POLLINATORS AND CLIMATE CHANGE

Building Climate Resilience into Pollinator Habitat Restoration in the Central Valley

LEFT: Climate-smart habitat includes a variety of native flowering plants. CENTER: Native bees provide vital pollination services in most terrestrial habitats, including cropland, urban areas, rights-of-way, and natural areas. RIGHT: Creating habitat, increasing habitat connectivity, and reducing other stressors will help declining species like the monarch butterfly (*Danaus plexippus*) become more climate resilient. (Photographs: left, Xerces Society / Jessa Kay Cruz; right, Xerces Society / Stephanie McKnight.)

More than 80% of terrestrial plant species require an animal pollinator (usually an insect) to reproduce. About one-third of food production depends on pollinators, and 75% of all fruits and vegetables produce higher yields when visited by pollinators. Unfortunately, pollinators are in decline.

A recent global analysis by the United Nations found that more than 40% of pollinator species may be at risk of extinction (IPBES 2016). A recent analysis by the Xerces Society and the International Union for Conservation of Nature found that 28% of bumble bee species in North America are at risk of extinction, including eight species of bumble bees in California. In the Central Valley, butterfly diversity and abundance is declining as well (Forister et al. 2010, 2011).

While habitat degradation, pesticides, and disease all contribute to pollinator decline, climate change is an increasingly significant stressor that may interact with these to further drive the decline of pollinators. A loss of pollinators in the Central Valley will affect both agricultural and natural ecosystems.

Pollinators are essential to the reproduction of many of California's specialty crops, including tomatoes, peppers, melon, squash, cotton, and almonds, as well as to natural ecosystems. California crops account for more than 13% of the nation's total agricultural value, and protecting pollinators is an important component of protecting California's agricultural legacy.

Farms, natural areas, rights-of-way, and urban spaces can all play a role in making the Central Valley a climate-resilient landscape for pollinators.

How Will Climate Change Affect Pollinators?

Climate change will alter a suite of variables that affect pollinators, including temperature, precipitation, humidity, and the frequency and intensity of extreme events (see Box 1). These abiotic variables can affect other important environmental parameters such as snowpack, the timing of snowmelt, and the severity and frequency of drought and flooding events, all of which may affect pollinators and their host plants.

Climate change will have a variety of effects on pollinators (see Box 2), including species range shifts, altered phenology, changes to species' physiological processing rates, altered species interactions, and changes to the diversity, quantity, and quality of floral resources; finally, climate change may exacerbate the effects of other stressors, such as habitat loss or pathogen exposure. These effects of climate change on pollinators are not mutually exclusive, as pollinators are likely to experience multiple effects of climate change. While some species may fare better under climate change, many species will be negatively

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Climate change is more likely to negatively affect specialists, such as the lilac-bordered copper (*Lycaena nivalis*), top, and declining species, such as the sylvan hairstreak (*Satyrium sylvinus*), bottom (Forister et al. 2011), than generalists or species with large, stable populations. (Photographs: Eric Laws.)

affected. In general, species that are specialists and species that are already experiencing declines are most likely to be negatively affected by climate change.

The magnitude of warming will also play a role in determining how strongly insects are affected. A recent study by Warren et al. (2018) modeled the distributions of different taxa under different climate change scenarios. With warming of 1.5°C above preindustrial levels, 6% of invertebrates were estimated to lose at least 50% of their range. At 2°C, this increased to 18%; at 3.2°C, 49%. Warming of 3.2°C above preindustrial levels is expected if countries meet only the minimum emissions reductions currently proposed under the Paris Climate Agreement, but make no further reductions.

Recommendations to Mitigate Effects of Climate Change on Pollinators

Given the wide variety of ways climate change may affect pollinators, strategies that mitigate these negative impacts are likely to sustain pollinator communities into the future. The Xerces Society is working with partners to restore and enhance pollinator habitat in the Central Valley in agricultural, urban, and natural areas, as well as along roadsides and other rights-of-way. Xerces' habitat-restoration projects in the Central Valley use a variety of drought-tolerant native plants and work to reduce pesticide pressure. This section recommends habitat-restoration practices that can increase climate resiliency of pollinators.

Enhance and Restore Connected Habitat

Enhancing and restoring pollinator habitat is crucial for improving climate resiliency of pollinator communities. Habitat with abundant pollinator-attractive floral resources that bloom throughout the season (spring through fall) is required to support large, stable, and diverse pollinator communities, which should better withstand bad years and extreme weather events that become more frequent with climate change. A diverse pollinator community is critical to maintaining the ecosystem service of pollination despite climate change. For example, Winfree et al. (2018) show that while a few species of bees may provide the majority of pollination services at a single site, a diverse bee community is necessary to maintain pollination services at a landscape scale, due to differences in bee composition among sites.

