are dependent upon continuous availability of nectar and flower rich habitats. Plant selection when conserving for bees, involve many factors. Due to levee regulation, all plants selected must be low growing. The low-growing nature and the context of the site implies plants that occur in grassland, prairies, and or meadow habitats.

There must also be a diverse set of flowers with different physiognomies as well as varying bloom times to accommodate the 1,600 different native species (Earnshaw 2018). In an agricultural matrix, bees tend to suffer due to the lack of resources during late fall when they prepare to hibernate. Therefore, it is important to provide floral resources during this period to help sustain the population. To better accommodate for the changing landscape, temporal analysis of land use for the third scale of analysis revealed that there is a tendency for crops to bloom mainly in spring and summer, very few in fall and none in winter (Figure 40). This suggests that during fall bees will be unable to obtain food from the fields and will require an alternative source. The need will be accommodated for by the plants selected for the pollinator patch. It is also best to select plants that are perennial because they tend to be richer in nectar resources and are able to store and secrete sugars form the previous seasons (Delaplane and Mayer, 1992).



FLOWERING TIMELINE

AM *Achillea millefolium*

AF *Asclepia fascicularis*

EC *Eschscholzia californica*

GC *Gilia capitata*

LP *Layia platyglossa*

LF *Lupinus formosus*

LM *Lupinus mirocarpus var densiflorus*

LS *Lupinus succulentus*

NM *Nemophila menziesii*

PH *Penstemon heterophlyllus*

PC *Phacelia californica*

SM *Salvia mellifera*

SB *Sisyrinchium bellum*

SV *Solidago velutina californica*

SC *Symphotrichum chilense*

TL *Trichostema lanceolatum*

figure 40| Flowering timeline of newly selected plants

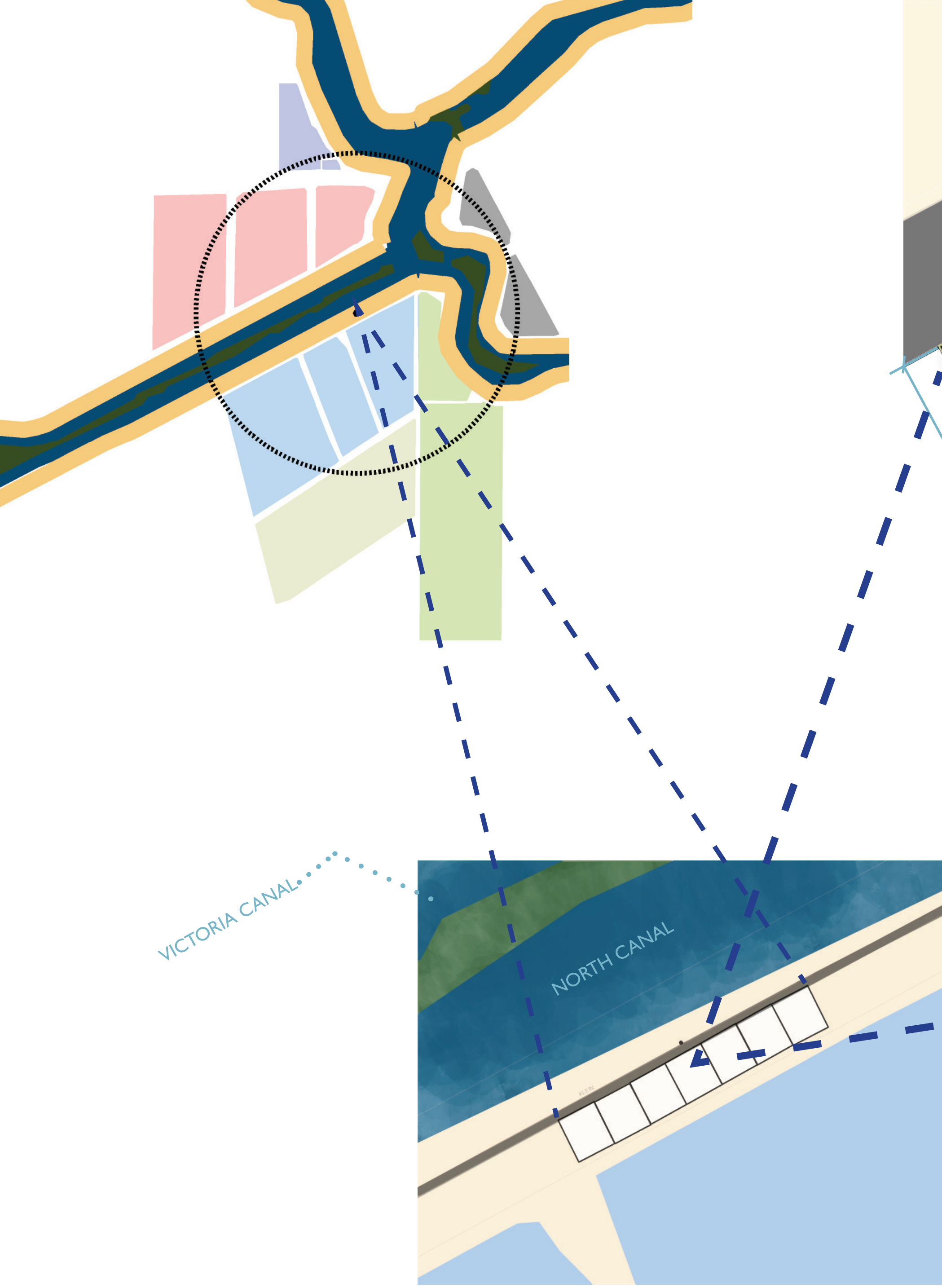


Figure 41| Each pollinator patch is 5,000 sq ft and can be replicated as many times as necessary on the levee.

