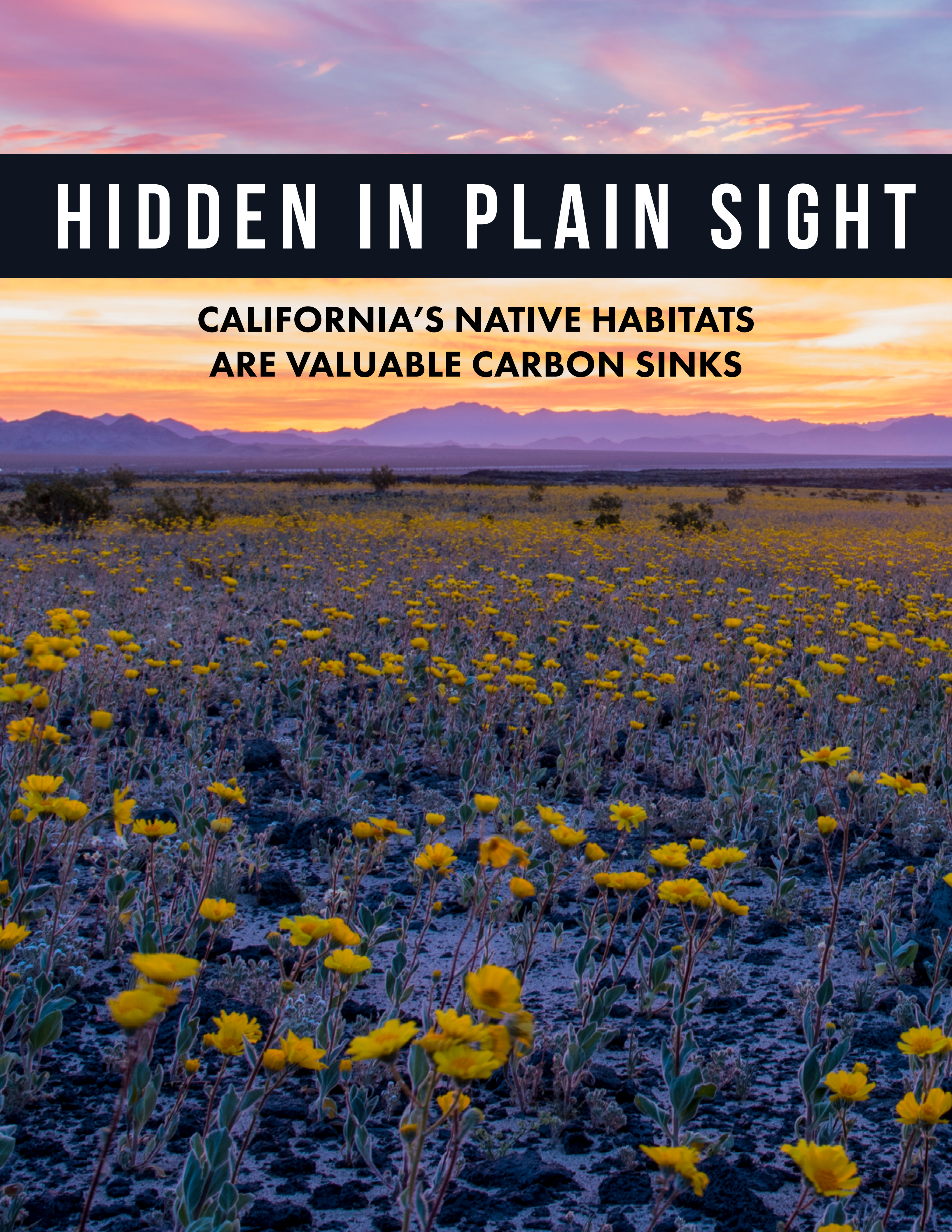
# HIDDEN IN PLAIN SIGHT

## CALIFORNIA'S NATIVE HABITATS ARE VALUABLE CARBON SINKS



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*Fort Ord National Monument*

# EXECUTIVE SUMMARY

California is at the forefront of the climate crisis. Poor land-use planning and extreme weather events have led to an onslaught of disasters harming communities and threatening the state's ecosystems. Strategies that maximize the carbon storage and sequestration of trees and forests are important to fight climate change. But **policymakers are ignoring other nature-based conservation strategies that are right in front of us**.

This report details the carbon sequestration value of California's most overlooked habitats and highlights conservation and science-based mitigation strategies that are crucial in fighting the climate crisis. It shows:

- Many tree-planting and other carbon offset programs are deeply flawed. They do not achieve the promised carbon storage gains and can unintentionally harm ecosystems and communities.
- Many at-risk diverse habitats of California — including shrublands, grasslands, deserts and riparian corridors — are significant carbon sinks.
- The benefits of preserving California's overlooked habitats go beyond carbon storage and sequestration. It protects biodiversity and Tribal resources, keeps communities safer from wildfire risks and offers more equitable access to open space.
- Our key recommendations for policymakers are to conduct more accurate accounting of carbon storage, prioritize habitat conservation and make smarter land-use decisions.

**Shrublands, grasslands, deserts and riparian corridors store and sequester large amounts of carbon**. Yet, even when significant new development projects are analyzed through the California Environmental Quality Act, the resulting carbon emissions from bulldozing habitat are too often left out or are grossly underestimated. Such analyses often inappropriately focus on the lost carbon storage and sequestration of trees that would be destroyed while ignoring or underestimating carbon loss from other ecosystems.

Consequently, proposed mitigation for a project's GHG emissions is often insufficient and ignores opportunities to combat the climate crisis that could help local communities. Most nature-based mitigation efforts for development projects involve so-called carbon credit programs that prioritize faraway forests or tree-planting programs that are flawed and not based on science.