Creating and protecting habitat throughout the Central Valley—within the agricultural matrix, on rights-of-way, and in natural areas and urban settings—can help buffer pollinators from extreme weather events by creating important refugia for pollinators (spaces where they can be protected from heatwaves or other extreme weather events). This habitat also provides important pollinator nesting sites that may be less abundant in cultivated areas.

As species' distributions shift with climate change, land managers may eventually find new ecological communities forming and discover that some species' optimal habitats shift. Protecting and enhancing habitat now will help ensure that optimal areas for species of concern and host-plant specialists will be available under future climate scenarios.

Improving habitat connectivity is another key aspect of creating a climate-resilient environment. Habitats created in farms, roadsides, and urban areas are important as movement corridors to connect larger natural areas, which can act as reservoirs of pollinator diversity. Habitat corridors and stepping stones allow bees, butterflies, and other insect pollinators to move around the landscape and to migrate into new areas. While not all species will change distributions in response to climate change, increasing habitat connectivity provides the opportunity for those that will. Improving habitat connectivity will enable individuals to move among populations, increasing gene flow and helping to prevent populations from becoming too small.

Climate-smart habitat prioritizes biodiversity. A diverse plant community will support more pollinators than a species-poor plant community and is more likely to support specialist pollinators. Soils in habitat with high plant diversity sequester more carbon than soils in areas with low plant diversity. (Photograph: Xerces Society / Jessa Kay Cruz.)

Steps to Creating a Climate-Resilient Landscape for Pollinators

Provide diverse floral resources, including a diverse flowering phenology

Xerces recommends that pollinator habitat–restoration projects should ensure that at least three species of nectar plants bloom at all times during the season of activity for bees and butterflies (generally from mid-March to the end of October in the Central Valley). This practice will help reduce the effects of phenological mismatches (see Box 2) between hosts and pollinators by ensuring that some plants will be available. However, this may be more effective for generalist pollinators than for specialists that need specific plant species. If possible, work to better understand what specialist pollinators might be found on the property in question and develop a restoration plan tailored for both generalists and specialists. This might include providing specific flowering resources for bees as well host plants for at-risk butterflies. To aid restoration projects, Xerces has created a list of host plants for specialist bees, specialist butterflies, and butterflies known to be declining in California. Please contact centralvalleypollinators@xerces.org for a copy of these data.

Climate change is likely to also affect the quantity and quality of floral resources for pollinators. Increased drought frequency is projected for California, and drought-stressed plants produce fewer flowers with less nectar, lowering pollinator carrying capacity. In addition, abiotic factors associated with climate change, such as increased temperature or atmospheric CO_2 concentrations, could affect the quantity and quality of nectar and pollen as well as floral attractiveness to pollinators (Ziska et al. 2016; Glenny et al. 2018). Because the effects of climate change on these plant traits are likely to be species specific, having a diverse array of flowering plants will help ensure pollinators have the resources they need. This type of species-specific response to climate change may mean some of the pollinator plants we currently recommend will be of lower quality to pollinators in the future. To help guide future plant-selection decisions, adaptively manage and monitor pollinator use and preference for floral resources and host plants.

Finally, a diverse plant community will have greater habitat heterogeneity that can provide an array of microclimates, which will serve as important refugia for pollinators during heatwaves and other extreme weather events.

Use drought- and heat-tolerant native plants

We recommend the use of drought-tolerant native plant species in pollinator habitat–restoration projects in the Central Valley. California is projected to experience increased drought frequency and severity, so this practice will help ensure that floral resources are available to pollinators, even in dry years. Xerces has prepared lists of appropriate plant species for California pollinators.

Provide nesting habitat for native bees

When many people think about bees they think about honey bee hives or bumble bee nests; however, the vast majority of bees are solitary—either nesting in the ground or in wood. About 70% of native bees nest in the ground, and leaving some ground bare will provide

TOP: Providing appropriate nesting habitat for native bees is an important component of climate-smart habitat. Ground-nesting bees need areas of bare soil to dig their nests, while cavity-nesting bees often use pithy-stemmed plants. LEFT: Hedgerows and other linear habitats are excellent for increasing habitat connectivity. RIGHT: Climate-smart habitat in California and much of the arid West relies on the use of drought-tolerant native plants, such as this penstemon (*Penstemon heterophyllus*). Native plants are more likely to be used by a variety of pollinators, including specialists. (Photographs: Sara Morris; Xerces Society /Jessa Kay Cruz; Xerces Society / Kitty Bolte.)

areas for these species to build nests. About 30% of native bees nest in wood or pithy-stemmed plants. Retaining downed logs and snags will provide nesting habitat for some of these species, while planting native, pithy-stemmed plants like elderberry or goldenrod will provide nesting habitat for others. Appendices E and F of Xerces' *Bee Better Production Standards* contain lists of common plants used by cavity-nesting bees. In general, a diverse plant community is more likely to provide necessary nest sites and nesting materials for a diverse community of pollinators.