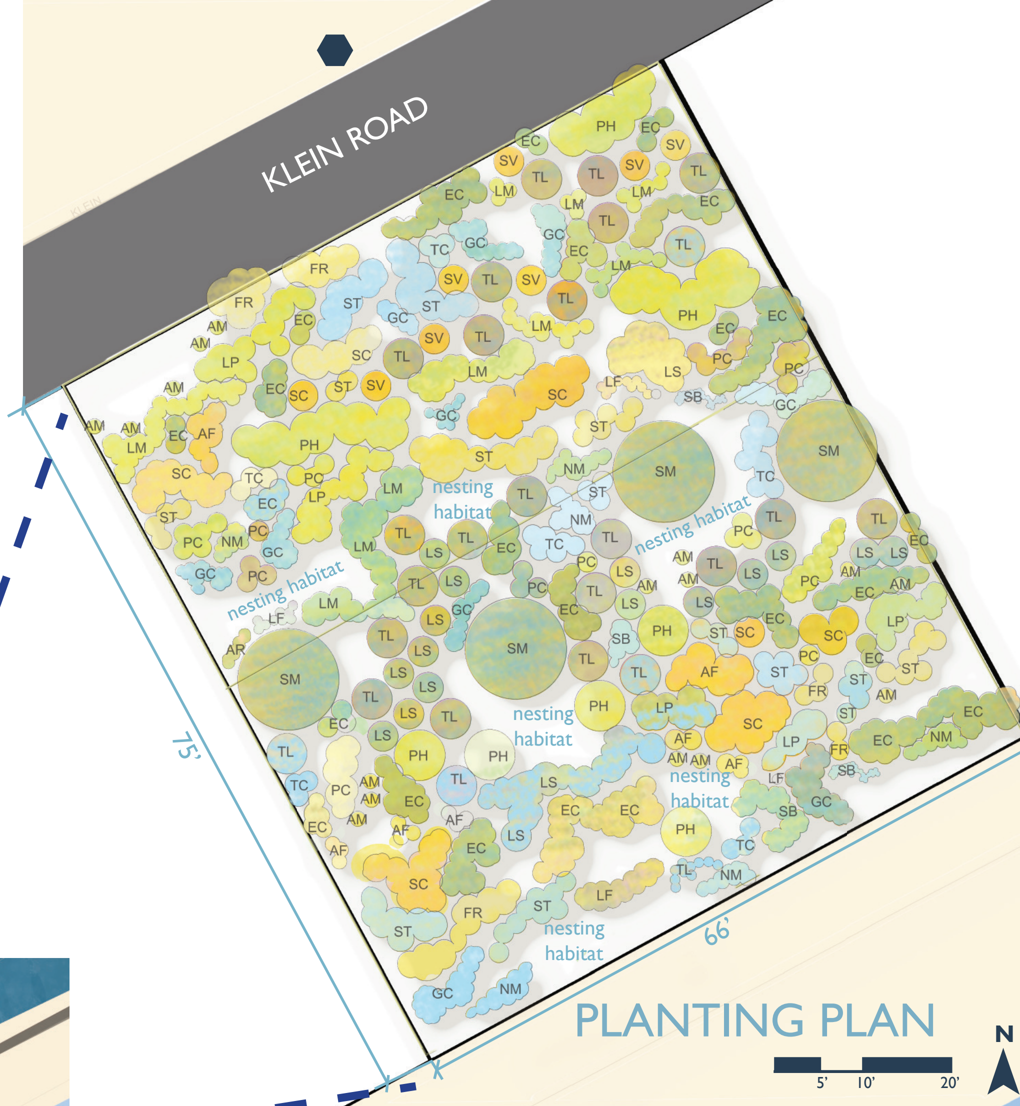


Figure 42| Planting Plan features a diverse array of flowering plants with 2 grasses for levee stabilization, weed and flower control. Areas of barren ground is required for nesting habitat.

As discussed previously, bees see ultraviolet light. As a result, they are particularly attracted to flowers that are blue, yellow, white and purple. In addition to flowering plants, two native grasses are included for the purpose of weed maintenance and stabilizing levee slopes.

The initial direction of the project was interested at targeting specific species of native bees. However, the new selection of plants feature a variety of native flowering plants all under 5 feet tall, are blue, white, purple, yellow or pink, and are available at farms within a 100-mile radius from the San Joaquin Delta. A handful are annuals and should be grouped together. Although the flowers bloom at different times, it is best to weave them together in plantings of at least 1square meter (4 sq ft). This will prevent the levee from having clumps of blooming flowers throughout the season. Two additional grasses are added to the mix. Native grasses help naturally keep weeds out, and can help with bank stabilization. It is important but not essential to have all plants be native, as long as non-native plants are non-invasive. Having