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 (5⅛–35⅛ 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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POLLINATORS AND CLIMATE CHANGE

Climate-Smart Urban Habitat

LEFT: Climate change can have a variety of effects on pollinators, including native bumble bees. MIDDLE: Pollinator habitat can enhance home gardens, parks, office spaces, places of worship, and retail spaces. RIGHT: Native plants and trees provide important food sources for pollinators.

In California, climate change is expected to cause higher temperatures, more frequent and longer heat waves, and increased drought frequency and severity. Extreme weather events will also become more common. These challenges posed by climate change are extensive, but there ways you can increase climate resilience for pollinators in your yard, neighborhood park, or whole community.

Pollinators play a vital role in ecosystems, pollinating more than 85% of all flowering plants. About one-third of food production also depends on animal pollinators. Although honey bees are key for crop pollination, native bees are important pollinators in most natural ecosystems. California is home to about 1,600 species of bees, and this diverse group provides pollination services throughout the state, from Yosemite National Park to your home garden. Other insect pollinators include butterflies and moths, as well as some flies, beetles, and wasps. Unfortunately, many species of pollinators have undergone population declines. Pesticide use, disease, habitat loss, and climate change are all linked to worrying decreases in pollinator diversity and abundance.

The good news: cities and towns can provide important habitat for insect pollinators. In some urban areas, native bee diversity is quite high—in many cases higher than in agricultural areas. Parks, home gardens, and abandoned lots have the potential to provide high-quality habitat for insect pollinators.

Pollinators and Climate Change

Urban areas tend to be warmer than the surrounding landscape. This is called the urban heat island effect, and it is a result of a large amount of impervious surfaces, such as asphalt and concrete. In urban areas, one global climate change concern is that the urban heat island effect will exacerbate heat waves and increased temperatures. Bees and other insect pollinators are sensitive to temperature, and each species needs to stay within a particular temperature range to survive. Nonlethal temperatures outside the optimal range can have a variety of negative effects on pollinators, including reductions in survival, growth rates, or reproduction.

Climate change may have a variety of additional effects on pollinators. For example, some species may change their distributions to track a more favorable climate. Climate change may also affect phenology, which is the timing of biological events. For many bees and other pollinators, their emergence in spring or summer is timed to match the flowering of preferred plants. A phenological mismatch may occur if pollinators and their host plants don't respond to climate change in the same way. Finally, global climate change can combine with other stressors, such as pesticide use, disease, and habitat loss, to negatively affect pollinators.

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You Can Help!

Global climate change presents an unprecedented challenge, but there are several actions you can take to increase climate resilience for pollinators in your neighborhood.

Create pollinator habitat

Creating habitat is crucial to increasing climate resilience for pollinators. Planting a pollinator garden at your home, office, place of worship, school, or local park will create habitat that provides for larger populations of pollinators. The larger a population is, the less susceptible it is to extinction.

- Include a variety of flowering plants with multiple species in bloom during spring through fall (for plant lists specific to your region, visit xerces.org). A garden with many plant species provides small spaces, called microhabitats, that vary in temperature and amount of cover. These provide refuges for pollinators during heat waves or other extreme weather events.
- Use drought-tolerant native plants. Native species tend to be adapted to the local climate and can often resist drought more effectively than cultivars. Native plants also provide important food resources for specialist bees and butterflies that have narrow resource requirements, and they tend to be attractive to more insects than ornamentals and introduced plant species.
- Plant native bunch grasses, which can provide important nesting habitat for bees and are host plants for some butterflies.
- Provide nesting areas for native bees. Leave areas of bare ground for ground-nesting bees. For cavity-nesting bees, provide pithy-stemmed native plants, such as elderberry, goldenrod, and wild rose. Avoid aggressively cutting back these plants in order to leave dried stems and twigs for bees to nest in.
- Reduce pesticide use as much as possible. Eliminating cosmetic use is a good first step. See the fact sheet *Guidance to Protect Habitat from Pesticide Contamination* (available at xerces.org) for more ideas. Protecting pollinators from pesticides can allow bees to be more resilient in the face of climate impacts such as extended heat waves.
- Avoid using neonicotinoids and other systemic insecticides. Avoid buying plants that have been treated with neonicotinoids. One reason systemic insecticides are so problematic is that they can stay in the ecosystem for months or years, continuing to affect pollinators and other beneficial insects long after they were applied.