**Offset programs are massively failing to accomplish the proclaimed carbon storage gains or forest protections.** Since its inception in 2013, California's cap-and-trade program has over-credited developers, corporations and governments for forest carbon offset programs by an estimated 30 million tons of carbon dioxide equivalents. These shortcomings are valued at an estimated $410 million in 2021 market prices.

To address the climate crisis in a meaningful way, we must not only protect forests but also recognize the carbon storage and sequestration power of California's other important ecosystems. The U.N. Intergovernmental Panel on Climate Change estimates that the world needs to cut 48% of GHG emissions by 2030 and achieve net zero carbon emissions by the early 2050s to limit global temperature rise to 1.5 degrees Celsius and avoid the worst damages of the climate crisis. In addition to rapidly phasing out fossil fuels, scientists point to nature as an effective and efficient tool to help limit warming by storing and sequestering carbon.

**California's nonforest habitats play an unappreciated but critical role**. As with forests, nonforest habitats can store carbon by keeping it from being released and sequester it by removing it from the atmosphere.

Habitats in arid and semi-arid regions — including shrublands, grasslands, and deserts — have been found to store significant amounts of carbon while being resilient to drought and increased atmospheric carbon. Grasslands may appear unimpressive aboveground, but belowground native grasses can store as much or more carbon as trees. Riparian habitats meanwhile can store and sequester substantial carbon while providing a cooler microclimate for species to find refuge. These habitats near rivers and streams also increase water infiltration and groundwater replenishment, and they facilitate species movement as ranges shift with a changing climate.

California shrublands, grasslands, deserts, and riparian corridors cover and connect vast areas of the state while supporting high levels of biodiversity and endemism. Collectively they play an integral role in the carbon cycle. Their preservation would not only aid in combatting climate change through their role as natural carbon sinks but also benefit local communities by providing much needed access to nature and bring the state closer to California Gov. Gavin Newsom's 30 by 30 executive order to conserve more than 30% of its lands and coastal waters by 2030.

*Joshua Tree National Park by Joan Amero*

*Wildfire damage in Santa Rosa by Bay Area Media Masters*

## CLIMATE CHANGE IS ALREADY HERE

Human-caused climate change is bringing widespread harms to animals and plants. Hundreds of species have experienced climate-related local extinctions[1] and 82% of key ecological processes have been affected by climate change.[2] If climate change continues unabated, more than one-third of all plant and animal species could become extinct in the next 50 years.[3]

Climate change is also causing widespread harms to human communities around the world. California has experienced extended drought and mass flooding simultaneously[4], along with a longer fire season, larger areas burned and more community destruction by wildfires.[5–7] Flooding due to sea-level rise has led to severe property damage and social disruption in the Pacific Islands.[8] Drought and saltwater intrusion in the Mekong River Delta in Vietnam are affecting rice production and livelihoods.[9] Severe drought and famine are affecting millions in Eastern Africa[10] while people in Nigeria are inundated with floods.[11] Recent record heatwaves across the globe have caused thousands of deaths, driven unprecedented wildfires, and impaired critical infrastructure, like airport runways, streetcar power cables, and rail lines.

There is a palpable urgency to take immediate, aggressive action to combat climate change.

## TREE-PLANTING PROGRAMS AND CARBON OFFSETS ARE INEFFECTIVE

Most nature-based mitigation efforts for a development's greenhouse gas emissions involve so-called carbon credit programs that prioritize faraway forests or tree-planting programs. Although trees and forests store the largest percentage of carbon compared to other terrestrial ecosystems,[12] such approaches are often inadequate and ignore additional opportunities to combat the climate crisis while helping local communities.

Tree-planting programs are often used to "offset" GHG emissions resulting from a corporation's polluting activities. "Offsets" or "carbon credits" allow corporations to fund projects to remove the same amount of carbon from the air as that which is produced by the polluting activity elsewhere. Examples of popular offsets include building renewable energy systems, upgrading to waste and landfill management, methane abatement, fuel switching, improving energy efficiency, reforestation and tree-planting. Offsets vary from voluntary efforts by a corporation's marketing campaign to mandatory mitigation measures under regulatory or permitting requirements (See California Health & Safety Code § 38562).

Many governments and businesses are quick to tout their tree-planting contributions, but the actual amount of reduced carbon emissions can vary greatly based on the reliability, enforceability, monitoring and longevity of the offset program.[13] The success of the program also depends on whether there is an actual reduction in emissions or if those reductions would have occurred anyway.

Large-scale tree-planting initiatives around the world in the past 50 years have not led to the promised carbon storage or sequestration gains.[14] In addition to high tree mortality rates, such programs have unintentionally harmed biodiversity, water availability, wildfire severity, and the livelihoods of rural communities.[14–17] Tree planting programs can suffer from faulty accounting, manipulation and, in some instances, seizing forest stewardship away from Indigenous communities.[14,16–18]

Such programs require careful planning that includes planting appropriate tree species in appropriate locations while allowing some forests to regrow on their own. A successful program should avoid biodiversity-hindering and nutrient-depleting monoculture plantations and have a long-term adaptive management plan with accountability measures in place to ensure planted trees survive and grow.[14,16,17] Tree-planting efforts should avoid areas undergoing natural habitat regeneration, where tree-planting is unnecessary and can be ecologically harmful (e.g., post-fire clearcutting and replanting). Adequate funding and engagement with local communities are also key.[14,16,17] Unfortunately, most proposed tree-planting programs lack these important features to ensure successful carbon storage and sequestration.