native plants are beneficial due to their innate adaptation to the landscape and the adaptation of the native bees to native plants. However, there are nonnative species that work just as well in attracting native species. If choosing these species, it is important to consider the plant's growth habits and monitor it to prevent it from out competing all the natives or invading agricutlural fields. None of the selected plants in this project are classified as invasive from the California Invasive Plant Council (Cal IPC).

MEET THE PLANTS

Hedgerow Farms
21905 County Road 88
Winters, CA 95694

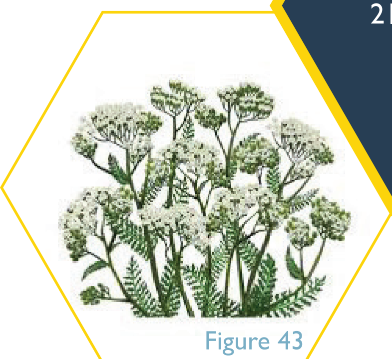


Figure 43

Achillea millefolium


Figure 44


Figure 46

Eschscholzia californica

Lupinus formosus


Figure 45

Lupinus succulentus


Figure 47


Figure 48

Lupinus microcarpus var densiflorus


figure 49

Phacelia californica

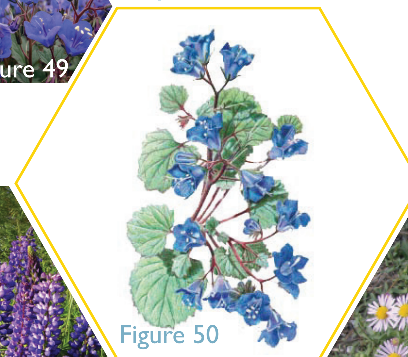


Figure 50


Figure 51

Sisyrinchium bellum

Symphyotrichum chilense


Figure 52


Figure 53

Solidago velutina californica


Figure 54


Figure 55

Layia platygossa

Trichostema lanceolatum

Elderberry Farms
2140 Chase Dr,
Rancho Cordova, CA 95670


Figure 56

Gilia capitata

Nemophila menziesii


Figure 57

Cornflower Farms
9811 Sheldon Rd,
Elk Grove, CA 95624

Asclepia fascicularis


Figure 58


Figure 59

Festruca rubra 'Molate'