Reduce the urban heat island effect

There are several actions you can take to reduce the urban heat island effect in your city or town.

- Depave, removing impervious surfaces such as concrete or asphalt where appropriate. Replacing impervious surfaces with gravel or vegetation reduces temperatures and has the added benefits of reducing flood risk and the amount of pollutants in our water.
- Plant native trees and other vegetation, which can reduce temperatures. As a bonus, trees are excellent at carbon sequestration.
- Support policies that promote green infrastructure, such as green roofs.

Advocate for change

While these actions help mitigate effects of climate change on pollinators, they can only go so far. It is vital that we work to reduce the magnitude of climate change by supporting policies and policy makers focused on limiting global warming.

- Advocate for policy change locally and nationally. Limiting climate change is an attainable goal, but it requires political will and immediate action. Let your representatives know that you support bold action on climate change.
- Reduce your carbon footprint. Actions such as using public transportation, reducing food waste, and choosing energy-efficient appliances can add up.

Additional Resources

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

Xerces Society, Pollinator-Friendly Plant Lists, other areas: xerces.org/pollinator-conservation/plant-lists/

Xerces Society, *Recommended Plants for Pollinators and Beneficial Insects: California Central Valley Region*: xerces.org/pollinator-conservation/plant-lists/pollinator-plants-california/

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Thank you to the Wildlife Conservation Society Climate Adaptation Fund for their generous support of our work. Additional support provided by Annie's, California Community Foundation, Cascadian Farm, Ceres Trust, Cheerios, CS Fund, The Dudley Foundation, General Mills, Häagen-Dazs, Justin's, Nature Valley, The Starbucks Foundation, Turner Foundation, White Pine Fund, and Whole Systems Foundation.

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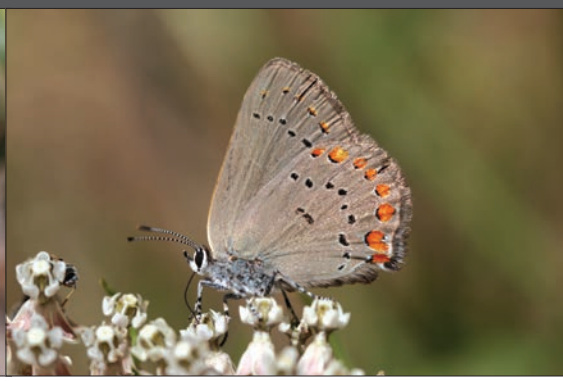
POLLINATORS AND CLIMATE CHANGE

Climate-Smart Natural Habitat





LEFT: Natural areas provide important host plants for native pollinators. MIDDLE: Climate change will have a variety of effects on pollinators, including bumble bees. RIGHT: Considering of the needs of specialist pollinators, like the coral hairstreak (*Satyrium titus*), in restoration can help make these species more climate resilient.

Pollinators are essential, providing a valuable service that affects the structure and function of terrestrial ecosystems. More than 85% of all flowering plants are pollinated by animals, primarily insects. Bees are the most effective insect pollinators, and there are more than 1,600 species of native bees in California. Unfortunately, many pollinators are at risk. The primary drivers of pollinator population decline include habitat loss, pesticide use, and climate change.

In California, climate change is expected to lead to higher temperatures and longer, more frequent heat waves. Drought frequency and intensity is forecasted to increase, as is the occurrence of extreme weather events. Precipitation is not expected to vary greatly, however more winter precipitation will fall as rain instead of snow, reducing snow pack.

Effects of Climate Change on Pollinators

The abiotic changes associated with climate change can have a variety of effects on pollinators, including:

- **Species range shifts.** Species may shift distributions to track more favorable climate. In general, species are expected to shift poleward and to higher elevations. Not all species will shift their ranges, and in some cases ranges may merely shrink. Range shifts may lead to the formation of new ecological communities.
- **Phenological mismatches.** Phenology, or the timing of biological events (such as the timing of budburst or the emergence of a pollinator species), is often influenced by temperature. Phenological mismatches are possible when pollinators and their host plants respond differently to climate change.
- **Physiological responses.** Many processes, such as metabolism, activity, and digestion, are temperature dependent in insects. As such, insect performance, including survival, growth rates, and fecundity, can all vary in response to warming. These effects on pollinators may be positive or negative.
- **Altered species interactions.** Climate change can alter species interactions, including pollinators' interactions with predators, pathogens, or competitors. Changes to species interactions can alter pollinator community composition.
- **Changes to the diversity, quantity, and quality of floral resources.** Plants will also respond to climate change. Alterations in plant diversity and abundance are likely to affect pollinators, especially specialists that rely on a narrow set of plants for food. Changes to the quality of floral resources, which can occur with events such as drought or even as a response to increased CO_2 levels, will affect pollinator carrying capacity.
- **Combined effects**. Climate change may combine with the effects of other stressors, such as habitat loss, pesticides, and pathogens, to exacerbate the effects of each stressor.