Provide corridors for pollinators

Pollinators will need high-quality travel corridors and stepping-stone habitats to move across the landscape in search of new climate niches. A variety of urban and rural landscapes can provide habitat connections, including farms, rangelands, roadsides, and urban and suburban parks. Recent research indicates that existing linear habitats, such as field borders, hedgerows, roadsides, and greenways, can act as corridors for pollinators. Providing additional habitat along roadsides and managing and restoring farm hedgerows, power line corridors, and other linear habitats may allow species to move across the landscape to more hospitable areas as climate changes.

Remove other stressors to native pollinators

The effects of climate change on pollinators can combine with other stressors. Often, the effects of multiple stressors together can be greater than expected based on the effect of each stressor alone, exacerbating negative effects on pollinators. Mitigating the effects of climate change on pollinators will require efforts to reduce other important stressors such as exposure to pesticides and pathogens.

- **Reduce pesticide use.** Pesticide use is likely to increase with climate change due to faster generation times and increased performance of insect pests expected at higher temperatures (Delcour et al. 2015). The use of pesticides—including insecticides, fungicides, and herbicides—can harm pollinators. Moreover, pollinators are often exposed to multiple pesticides, potentially magnifying negative effects of each pesticide on exposed pollinators. These exposures, combined with climate change, could further magnify negative effects on many pollinator species. We recommend incorporating physical, mechanical, and other nonchemical pest-management methods into pest-management plans and using pesticides only when pest levels pose economic harm. Xerces' fact sheets *Guidance to Protect Habitat from Pesticide Contamination* and *Protecting Pollinators from Pesticides: Fungicide Impacts on Pollinators* include recommendations on placement of habitat relative to treated areas and ways to implement diverse mitigation measures to reduce exposure. Designing and implementing an integrated pest management plan and working to reduce dependence on pesticides can reduce the total number of stressors on pollinators, making pollinator communities more resilient to the effects of climate change.
- **Reduce exposure to pathogens.** Exposure to pathogens is likely an important driver of many native bee declines. Pathogens can be transmitted from managed pollinators—such as honey bees, commercial bumble bees, and orchard mason bees—to wild bees. To reduce the risk of pathogen exposure to native pollinators, we

Exposure to pathogens from managed pollinators can be detrimental to native bees and is implicated in the declines of several bumble bee species, including *Bombus occidentalis*. Reducing additional stressors, such as pathogen exposure from managed bees, is an important component for building climate resilience in pollinators. (Photograph: Rich Hatfield.)

recommend limiting the placement of managed bees near native pollinator habitat in natural areas. We also recommend not using managed bumble bee colonies in open-field situations. If managed bumble bees are used in greenhouses, they should be well screened with queen excluders to prevent managed bees from escaping the greenhouse. Xerces has created recommendations for honey bee hive placement in natural areas, and you can find more on the conservation concerns associated with use of commercial bumble bees in the publication *Conserving Bumble Bees: Guidelines for Creating and Managing Habitat for America's Pollinators* (see Additional Resources).

Maintain high genetic diversity

An additional key to climate resilience is evolutionary resilience. In response to a changing climate, species must either move to areas with a more favorable climate or adapt to the new climate. Those that cannot move or adapt face extinction. The ability to adapt to climate change will depend on the amount of genetic variation in a population. Conservation practices that enhance and maintain genetic variation, in both pollinators and their host plants, may further resilience to climate change (Sgrò et al. 2011). Larger populations tend to have higher genetic variation than smaller populations; therefore, increasing habitat availability and connectivity, which increases population sizes, will also increase genetic variation. High habitat connectivity also increases genetic variation through increased gene flow.