Penstemon heterophyllus


Figure 60

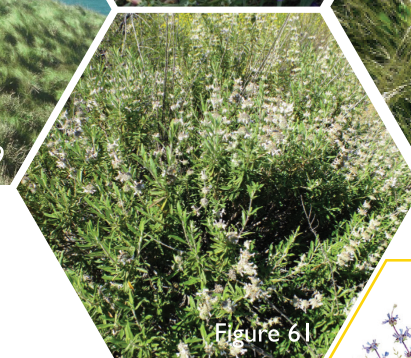


Figure 61

Salvia Millifera


Figure 62


Figure 63

Stipa cernua

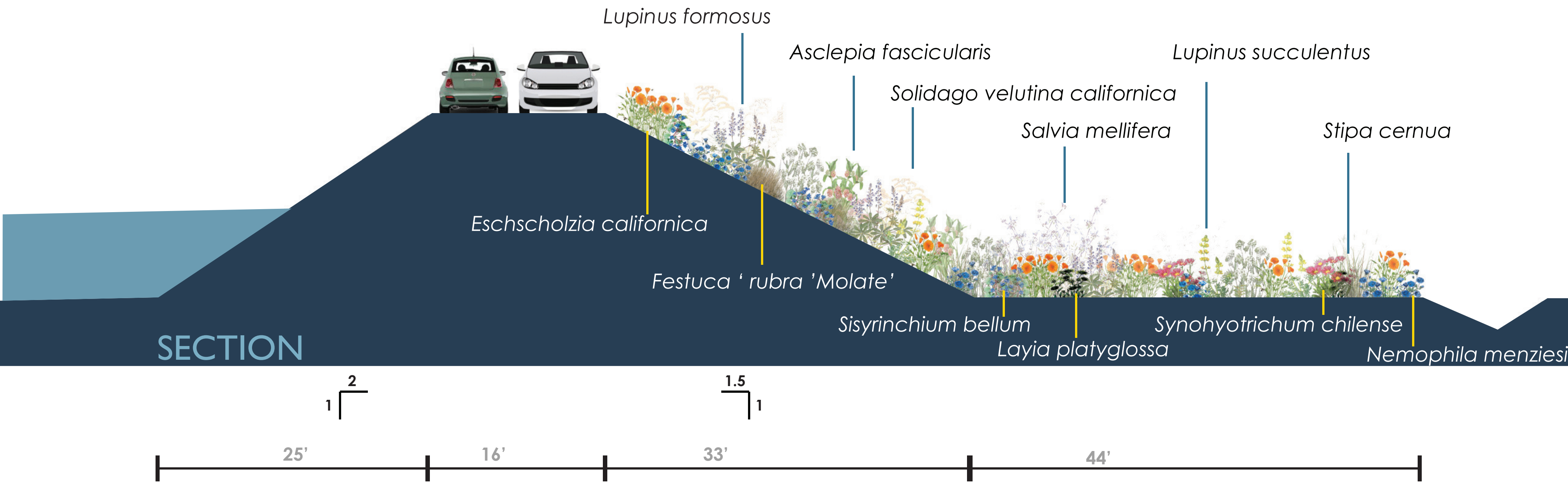
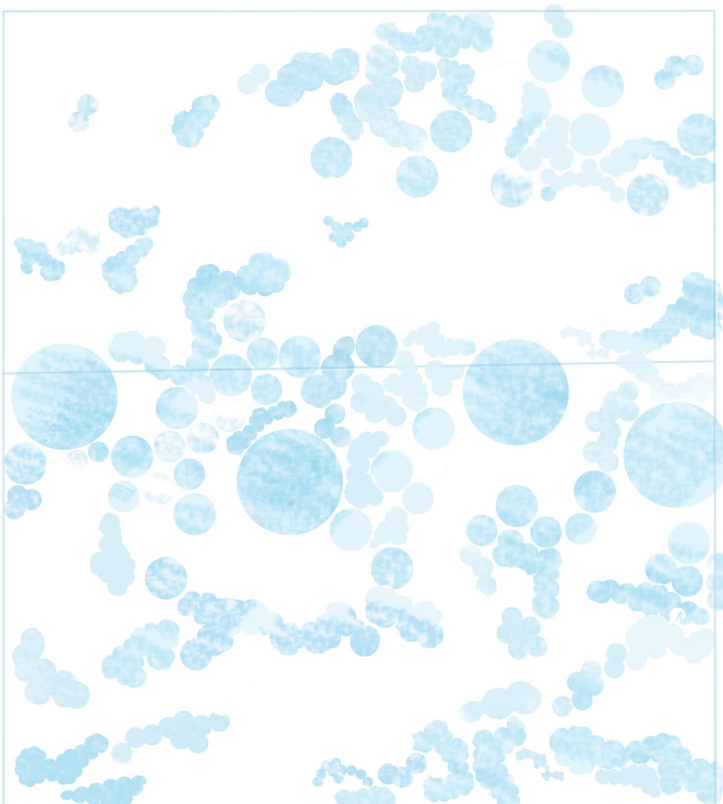