*Flooding in downtown Sebastopol, in western Sonoma County, after an atmospheric river in 2019 dumped up to a foot of rain over 48 hours.*

*Left: A coast live oak sapling resprouting four months after the 2019 Cave Fire in Santa Barbara. Photo: Bryant Baker*

*Having evolved with fire in California for millennia, many native plants are adaptable and resilient when it comes to wildfires, and in some cases, dependent on them. Yet developers interested in building in fire-prone areas often assume that previously burned areas are dead zones and proclaim that a tree-planting program would be adequate mitigation for a project's carbon emissions. They believe such a program would increase carbon storage and sequestration in burned areas, when in fact it can do more harm than good. Allowing ecosystems to regenerate on their own or with light-touch management would be much more effective and economical. These photos show two examples of fire resilience.*

*Right: Basal and epicormic resprouting of California redwoods can be seen following light-touch management. The resprouting at Big Basin State Park in Santa Cruz County is taking place two years after the CZU Lightning Complex Fire. Photo: Tiffany Yap*

Carbon offsets that theoretically protect faraway forests (either within the state, within the country or abroad) to mitigate the impacts of a development or a corporation's polluting practices are also common. But research shows that many forest carbon offset projects are flawed and do not achieve the proclaimed climate benefits, nor do they result in actual forest protection.[18–22]

In California, scientists found that carbon offset projects were not sequestering enough carbon to mitigate emissions as intended, while timber companies continued logging in offset project areas that are meant to be off limits.[19] California's offset projects are often over-credited due to inaccurate assumptions that all tree species store the same amount of carbon. Less carbon-sequestering tree species and forests that are not at risk from logging are often selected to "offset" higher-quality habitat, which has led to over-crediting developers, corporations, and governments an estimated 30 million tons of carbon dioxide equivalents valuing an estimated $410 million at 2021 market prices.[23]

Also troubling are offset programs located far from the polluting activity because they shift GHG emissions reductions away from the communities and habitats harmed by the pollution. A community that now has a new freeway, warehouse logistics center or oil refinery will face worse air quality and see none of the benefits of new trees planted thousands of miles away.

Over reliance on ill-conceived offset programs, including international tree-planting efforts, undermines local and state efforts to combat the climate crisis and worsens inequity by placing disproportionate pollution burdens on low-income, minority communities where polluting infrastructure is often sited. [24]

Although forests store the largest percentage of carbon compared to other terrestrial ecosystems,[12] trees and forests need support from other habitats. About 30% of described tree species are threatened with extinction,[25] and climate change is affecting the ability of forests and trees to survive.[25–31] Higher temperatures and extended drought are making trees more susceptible to stressors like insects, disease, and wildfire.[32–35] Drier conditions are causing trees to transpire more quickly and dry out, which is reducing tree growth and forest health globally.[36–38] In addition, there is evidence in high-elevation forests that increased atmospheric carbon is leading to shorter carbon residence time in trees, with trees growing faster and dying more quickly.[30] And the carbon storage capability of tropical forests could rapidly deteriorate if global surface temperatures increase by more than 2 degrees Celsius of preindustrial levels.[39–42]

Land-use planners must urgently look to additional measures that reduce emissions and store carbon locally to increase our chances of fighting the climate crisis in an effective and equitable manner.

*San Ardo Oil Fields*
*by Drew Bird Photography*

# DIVERSE HABITATS SERVE AS IMPORTANT CARBON SINKS

California has incredibly diverse natural habitats beyond forests that need to be included in the conversation about natural solutions to combat the climate crisis. Habitats like shrublands, grasslands, deserts, and riparian habitats offer vast opportunities to effectively sequester carbon. (Figure 1). Yet these habitats are often excluded from carbon calculations and neglected as important carbon sinks.