Box 1. Projected Climate Change Effects in California

- The average daily temperature is expected to increase approximately 2–6°C by the year 2100.
- Between 2070 and 2100, increased temperatures will minimize weather differences among seasons.
- Heatwaves and extreme temperatures will increase.
    - Between 2070 and 2100, the proportion of days with extreme temperatures is expected to increase from 5% of the year (now) to approximately 12–30% of the year.
    - By 2100, the season for heatwaves, with each wave defined as 3 or more days above 32°C (89.6°F), will increase by 5–13 weeks per year.
- No clear changes in precipitation are expected by 2100, but there will be a slight trend toward increased winter precipitation.
    - Some models show decreased winter precipitation of 15–30% in the Central Valley.
    - Events with extremely heavy precipitation are likely to become more frequent.
- Increased winter temperatures mean more precipitation will fall as rain instead of snow, leading to reduced snowpack.
    - Snowpack is projected to decrease 12–47% by 2060 and 90% by 2100.
    - More runoff will occur earlier, in winter instead of spring.
- Drought length and frequency will increase.
    - The proportion of dry years will increase from 32% (now) to 50–64% by 2100.
- Sea levels will rise 13–89 cm (5⅛–35¹⁄₁₆ in.) by 2100.

Box 1 references: Bedsworth et al. 2018; Hayhoe et al. 2004; Cayan at al. 2008; Swain et al. 2018

Special Considerations for Different Land-Use Types

Natural areas

Natural areas are important for providing high-quality habitat to a diverse assemblage of pollinators. Natural areas adjacent to farms have been shown to increase pollinator services on those farms. An added benefit to protecting and restoring natural habitats is that intact ecosystems act as carbon sinks, providing natural climate solutions that can help achieve international goals to limit the magnitude of climate change (Griscom et al. 2017), and therefore limit the impacts of climate change on pollinators and other organisms. Forests and reforestation are a primary component of natural climate solutions, but grasslands and well-managed rangelands can also contribute significantly to carbon sequestration, especially in arid regions like California (Dass et al. 2018).

Box 2. Potential Effects of Climate Change on Pollinators

Climate change will have a variety of effects on pollinators.

- Species range shifts: Species may change their distributions to track more optimal climates. In general, species are expected to shift poleward or to higher elevations. However, not all species will respond in the same way, meaning that range shifts can lead to spatial mismatches between pollinators and their host plants. As ranges shift, habitat corridors will be necessary for species to move through.
- Altered phenology: Phenology is the timing of biological events. Shifts in phenology in response to climate change may be especially problematic if pollinators and the plants they rely on respond differently, leading to phenological mismatches.
- Changes to species' physiological processing rates: Processes such as metabolism or growth are temperature dependent in insects, meaning that climate change can affect pollinator performance (e.g., survival, fecundity, size at maturity, etc.) through physiological responses.
- Altered species interactions: Climate change can affect the outcome of species interactions, such as competition, predation, or disease.
- Changes to the diversity, quantity, and quality of floral resources: Plants will also respond to climate change. Changes in plant diversity or community composition will affect competitive relationships among pollinators. Specialist pollinators should be especially sensitive to such changes in plant communities. Drought, heatwaves, temperature rises, and increasing atmospheric CO_2 concentrations can all affect the quantity and quality of pollen and nectar.
- Combined stressors: Climate change may exacerbate the effects of other stressors, such as habitat loss, pesticide use, and pathogen exposure, magnifying effects on pollinators.

Agricultural areas

Since agriculture is widespread in the Central Valley landscape, extensive opportunities exist to work with producers to create climate-smart habitat for pollinators in the form of hedgerows, cover crops, and other wildflower plantings. These agricultural pollinator habitats are vital for increasing habitat connectivity within the Central Valley, and for connecting natural areas within and outside the valley. Furthermore, studies have found that natural areas can ameliorate the negative impacts of high temperatures on pollinators in agricultural areas. For example, one study in Germany found that the negative effects of increased temperatures on bee diversity were reduced in areas with higher availability of natural habitat, such as hedgerows (Papanikolaou et al. 2017).

As temperatures increase with climate change, many insect crop pests may increase rates of feeding and population growth. Because of this, an increase in pesticide use is expected with climate change (Delcour et al. 2015). Hedgerows and cover crops promote populations of beneficial insects, including predators, which may lessen the need for pesticides. Care should be taken to minimize pesticide contamination of pollinator and beneficial insect habitat. Integrated pest management and alternative methods may help reduce pesticide use. In agricultural areas, pesticide use can be reduced while still retaining profitability and productivity (Lechenet et al. 2017), and recent research shows that pollinator abundance correlates with positive economic returns, while pesticide use does not (Catarino et al. 2019).