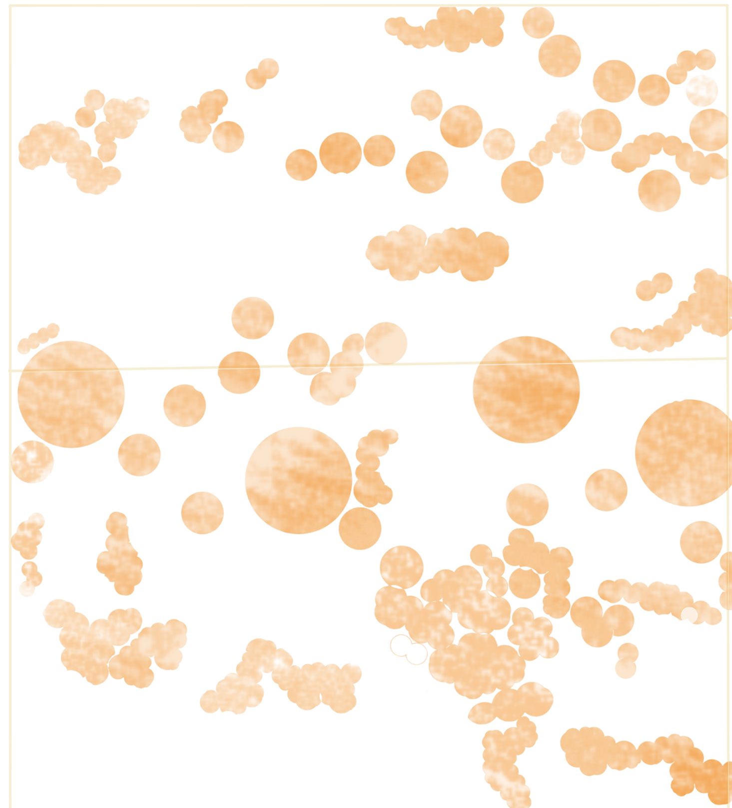
Figure 65 | Section cut of levee



WINTER

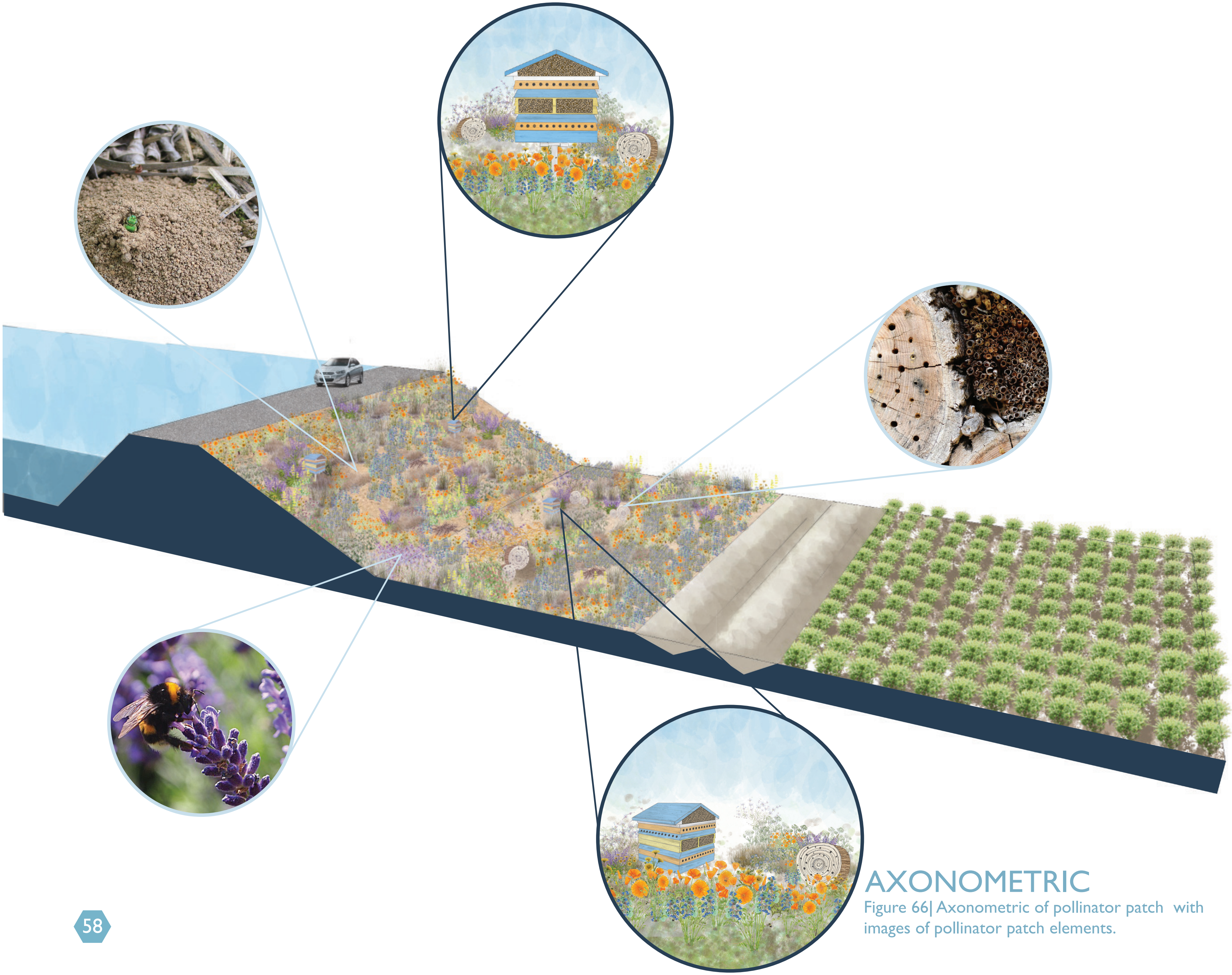
SPRING

SUMMER



FALL

figure 64 | Plants flowering during the different seasons



AXONOMETRIC

Figure 66| Axonometric of pollinator patch with images of pollinator patch elements.

NESTING

Along with a variety of flowering plants, pollinator patches must have nesting resources for native bees. This will ensure that native bees will stay in the area and reproduce. Nesting resources provided should include areas of bare soil for ground nesting bees, piles of twigs, bee hotels, and a variety of hollow twigs and cavities such as those in figure 66. The more variety of nesting resources provided at the patch, the more variety of native bees will be seen. It is best to cluster fall and winter flowering plants near nesting resources to minimize the distance native bees have to travel to forage for food in preperation for hibernation.

IMPLEMENTATION

A project like this could be implemented through a Resource Conservation District (RCD). RCDs are special districts created by the state of California. They have locally appointed or elected, independent boards of directors that implement projects on public and private land to educate both landowners and the public about resource conservation. RCDs conduct projects on watershed planning and management, water conservation, agricultural land conservation, soil and water management on non-agricultural lands, wildlife habitat enhancement, irrigation management, conservation education and more. State of California 2017).