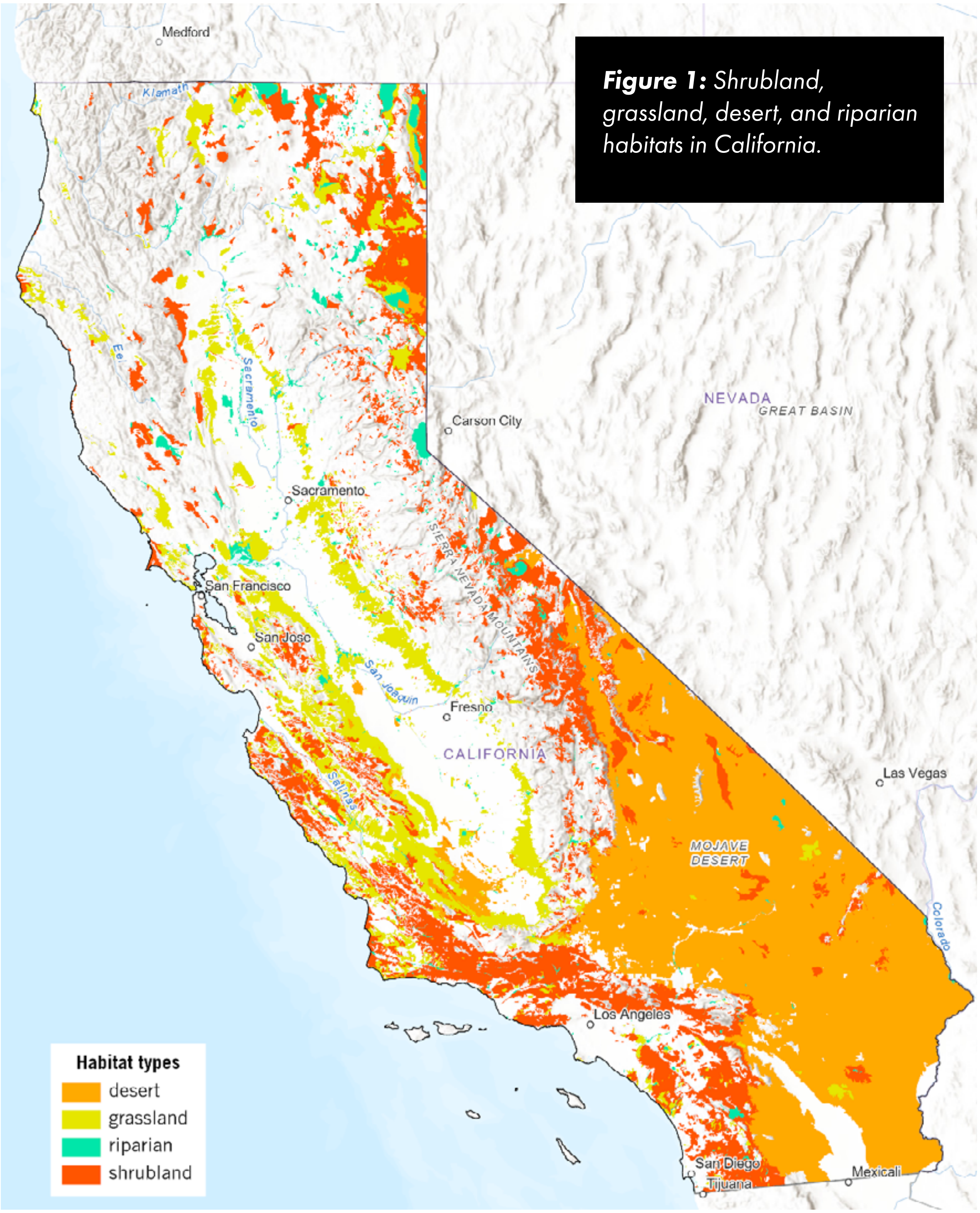


***Figure 1:*** *Shrubland, grassland, desert, and riparian habitats in California.*

*Note: For clarity purposes, the map does not include woodland habitats that often have grasslands as a large part of their understory, like blue oak woodlands and Douglas fir woodlands. Woodland habitats would fill in more of the foothills, particularly between the Central Valley and the surrounding mountain ranges. Data source: California Department of Fish and Wildlife's California Wildlife Habitat Relationships Model (2019).*

*Coastal sage scrub in Charmlee Wilderness Park by Ileene Anderson*

## SHRUBLANDS

Shrublands in Mediterranean climates, such as vegetation communities dominated by chaparral and coastal scrub, support high levels of plant and animal diversity, including sensitive species like coastal California gnatcatchers and *Ceanothus* species. They also cover a large portion of the state (Figure 1) and store a significant amount of carbon in their aboveground and belowground biomass, leaf litter, and soils[43–47] (see Appendix for details).

Researchers found that mixed chaparral and chamise chaparral in California stored an estimated 34.1 and 22.5 metric tons of carbon per acre, respectively[43,48] (Table 1). They were found to have an average carbon sequestration rate of 0.45 to 1.7 metric tons of carbon per acre, per year, and the amount of carbon stored and sequestered increased with the age of the shrubs.[43,47] Although the data vary by age of the shrubs and fluctuate based on varying environmental conditions, these statistics represent the carbon storage and sequestration potential of these habitats (see Appendix for details).

To provide some perspective, natural forests in Oregon and Northern California have been estimated to store an average 48.6 (ranging from 26.3 to 76.9) metric tons of carbon per acre with a sequestration rate of 1.21 to 3.16 metric tons of carbon per acre, per year[49] (Table 1). Estimations of carbon stored in urban trees in California cities range from an average 3.3 to 6.2 metric tons per acre with an estimated sequestration rate of 1.3 to 2 metric tons per acre, per year.[50] Similar to shrublands, stored and sequestered carbon was greater with mature forests and trees.

*Coastal California gnatcatcher*

*Hairy Ceanothus (Ceanothus oliganthus) flowers by Ileene Anderson*

***Table 1****: Carbon storage and sequestration of different habitat types in California. See Supplemental Table in Appendix for more details.*

| Habitat Type | Average Carbon Storage (metric tons/ acre) | Average Carbon Sequestration Rate (metric tons/acre/ year) | Carbon Sink | References |
|---|---|---|---|---|
| **Riparian Habitat*** | 325.7 | 0.81 | total biomass, soil (50 cm deep) | 51 |
| **Native Grasslands** | 59.5 – 71.2 | 2.18 – 5.58 | soil (50 cm deep) | 52 |
| **Shrublands** | 22.5 – 34.1 | 0.45 – 1.7 | total biomass, leaf litter, soil (100 cm deep) | 43 |
| **Rangelands** | 15.8 – 23 | | soil (40 cm deep) | 53 |
| **Desert**** | 4.17 | 0.4 – 0.51 | total biomass, soil (1 m deep) | 54–56 |
| **Natural Forest***** | 48.6 | 1.21 – 3.16 | total biomass | 49 |
| **Urban Trees** | 3.3 – 6.2 | 1.3 – 2 | total biomass | 50 |

*Only maximum estimates of carbon storage and carbon sequestration rates are provided. Estimates include carbon in channel, flood plain and upper bank.
**Estimates are based on measurements taken in the northern Mojave Desert in Nevada.
***Estimates include forests in Northern California and Oregon.

These statistics are not strictly comparable since shrubland estimates include aboveground and belowground carbon, leaf litter and soil carbon while the natural forest and urban tree estimates only considered tree biomass. However, the numbers indicate the untapped potential of shrublands for carbon storage and sequestration in the fight against climate change.

Mediterranean shrublands may also provide resilience to climate change. They are adapted to hot and dry weather conditions in water- and nutrient-limited environments and have been found to be resilient to drought.[46,57]

Although there is some uncertainty with climate change,[i] it is clear that shrublands can provide significant carbon storage and sequestration. Given their vast distribution in California and their potential resilience to changing environmental conditions, preserving local shrublands instead of planting trees or focusing on faraway forest offsets is an effective pathway to improve our ability to stave off the worst-case scenarios of climate change while protecting biodiversity.