These effects are not mutually exclusive, as pollinators are likely to experience multiple effects simultaneously. While some species may fare better under climate change, many species will be negatively affected.

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Strategies to Increase Climate Resilience

Given the many ways that climate change is likely to affect pollinators and plant-pollinator interactions, we propose multiple strategies to increase climate resilience for pollinators in natural areas.

Increase habitat

Protecting habitat and increasing available habitat are the most crucial steps to increasing climate resilience for pollinators and other organisms. Larger habitat patches can support larger populations, which are generally less prone to extinction than smaller populations. Restoring and enhancing habitat whenever possible will ensure that more pollinators, as well as the plants and ecosystems that rely on them, can persist.

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 climate change. Grasslands and well-managed rangelands can contribute significantly to carbon sequestration.

Use a variety of native plants

Providing a diversity of native plants that bloom from early spring through late fall will ensure that resources are available to pollinators, and it may buffer against potential effects of shifting phenology. Native plant species are more likely to be adapted to drought, which will become more common in California.

Consider specialists

Climate change is more likely to negatively affect specialist pollinators than generalists because they have narrower resource requirements. As host plants respond to climate change, changes in their abundance will have corresponding effects on specialist pollinator populations. The inclusion of host plants for specialist pollinators in restoration work may alleviate some of these potential effects. Contact centralvalleypollinators@xerces.org for a list of specialist bees and butterflies along with their host plants for California.

Increase habitat connectivity

Installing and enhancing habitat corridors to improve habitat connectivity will improve climate resilience in a number of ways. Habitat corridors enable range shifts by providing habitat for species to migrate through. Increased connectivity also allows populations to be larger and increases gene flow, and therefore genetic variability, among populations.

Increase genetic variation

An additional aspect to consider is evolutionary resilience. Species that can adapt to changing climate are more likely to persist, and populations with high genetic variation are most likely to be able to adapt. Because larger populations tend to have higher genetic diversity, increasing habitat availability and connectivity also serves to increase populations' genetic diversity. When selecting plant materials for restoration work, including a small portion from southern or low-altitude ecotypes may serve to increase genetic variation so that plant populations are better able to adapt to changing climate.

Reduce additional stressors

Multiple stressors may combine with climate change to have stronger than expected effects on pollinators. Pesticides, disease, and overgrazing are examples of important stressors for native pollinators. To help you reduce these stressors, Xerces has created guidance for reducing pesticide risk to pollinators and for placement of honey bees in natural areas (see Additional Resources).

Xerces is working to improve climate resilience for pollinators in California. If you are interested in partnering with us or if you would like to learn more, please contact us at centralvalleypollinators@xerces.org.

Additional Resources

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/pollinator-conservation/natural-lands

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

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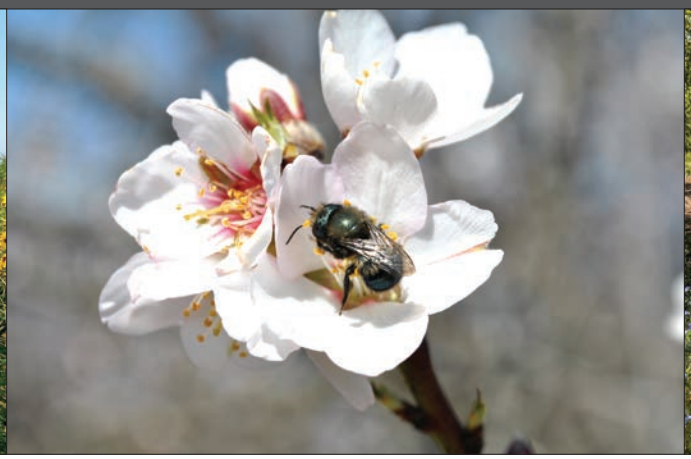
POLLINATORS AND CLIMATE CHANGE

Climate-Smart Agricultural Habitat


LEFT: Hedgerows and other linear habitat are key for increasing pollinator habitat connectivity. MIDDLE: Producers can play an important role in mitigating climate change and increasing climate resilience for pollinators. RIGHT: Practices that increase soil health, such as the use of cover crops, increase carbon sequestration while also providing resources for pollinators.