For the site in this project, pollinator patches would implemented by the San Joaquin County Resource Conservation District. The San Joaquin County RCD has incentive programs for farmers to engage in resource conservation. This project would fall under the Environmental Quality Incentives Program (EQIP). The Delta has the Bay Delta Initiative that works with the Natural Resource Conservation Service, RCDs and other local partners to address water issues and habitat restoration needs of the Bay Delta region. The organization fosters voluntary partnerships with landowners and farmers to create conservation projects that are then funded through EQIP ("Natural Resources Conservation Service" 2018).

Figure 67|Perspective of landscape after implementing pollinator patch concept

CONCLUSION

How can native bee habitat be conserved in the Sacramento-San Joaquin Delta to be mutually beneficial to farmers?

Native bee habitat can be conserved in the Sacramento-San Joaquin Delta by identifying undeveloped or unused space and determining if it is viable for pollinator habitat. Areas that are closer in proximity to crops are more suitable because of native bee flight limitations. Bees in general have evolved to pollinate plants. If the crops have flowers, they are considered food resource and will be pollinated if they are within the foraging distance of the species.

What space is available within the agricultural matrix for bee conservation?

Besides edges of fields, the existing levee system within the site boundary makes up 11,000 acres. This land holds no agricultural value other than keeping the Delta water at bay. Because of the levees are a necessity in the Delta, they will be there as long as agriculture remains in the area.