[i] As with forest ecosystems, shrubland carbon storage and sequestration capacity can fluctuate, and impacts of climate change are uncertain. For example, during drought the carbon sequestration capacity of Mediterranean shrublands has been observed to decrease,[45] and they can even become a carbon source.[46] Elevated atmospheric carbon dioxide levels have been shown to enhance photosynthesis and aboveground production and increase belowground carbon pools in chaparral by stimulating root and mycorrhizal growth,[143,144] though aboveground gains were only observed in years with above-average rainfall and it is possible that gains in carbon storage could be offset by increased decomposition activity and/or respiration by soil microbes and mycorrhizae during warmer and drier conditions.[143,145]

*Purple needlegrass, native to California, has roots that extend up to 20 feet deep. Oak woodlands are in the background. Photo: Ileene Anderson*

## GRASSLANDS

Grasslands cover about 10% of California's land area[58] (Figure 1). California's grasslands are varied and geographically unique, whether they occur in coastal prairies, desert or the central valley, which was once dominated by valley grasslands.[59,60] Originally these grasslands were primarily dominated by native perennial bunch grasses including bluegrasses and needlegrasses with a component of annual forbs, typically wildflowers. European contact initiated a transformation in California grasslands to nonnative annual grasses and forbs of Mediterranean origin including brome grasses, storksbill and clovers. These areas are often referred to as rangelands or grazing lands. Significant amounts of coastal prairie and valley grasslands have been converted to agriculture.[59,60]

Although grasslands are mostly dominated by nonnative plant species, they continue to be biodiversity hotspots. California grasslands support almost 90% of state-listed rare and endangered species and 75 federally listed plants and animals, including California tiger salamanders, burrowing owls and a variety of small herbivorous mammals.[58]

Their aboveground biomass may not be as impressive as forests or shrublands, but there is significant potential for carbon storage in their roots[52,61–64] and soils[65–67] (Figure 2). Although it depends on the species and ecological region, grasslands have been found to have large amounts of their biomass below ground.[61,62] And grasslands with higher plant diversity have been found to facilitate greater soil carbon storage and are likely more resilient to climate change.[57,62,65,68–74]

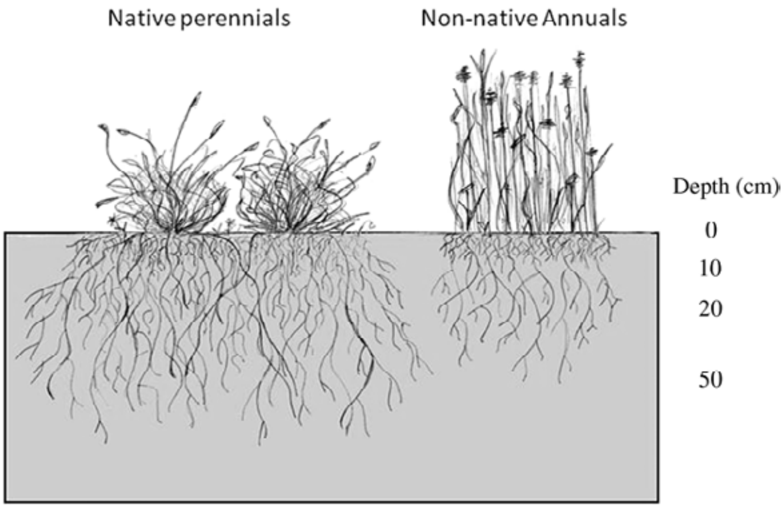


***Figure 2:*** *California native perennial and nonnative annual grasses. Grass morphology at the time of peak biomass in spring in the native perennial grass community, left, and nonnative annual grass community, right.*
*Source: Koteen et al. (2011)*[52]

*Tuolumne Meadows by Mark Turner*

In a recent statewide analysis in California, researchers estimated there are 15.8 to 23 metric tons of carbon per acre in soil organic carbon stocks (40 cm deep) in grasslands and grazing lands[53] (Table 1). The study was based on data collected in the San Joaquin Valley, Sacramento Valley, and Central Coast.[53] The reasons for such high variability in carbon stocks are unclear, though some variation could be due to climate, region, and differences in historical and current land use.[53]

Carbon storage estimates can vary depending on the species make-up and/or condition of the site. For example, in a study conducted in Northern California, native grasslands were found to store, on average, 59.5 to 71.2 metric tons of carbon per acre in their soils (50 cm deep) with a sequestration rate of about 2.18 to 5.58 metric tons of carbon per acre, per year[52] (Table 1). This suggests that despite the relatively small amount of aboveground vegetation of native grasslands, the amount of carbon stored in their soils could be greater than the carbon storage of total tree biomass in natural forests.[ii]

Similar to California shrublands, grasslands in semi-arid regions may be resilient to climate change because they have an adaptive capacity to drought and wildfire. Multiple studies suggest that diverse grasslands can adjust to increased drought,[57,73,74] though biodiversity declines due to drought could reduce functional stability.[75] Researchers also found that plant biomass and soil organic carbon stocks in grasslands increased with elevated carbon dioxide levels, which highlights the potential for grassland soils to store more carbon as atmospheric carbon dioxide levels rise.[76]

Although the historic fire regimes of California grasslands are not well documented, research has shown that when fires burn through grasslands, they release less carbon than woody habitats because most of the carbon they store is underground, and they can recover relatively quickly.[74,77] In fact, one study found that California grasslands may be a more reliable carbon sink than trees and forests in the face of climate change, particularly if global warming exceeds 1.7ºC above pre-industrial levels.[74] This further highlights the urgency of preserving and restoring remaining intact native grasslands and their biodiversity.

[ii] In the same study, nonnative grasslands were found to store, on average, 38.4 to 60.3 metric tons of carbon per acre in their soils (50 cm deep) and sequester an estimated 1.3 to 1.8 metric tons of carbon per acre, per year.[52] These numbers may seem to suggest nonnative grasses may have the potential to store and sequester as much or more carbon than native shrublands. However, it is important to understand the geographical and ecological context of the area in question. Multiple studies have demonstrated that the invasion and/or type-conversion of native shrublands to nonnative grasslands reduce carbon stocks.[146–148] In addition, the establishment of nonnative grasses can exacerbate wildfire issues by fueling a negative feedback loop that results in more fire and type conversion.[103] Therefore, the preservation and restoration of native grasslands and shrublands should be prioritized.