Finally, well-managed cropland with healthy soils can also serve as carbon sinks, contributing to natural climate solutions (Griscom et al. 2017). The COMET-Planner website (see Additional Resources) estimates the carbon-sequestration benefits that can be achieved through different conservation practices recommended by the Natural Resources Conservation Service and the California Department of Food and Agriculture Healthy Soils Program, demonstrating how producers can be part of the solution to climate change.

Urban areas

Urban areas tend to be warmer than the surrounding landscape. This phenomenon, called the urban heat island effect, is caused by the large amount of impervious surfaces (such as concrete or asphalt) found in urban areas. The urban heat island effect can exacerbate the effects of rising temperatures and heatwaves on pollinators. However, urban areas can also provide valuable, high-quality habitat for pollinators, and many cities have diverse pollinator communities. Using a variety of native plants to create pollinator gardens near homes and offices or in parks can expand habitat availability for pollinators. Planting trees and other vegetation, as well as removing asphalt and concrete where appropriate, can reduce the urban heat island effect, further protecting our urban pollinators while also providing important carbon-sequestration services. Xerces recommends eliminating cosmetic use of pesticides and avoiding the use of neonicotinoids and other systemic pesticides, which stay in the ecosystem for months or years, continuing to affect pollinators long after they were applied.

Roadsides and other rights-of-way

Habitat along rights-of-way can be valuable for many native bees and butterflies. Because roadsides and other rights-of-way create vast networks across the landscape,

TOP LEFT: Creating pollinator habitat along roadways, power lines, and other rights-of-way can significantly increase habitat connectivity—a key part of increasing climate resiliency for pollinators. TOP RIGHT: Restoring and enhancing pollinator habitat will increase pollinator diversity and population sizes, which will help pollinator communities be more resilient to climate change. LOWER LEFT: People living in cities and towns can help by creating pollinator gardens that use a variety of native plants protected from pesticides. LOWER RIGHT: Many sustainable farming practices can provide the dual benefits of protecting pollinators and helping to mitigate climate change. For example, cover crops can provide important resources for pollinators while improving soil health and increasing carbon sequestration. (Photographs: Anita Gould / Flickr; Stephanie McKnight; California Native Plant Society / Flickr Creative Commons Attribution 2.0 Generic; Xerces Society / Jessa Kay-Cruz.)

linear habitats created or maintained alongside them are key to improving habitat connectivity for California pollinators. Plants used in right-of-way habitat must be able to persist without irrigation, while still providing floral resources to pollinators. Hot, dry summers typical of the Central Valley and frequent drought make it especially important to use drought-tolerant native plants in these habitats. Reducing the use of pesticides as much as possible in these areas will help create climate-smart habitat for pollinators.

Summary

Climate change presents an unprecedented challenge for humanity. While this challenge can feel overwhelming, there are steps we can take to help reduce the impacts of climate change and make our pollinators more resilient to its effects. By taking advantage of the unique opportunities created by agricultural areas, rights-of-way, urban areas, and natural habitats, we can increase habitat availability and connectivity for pollinators in the Central Valley while simultaneously increasing carbon sequestration.

The Xerces Society is currently working to increase habitat availability and connectivity for pollinators in the Central Valley. By partnering with a variety of land managers and landowners, we work together to ensure that restoration efforts incorporate considerations of pollinators and climate change. Please contact us at centralvalleypollinators@xerces.org if you are interested in partnering with us or would like more information.

Additional Resources

COMET-Planner: http://comet-planner-cdfahsp.com/

Xerces Society, *An Overview of the Potential Impacts of Honey Bees to Native Bees, Plant Communities, and Ecosystems in Wild Landscapes: Recommendations for Land Managers*: https://xerces.org/publications/guidelines/overview-of-potential-impacts-of-honey-bees-to-native-bees-plant

Xerces Society, *Bee Better Production Standards*: https://www.beebettercertified.org/docs

Xerces Society, *Conserving Bumble Bees: Guidelines for Creating and Managing Habitat for America's Declining Pollinators*: https://xerces.org/publications/guidelines/conserving-bumble-bees

Xerces Society, *Guidance to Protect Habitat from Pesticide Contamination*: https://xerces.org/publications/fact-sheets/guidance-to-protect-habitat-from-pesticide-contamination

Xerces Society, *Protecting Pollinators from Pesticides: Fungicide Impacts on Pollinators*: https://xerces.org/publications/fact-sheets/protecting-pollinators-from-pesticides-fungicide-impacts-on-pollinators

Xerces Society, *Recommended Plants for Pollinators and Beneficial Insects: California Central Valley Region*: https://xerces.org/publications/plant-lists/ppbi-california-central-valley

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