California Pollinators and Climate Change

More than 80% of all 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. While honey bees are very important to agriculture, native bees, butterflies, moths, flies, beetles, and wasps also contribute to pollination in many crops and are essential for pollination in natural landscapes. Some crops require pollination by native bees—for example, tomatoes require buzz pollination by bumble bees; honey bees are unable to perform this task. In other crops such as sunflowers, native bees supplement the activities of honey bees, and research has shown that fruit set is higher when native bees and honey bees are present, compared with only honey bees.

Unfortunately, native pollinators are in decline, and these declines are likely driven by pesticides (including herbicides, fungicides, and insecticides), habitat loss, disease, and climate change.

In California, climate change is expected to lead to increased temperatures and frequent heat waves. Droughts will become more frequent and last longer, and snowpack will be reduced. All of these factors may influence pollinators and the crops that rely on them. For example, changes in temperature can affect pollinator survival rates or their behaviors, including how much time they spend foraging (i.e., pollinating plants). Climate change may also influence pollinators by affecting plant communities. Changes in the abundance and diversity of flowering plants, as well as drought-related reductions in floral resources, can affect the pollinators that rely on these plants for food. Finally, climate change can interact with other stressors, such as habitat loss or pesticides, to amplify negative effects on pollinators.

You Can Help

You can take several actions to alleviate effects of climate change on pollinators. The first step is to provide habitat for pollinators. Pollinator habitat can take the form of cover crops, hedgerows, and wildflower plantings, as well as pollinator gardens near your home or other buildings. Increasing habitat availability will benefit honey bees and support a larger, more diverse pollinator community, enabling pollinators to better survive extreme weather events and potentially improving crop pollination and pest-control services.

The second step is to increase habitat connectivity. Hedgerows and other linear plantings are particularly valuable because they provide habitat corridors for pollinators. Corridors act as "roadways" for pollinators, providing safe habitat pollinators can use to move through the landscape.

The third step is to reduce pesticide use. Alone, pesticides can harm pollinators, but their use may also interact with climate change, magnifying the negative effects on pollinators. Reducing pesticide exposure will make your landscape healthier and more climate resilient for pollinators.

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Creating Climate-Resilient Habitat

Providing pollinators with habitat and habitat corridors protected from pesticides is key to improving climate resilience for Central Valley pollinators.

Providing pollinator habitat

- Ensure that plantings have a variety of pollinator-attractive native flowering plants, with at least three species blooming at all times during early spring through late fall. Habitat with many species of plants provides small spaces, called microhabitats, that vary in temperature and amount of cover. Microhabitats provide places for insect pollinators to take refuge during heat waves or other extreme weather events. Diverse plantings are more likely to provide resources for more pollinator species, and diverse pollinator communities are shown to improve crop pollination services.
- Use native plants, which tend to be drought tolerant and can therefore provide more reliable nectar and pollen sources throughout dry seasons. Native plants can also be more pest resistant. A list of pollinator-friendly native plants for the Central Valley is available at xerces.org.
- Include host plants for native butterflies and specialist bees, which may be more vulnerable to climate change due to their narrower food requirements.
- Include nesting resources for native bees. Having areas of bare soil will provide nest sites for ground-nesting bees, while cavity-nesting bees build nests in pithy-stemmed plants, such as *Solidago*. See Appendices E and F of Xerces' *Bee Better Certified Production Standards*, available at xerces.org, for plants commonly used by cavity-nesting bees.

Reducing pesticide risk

- Adopt integrated pest-management practices designed to prevent pest problems, reduce pesticide use, and expand implementation of nonchemical management techniques.
- Select habitat sites protected from pesticide use (e.g., where a spatial or vegetative buffer limits contamination or an area upwind of pesticide applications). If such a site does not exist, consider planting a vegetative buffer or establishing a setback where pesticides are not applied.
- Don't use pesticides inside habitat, other than targeted spot treatments for invasive weeds.
- If pesticide use cannot be avoided next to habitat, time applications to limit use when the crop or habitat are in bloom. This is especially important for insecticide applications, including the planting of treated seed. Due to their persistence and systemic nature, neonicotinoids should never be used in areas adjacent to habitat.