Creosote desert scrub in Joshua Tree National Park by Jose Benedicto de Jesus

## DESERTS

Deserts represent one of the most undisturbed and ecologically intact biomes in the world.[78] In California, desert landscapes consist of dunes, desert scrub, sandy soil grasslands, juniper-pinyon woodlands and rock formations that cover 25% to 27% of the state (Figure 1). They host more than 2,400 native plant and animal species, including iconic Joshua trees and the Mojave fringe-toed lizard. Many species are endemic to these deserts.

Scientists estimate that globally deserts store 999 to 1,899 petagrams of carbon[79] In the United States, deserts sequester an estimated 50 teragrams of carbon per year.[80]

In the northern Mojave Desert, researchers measured an average of 4.17 metric tons of stored carbon per acre[54] and an average sequestration rate of 0.4 to 0.51 metric tons of carbon per acre, per year[55,56] (Table 1). Although this may seem low compared to other habitats and recognizing that carbon storage and sequestration is dynamic and fluctuates with environmental conditions, the vast expanse of the desert and the relative intactness of the Mojave Desert highlights their importance in the carbon cycle.

The Mojave Desert is dominated by deep-rooted shrub species, including creosote bush and white bursage, as well as many forbs, trees, grasses, and dunes. Carbon in these systems is stored in the form of soil organic carbon, soil inorganic carbon and vegetation[79,81–85] (Figure 3, see Appendix for more details).

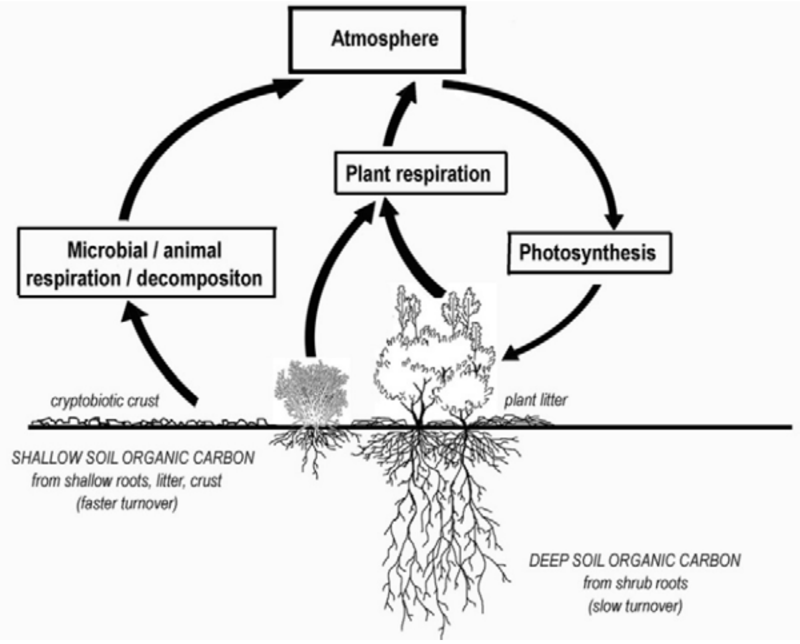


***Figure 3***: *The carbon cycle in a desert ecosystem. Source: Meyer (2012)* [86]

Although aboveground productivity is low compared to less arid areas, carbon storage occurs underground as soil organic carbon in extensive root networks, soil microbial communities, and in mycorrhizae. Deserts also have deep soil organic carbon and soil inorganic carbon that can be stored as caliche.[87] Caliche is calcium carbonate ($CaCO_3$) that is formed when rainwater, carbon dioxide from soil and root microbes, and calcium react, and its stability depends on the vegetation present. Deep soil organic carbon is generally stored at depths from 30 centimeters to 1 meter where mineral interactions primarily determine the stability of stored carbon[88] (see Appendix for more details).

The desert's role as a carbon sink could become amplified as climate change worsens. Researchers noted increased carbon sequestration in soil organic carbon when carbon dioxide levels were elevated.[54,79] Field experiments in the northern Mojave desert demonstrated that desert ecosystem carbon dioxide exchange plays a much larger role in global carbon cycling and in modulating atmospheric carbon dioxide levels than previously assumed.[55]

Conservation of intact deserts is increasingly important for our carbon sequestration efforts and combatting the climate crisis.

*Joshua trees and wildflowers in Joshua Tree National Park by Ileene Anderson*

*Mojave fringe-toed lizard by frankf/iNaturalist*

*Utom, also known as the Santa Clara River, is Southern California's last publicly accessible, mostly free-flowing river and supports more than 110 special-status plants and animals, including unarmored threespine sticklebacks and arroyo toads.[89] Photo: Ileene Anderson*

## RIPARIAN HABITATS

Riparian habitats consist of stream channels, vegetated floodplains and upland habitats that often include a variety of trees and shrubs, including California buckeyes, valley oaks, and arroyo willows. They support numerous wildlife, from common species, like acorn woodpeckers and Pacific chorus frogs, to species that are rarely observed in the wild, like elusive ringtails and subterranean salamanders. Riparian areas in California are key nesting areas for endangered songbirds, including the southwestern willow flycatcher, western yellow-billed cuckoo and least Bell's vireo. Riparian areas in deserts, called microphyll woodlands or dry desert wash woodlands, create important desert refugia for many animals including migratory birds.

Riparian habitats are one of many types of wetland ecosystems that support a wide range of species and ecological functions. Vernal pools, salt and freshwater marshes, wet meadows and other wetlands in California can be important carbon sinks.[90,91] However, their complexity and diversity make broad calculations about their estimated carbon storage and sequestration value challenging.