Agriculture has been a leading industry in the San Joqauin Delta for many years. This is not likely to change in the near future. Its dependence upon managed honey bees have made farmers susceptible to financial strain due to the occurence of CCD since the mid 2000s. Although the apiary industry has seen an increase in gross value, the cost for farmers to import honey bee hives impacts the cost of food for everyone. This project looks at ways we can lower that dependence by providing an alternative source of pollination services.

The Pollinator Patch Concept has the ability to adapt and change with the landscape, ensuring pollination sustainability. It bridges the needs of farmers as well as needs of native bees to create a design that benefits both parties. This is only possible by looking at current research on native bees, analyzing temporal and spatial data to identify patterns and areas of suitability.

This project takes on a conservative approach, utilizing the 600m foraging range to determine the feasibility of using the levees for native bee habitat. The regional analysis showed that there are crops within the 600m range that require pollination services. Having crops within the forgating range is integral as well as providng natural habitat.

Once the relationship between the crops and levees are established, elements for native bee habitat on the levee can be determined. Two elements are identified that are essential in attracting and keeping native bees, adequate foraging and nesting resources. One of the reasons native bees have a difficulty in thriving in an agricultrual matrix is the lack of food year round. Most crops bloom in spring and summer leaving the landscape barren during fall and winter. Fall and winter are integral times for native bees. During this time, native bees gather food in preperation for reproduciton and hibernation. Providing adequate floral resources during these seasons will greatly increase the chances of maintaining native bee populations in the area. The project incorporates a variety of native plants that bloom during different seasons. The plants chosen have been identified by researchers to be beneficial and attractive to native bees. With the new planting list along with a variety of nesting types, Pollinator Patches have promise to bring native bees back to agricultural lands.

The Pollinator Patch Concept is just the beginning. Although the range maps (figure 23 & 24) show coverage of much of the regional area, there are still areas that fall outside the service range. Further development of the project would include addressing the the gaps in pollination service from the Pollinator Patch Concept, and implementing and testing the patches. This may include but is not limited to the cost of maintanence, the sighting of bees, and comparing honey bee hive rental numbers before and after installation of the patch.

There is still much to learn and understand about native bees. Solutions to the issue should consider the regional and local context. There are many stakeholders that play a role in saving not only native bees, but our food supply. Both the public and private sectors play an intergral part through policy making, research, and action to convert areas for habitat to solve the issue at hand.