Creating pollinator habitat will have additional benefits. It can improve soil health, increasing water retention and reducing runoff. Healthy soils are better at sequestering carbon than poor soils. You can use a tool called COMET-Planner, created by the USDA and their partners, to estimate how different Natural Resources Conservation Service (NRCS) farming practices can affect carbon sequestration on your farm. For example, adding 0.5 acres of hedgerows leads to the sequestration of an additional 4 metric tons of carbon per year. Well-managed farms with healthy soils can be part of the solution to climate change by providing enhanced carbon-sequestration services while protecting pollinators.

Additional Resources

Bee Better Certified: https://beebettercertified.org/

California Department of Food and Agriculture, Healthy Soils Program: http://www.cdfa.ca.gov/oefi/healthysoils/

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

NRCS, vegetative buffers information: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs143_023568

University of California Statewide Integrated Pest Management, Precaution Pesticide Ratings: https://www2.ipm.ucanr.edu/beeprecaution/

US Fish and Wildlife Service, Partners for Fish and Wildlife Program: https://fws.gov/partners/

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

Xerces Society, *Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms*: https://xerces.org/publications/guidelines/farming-for-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, Pollinator Habitat Installation Guides: https://xerces.org/publications/higs

Xerces Society, Pollinator Resources–California: https://xerces.org/pollinator-conservation-resources/CA

Xerces Society, *Recommended Plants for Pollinators & Beneficial Insects: California Central Valley Region*: https://xerces.org/publications/plant-lists/california-central-valley-recommended-plants-seed-mixes-pollinators

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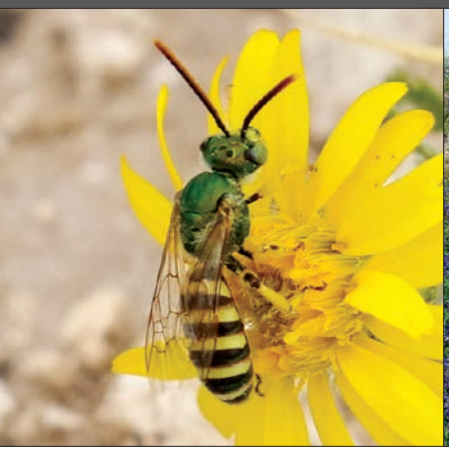
POLLINATORS AND CLIMATE CHANGE

Climate-Smart Right-of-Way Habitat



LEFT: Roadsides can provide important habitat for pollinators and other beneficial insects. MIDDLE: Adding pollinator habitat along roadsides and other rights-of-way increases habitat connectivity, an important step for increasing climate resilience of pollinators. RIGHT: Climate change will have a variety of effects on pollinators and the pollination services they provide.

California Pollinators and Climate Change

Insect pollinators, including bees, butterflies, moths, flies, beetles, and wasps, provide the vital service of pollination in croplands, urban areas, and natural areas. Bees are especially important pollinators, and California is home to more than 1,600 bee species. To provide pollination, pollinators need habitat that includes flowering plants and shelter. Roadsides and other rights-of-way can provide valuable habitat for these pollinators that are important to our economy and environment.

Unfortunately, pollinators are in decline, and these declines are likely driven by pesticides (including insecticides, fungicides, and herbicides), habitat loss, disease, and climate change.

In California, climate change is expected to lead to increased temperatures and longer, more frequent heat waves. Droughts will become more frequent and last longer. All of these factors may influence pollinators and the ecosystems that rely on them. For example, climate change may cause pollinators to shift their distributions or their timing of emergence. Climate change may also influence pollinators by affecting plant communities: changes in the abundance and diversity of flowering plants, as well as drought-related reductions in floral resources, can affect pollinators that rely on these plants for food. Finally, climate change can interact with other stressors, such as habitat loss or pesticides, to amplify negative effects on pollinators.

Building Climate Resilience for Pollinators

Several actions can improve pollinator resilience to climate change: restore and enhance pollinator habitat, increase habitat connectedness, and reduce other stressors. Protecting and expanding habitat is critically important; as the size of habitat increases, it supports larger populations and a greater diversity of species. Larger populations are better able to survive bad years and extreme weather events expected with climate change.