Riparian streams can flow year-round or seasonally with the rains. Although they are estimated to make up less than 0.5% of California's total land area at about 360,000 acres[92] (Figure 1), riparian habitats provide critical carbon sequestration value and resilience to climate change, particularly in arid and semi-arid regions.

*Pacific Tree Frog by The High Fin Sperm Whale/Wikimedia*

In Mediterranean regions, riparian habitats could be considered "carbon hotspots."[51] Riparian forests are able to store more carbon in their biomass and soils as they mature.[93,94] Scientists estimated that riparian habitats in California could store up to 325.7 metric tons of carbon per acre in their biomass and soils while accumulating about 0.81 metric tons of carbon per acre, per year[51] (Table 1). The researchers acknowledged that these estimates likely represent the upper limit of these habitats' carbon capacity.

In addition to storing and sequestering carbon, riparian habitats also allow a wide range of species to become resilient and adaptable to climate change. The canopy cover of riparian trees and the availability of groundwater have a cooling effect for both air and water temperatures, which creates a cooler microclimate for both terrestrial and aquatic species to find refuge from a warming climate.[95–97]

Riparian areas are also vital movement corridors between heterogeneous habitats for a wide variety of species, including mountain lions, toads, butterflies and birds. Such connectivity is important for animals and plants to adjust to shifts in resource availability and maintain a suitable climate space as climate change alters habitats and ecological processes.[1–3,98–100]

Their carbon capacity and their role in resiliency and adaptability to climate change makes it imperative that riparian habitats are included in carbon calculations. The preservation and restoration of riparian habitats should be prioritized.


*Southwestern willow flycatcher by Andrew Newmark/iNaturalist*


*Ringtail by Brooke Smith/iNaturalist*


*California buckeye by Eric Hunt*

## IMPORTANT CARBON SINKS UNDER THREAT

*Large freeways, oilfields, warehouses, landfills and low-density residential areas are expanding into an important wildlife connectivity area in Southern California between the Santa Susana and San Gabriel mountains. Expansion into this corridor destroys habitat and releases carbon while driving the local puma population closer to extinction. Photo: Tiffany Yap*

**Reckless land-use decisions exacerbate climate change** and threaten our ability to limit global warming to 1.5 degrees Celsius above preindustrial levels. Shrublands, grasslands, deserts and riparian habitats have enormous carbon storage and sequestration value but are often paved over without much foresight. These crucial habitats are routinely replaced with agriculture and vineyards, urban development, energy facilities, industrial mining, oil exploration, off-road vehicle recreational areas, and other uses. And local and federal governments throughout the state continue to disregard their value by approving projects that would further degrade and destroy them.

In 2019 Los Angeles County approved the 12,000-acre Centennial development, which would have destroyed more than 6,000 acres of native grasslands and wildflower fields and more than 400 acres of native shrublands. That same year the county also approved the 1,300-acre Northlake development, which would have buried 3.5 miles of Grasshopper Creek and its associated riparian habitat and more than 600 acres of sage scrub.

In 2022 Napa County re-approved the Walt Ranch vineyard development, which would have destroyed more than 100 acres of shrublands, about 84 acres of grasslands, and about 6 acres of riparian woodlands. The vineyard conversion project would have also destroyed approximately 376 acres of deciduous and oak woodlands and more than 14,000 mature oak trees. The proposed mitigation for the project's carbon emissions from the destroyed oak trees included a misguided tree-planting program to place fewer than 17,000 seedlings where many trees, chaparral, and grasslands were already recovering from a recent wildfire.

When proposed, none of these projects adequately accounted for the carbon that would be released by destroying these habitats or the loss of potential carbon sequestration when the developments would be built.

Similar destructive projects have been proposed in San Diego. In 2019 and 2020 San Diego County approved Otay Ranch Villages 14 and 13, respectively, which cumulatively would destroy more than 1,300 acres of sage scrub habitat and about 150 acres of grasslands. In 2020 Lake County approved the 16,000-acre Guenoc Valley Luxury Resort, which would destroy more than 500 acres of grasslands, more than 600 acres of shrublands, more than 13 acres of streams and hundreds of acres of other carbon-sequestering habitats like woodlands and wetlands.

As proposed these projects would not only remove important carbon sinks and destroy critical habitat for sensitive species but also increase wildfire ignition risk. Accidental human-caused ignitions are responsible for 95% to 97% of unintentional wildfires in California's Mediterranean region,[101] and the shift in historical fire regimes has led to the conversion of native shrublands and grasslands to nonnative grasses and forbs.[102–104] Such developments could lead to a negative feedback loop that would convert these high-value carbon-storing habitats to more flammable nonnative grasses with less carbon storage capacity.[iii]

*Firefighters defended the neighborhood of Oak Park, surrounded by shrubland and grassland, from the 2018 Woolsey Fire. Caused by Southern California Edison electrical equipment, the fire killed three people, burned more than 96,000 acres, destroyed 1,643 structures, and caused 295,000 people to evacuate. Photo: Wendy Leung*

Deserts also face an additional threat from poorly planned and ill-sited renewable energy projects, like remote solar farms. Although solar energy is an important renewable resource that reduces the need for fossil fuel extraction and lowers carbon emissions, these types of projects also destroy large swaths of intact desert ecosystems. In doing so, they release large amounts of carbon into the atmosphere while eliminating important carbon sinks and destroying essential habitat for struggling species, like desert tortoises and Mohave ground squirrels, all in the name of delivering "clean" energy and combatting climate change.

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[iii] Lawsuits are ongoing for the Lake County and San Diego County projects mentioned. Following a legal challenge to Los Angeles County's decisions to approve the developments, courts ordered the approvals for the Northlake project and the Centennial project be set aside because of inadequate environmental review under CEQA. Although the Walt Ranch project was re-approved, after years of community opposition and legal challenges, in May 2023 the area was acquired and permanently protected by the Land Trust of Napa County.