IF WE DIE , WE'RE TAKING YOU WITH US

APPENDIX

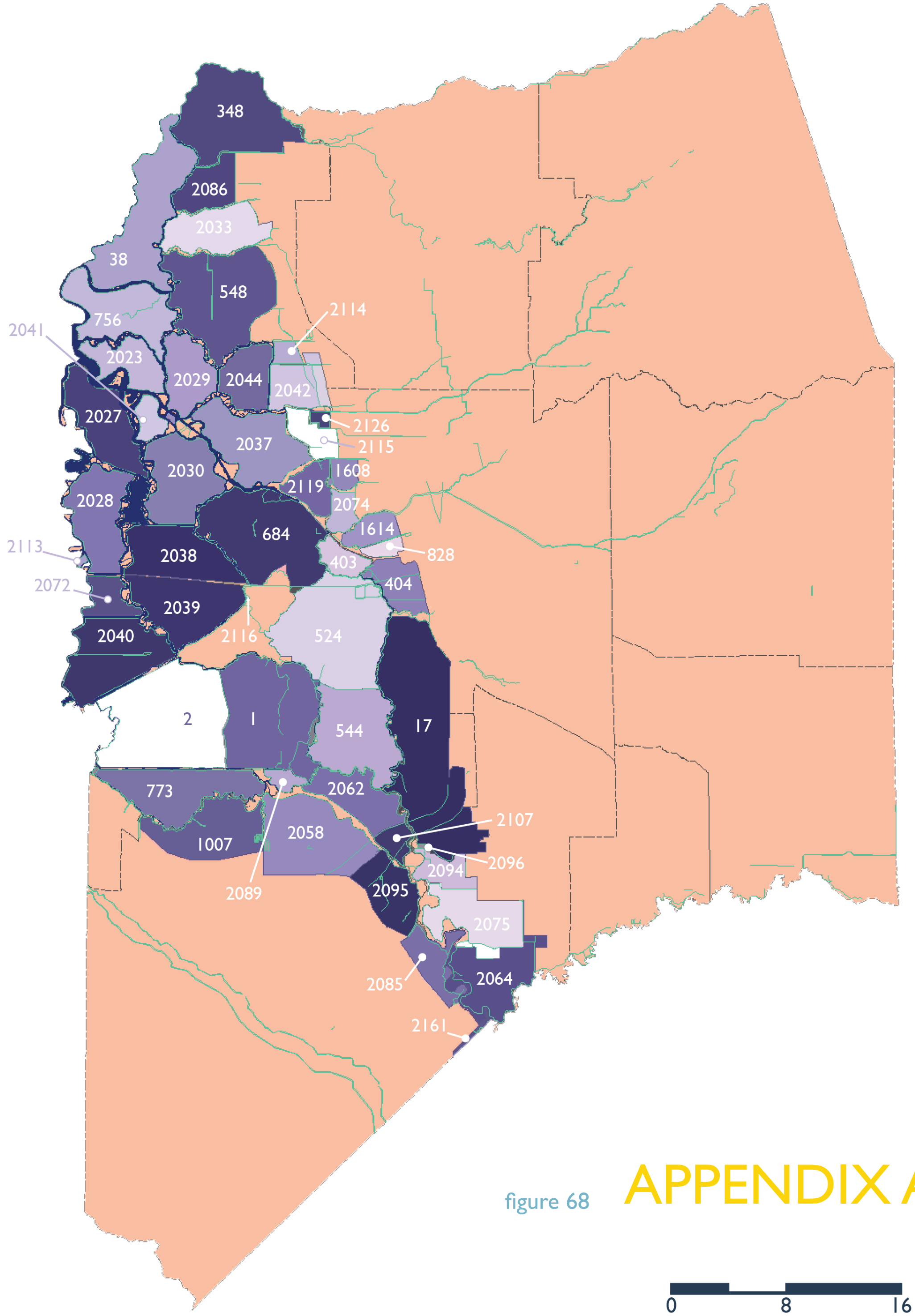


figure 68

APPENDIX A

RECLAMATION DISTRICT

1	UNION ISLAND
2	UNION ISLAND
17	MOSSDALE
38	STATEN ISLAND
348	NEW HOPE
403	ROUGH AND READY ISLAND
404	BOGGS TRACT
524	MIDDLE ROBERTS ISLAND
544	UPPER ROBERTS ISLAND
548	TERMINOUS
684	LOWER ROBERTS ISLAND
756	BOULDIN ISLAND
773	RABIAN TRACT
828	WEBER TRACT
1007	PICO AND NAGLEE
1608	SMITH TRACT
1614	SMITH TRACT
2113	FAY ISLAND
2114	RIO BLANCO TRACT
2115	SHIMA TRACT
2118	LITTLE MANDEVILLE ISLAND
2119	WRIGHT-ELMWOOD TRACT
2023	VENICE ISLAND
2027	MANDEVILLE ISLAND
2028	BACON ISLAND
2029	EMPIRE TRACT
2030	MCDONALD ISLAND
2033	BRACK TRACT
2037	RINDGE TRACT
2038	LOWER JONES TRACT
2039	UPPER JONES TRACT
2040	VICTORIA ISLAND
2041	MEDFORD ISLAND
2042	BISHOP RANCH
2044	KING ISLAND
2058	PESCADERO DISTRICT
2062	STEWART TRACT
2064	RIVER JUNCTION
2072	WOODWARD ISLAND
2074	SARGENT-BARNHART TRACT
2075	MCMULLIN RANCH
2085	KASSON DISTRICT
2086	CANAL RANCH
2089	STARK TRACT
2094	WALTHALL
2095	PARADISE JUNCTION
2096	WETHERBEE LAKE
2101	BLEWETT
2107	MOSSDALE
2108	TINSLEY ISLAND
2116	HOLT STATION
2126	ATLAS TRACT

APPENDIX B

HEDGEROW FARMS

Located in Winters, CA, Hedgerow Farms is bringing back an old time landscape feature that will help provide many environmental benefits. The group promotes and educates farmers and the public about the use of hedgerows on edges of farm fields to increase habitat, prevent erosion, weed control, bank stabilization, reduce groundwater pollution and many more. Hedgerows are a great way to create stepping stones for wildlife to move across the agricultural matrix. A diversity of shrubs and forbs are used to provide year-round flowering (Earnshaw 2018). The Pollinator Patch Concept draws from these ideas to create habitat for native bees.


figure 69| Zamora Ca hedgerow adjacent to almonds


figure 70|deer in native grass production field


figure 71| native-plant plugs grown at Hedgerow Farms


figure 72| Deer

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