Habitat connectivity allows for several benefits to pollinator populations: larger populations, increased gene flow (enabling species to adapt to new conditions), and mobility for species to track favorable climates. Installing habitat corridors between habitat patches can help achieve this connectivity. Research suggests that linear corridors, such as those along roadsides or utility corridors, may be especially important in facilitating pollinator movement across landscapes. With a network of potential habitat crisscrossing the landscape, roadsides and other rights-of-way present an ideal opportunity to increase habitat connectivity for California pollinators.

Climate-Smart Pollinator Habitat along Roadsides and Other Rights-of-Way

Incorporating the provided suggestions can make habitat corridors more beneficial to pollinators and more climate resilient.

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Managing habitat

- Inventory and identify existing native flowering vegetation remnants along roadsides and other rights-of-way.
- Maintain wildflower diversity through invasive species removal or carefully timed mowing.
- Minimize mowing to once per year or less to avoid degrading important habitat. Along roadsides, reduced mowing can occur beyond the safety zone. If possible, avoid mowing sensitive pollinator habitat during spring and summer, when pollinators are active (for monarchs, avoid mowing from mid-March through October). Areas that provide little or no pollinator habitat could be mowed during spring and summer to keep to mowing schedules.
- Evaluate a range of management techniques (e.g., chemical, physical, or mechanical) to select the least harmful, most effective, and most feasible weed-management method.
- Reduce the effect of herbicides on pollinator habitat by using selective herbicides, and by applying herbicides in the most targeted manner possible and when weeds are most vulnerable.
- Whenever possible, prevent conditions that would allow the establishment or reestablishment of incompatible vegetation or invasive species. For example, wash equipment prior to accessing a new site to avoid transferring weed seeds among sites.
- To reduce drift, avoid applying pesticides when wind speeds are above 15 mph and during temperature inversions.

Restoring habitat

- Incorporate drought-tolerant native plants into habitat. This will help ensure that floral resources are available to pollinators, even during dry periods, as drought in California is expected to become more frequent and severe. Native plants provide important food resources for specialist bees and butterflies that have narrow resource requirements. Native plants tend to attract more species of insects than ornamentals and introduced plant species, and they support more birds and other wildlife.
- Use a variety of flowering plant species, and aim to have at least three species flowering at all times from spring through fall. Habitat with many types of plants also provides small spaces, or microhabitats, that vary in temperature and amount of cover and provide important refuge during heat waves or other extreme weather events.
- Provide nest sites for native bees. Areas of bare soil will provide nesting habitat for ground-nesting bees, and pithy-stemmed plants such as goldenrod (*Solidago* spp.) or primrose (*Oenothera* spp.) will provide nesting habitat for cavity-nesting bees. Native bunch grasses also provide nest sites for many bees, including some species of bumble bees. Appendices E and F of Xerces' *Bee Better Certified Production Standards*, available at beebettercertified.org, contain lists of plants used by cavity-nesting bees.

Improving pollinator habitat along roadsides and rights-of-way has many benefits beyond providing habitat for these important insects. First, carbon sequestration tends to be higher in restored areas and areas with high plant diversity compared to degraded areas with low plant diversity. Thus, creating and restoring pollinator habitat in these areas can also help to mitigate climate change. Second, pollinator habitat improves soil stabilization and leads to better infiltration of water, reducing runoff. Third, pollinator habitat also provides habitat for beneficial insects like predators and parasitoids that contribute to crop-pest control in neighboring farmland. Finally, pollinator habitat is attractive and provides a way to showcase California's local wildflower diversity.

Pollinator habitat along roadsides and rights-of-way can improve climate resilience of California pollinators by greatly increasing pollinator habitat connectivity. Please contact us at centralvalleypollinators@xerces.org if you are interested in collaborating with Xerces to create pollinator habitat or would like more information.

Additional Resources

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

Xerces Society, *Literature Review: Pollinator Habitat Enhancement and Best Management Practices in Highway Rights-of-Way:* https://xerces.org/pollinator-conservation/roadsides

Xerces Society, *Pollinators and Roadsides: Best Management Practices for Managers and Decision Makers:* https://xerces.org/pollinator-conservation/roadsides

Xerces Society, *Roadside Best Management Practices that Benefit Pollinators: Handbook for Supporting Pollinators through Roadside Maintenance and Landscape Design:* https://xerces.org/pollinator-conservation/roadsides

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