Distributed solar with net-metering on existing structures reduces GHG emissions and preserves intact habitats while making energy more affordable and accessible.[105] Los Angeles County has the opportunity to generate more than 19,000 megawatts of energy by installing solar panels on 1.5 million available rooftops,[106] but instead has prioritized industrial solar farms in remote desert areas.

Desert ecosystems are also vulnerable to invasive plant species and the fire risk they bring. Human disturbance, including livestock grazing, off-highway/off-road vehicle use, fire, urbanization, roads, and agriculture, has led to the establishment of nonnative grasses and forbs in California's desert ecosystems.[107] In addition, nitrogen deposition from air pollution leads to fertilization that disproportionately benefits nonnative species, which outcompete native vegetation.

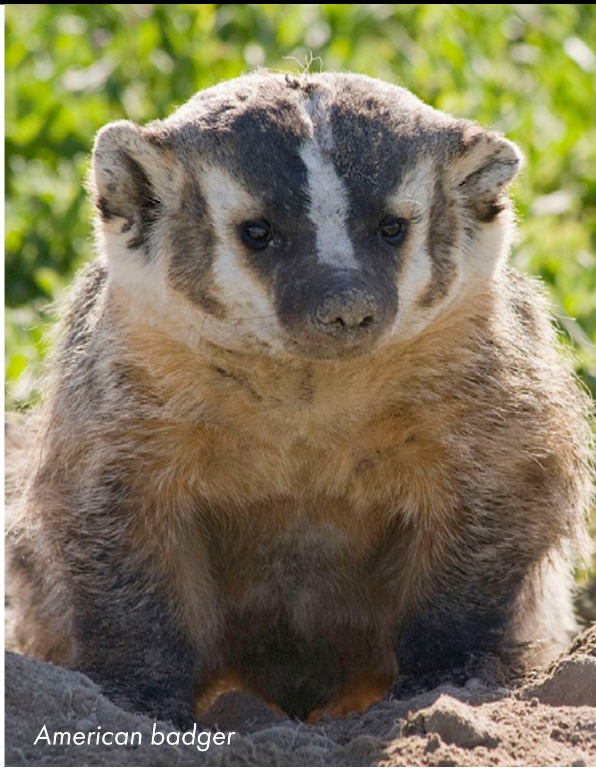
The increased biomass accumulation fuels more frequent and larger fires in desert ecosystems that rarely burned historically and are not well-adapted to extensive wildfires [108–114]. Hotter temperatures and more frequent fires favor the establishment of invasive grasses, shift the area's fire regime, perpetuate the conversion of California's desert ecosystems, and eliminate their capacity to store and sequester carbon.[107,108,110–113]

Further destruction and degradation of California's habitats will diminish our ability to effectively combat climate change. To improve our chances of limiting global warming, we must do more to protect and enhance valuable carbon sinks across diverse habitats.

*The Centennial project in Tejon Ranch, Los Angeles County would develop one of California's last remaining intact native grasslands. Photo: Richard Dickey*

# DIVERSE HABITATS OFFER MYRIAD CO-BENEFITS

There are many co-benefits to preserving diverse habitats when mitigating GHG emissions from a harmful project. Not only does preserving heterogeneous habitats protect biodiversity and communities from wildfire risk, it also protects Tribal and cultural resources, makes our communities healthier and more resilient to climate change, provides equitable access to nature, and moves California closer to attaining its 30 by 30 goals.


*American badger*

## BIODIVERSITY AND WILDLIFE CONNECTIVITY

Protecting and restoring diverse habitats will also help protect the state's unique biodiversity and improve habitat connectivity. Poor land-use practices have led to fragmented landscapes that harm native plants and animals by isolating populations and preventing individuals from finding food, water, shelter and unrelated mates.[115] Protecting nonforest habitat will provide sensitive species like American badgers, blunt-nosed leopard lizards, and coastal California gnatcatchers with live-in habitat, refuge, and opportunities to adjust to shifts in resource availability as climate change worsens.

## EQUITABLE ACCESS TO OPEN SPACE

Preservation of remaining diverse habitats for carbon sequestration can also serve as "local offsets" and GHG mitigation opportunities that bring benefits directly to the communities harmed by the polluting activities.

Protecting existing habitats locally and increasing green space with native plants in historically marginalized communities would help facilitate equitable access to open space, which is vital for communities to experience the physical and mental health benefits of nature.[116] Studies conducted in Southern California have shown that children living closer to open space had fewer asthma emergency department visits[117] and were less likely to experience obesity[118] compared to those living further away from open space. Similarly, residents living closer to urban parks had better mental health scores compared to those living further away[119] and psychological well-being increased with increasing biodiversity in urban green spaces.[120]


*Families exploring Santa Monica Mountains*

The U.S.-sanctioned policy of redlining segregated and suppressed Black Americans to areas that were perceived as less desirable and had less government support. This type of structural racism, combined with poorly planned development, has resulted in highly urbanized, poorer neighborhoods where communities of color are more likely to be exposed to dangerous levels of air pollution, heat, and contaminated water.[121] These areas also have significantly less green space and biodiversity compared to predominantly white neighborhoods with more resources.[121]

Although there are some tradeoffs between housing densification and biodiversity, scientists have found that designing denser neighborhoods with creative green solutions can increase affordable and accessible housing while supporting and enhancing biodiversity.[122] Examples of science-based solutions, or green interventions, include preserving remnant habitat patches, protecting riparian corridors, requiring onsite stormwater capture, green roofs, and creating managed urban parks.[122]

## TRIBAL SOVEREIGNTY AND STEWARDSHIP

Protecting diverse habitats for carbon storage and sequestration would also provide an opportunity to foster Tribal sovereignty and support Tribal stewardship on unceded ancestral lands. Numerous Tribes that have survived genocide and displacement are now working to heal the land.

In Northern California along the Klamath River, Karuk women are retraining Indigenous women on how to bring fire back to the land so they can protect their homes and families from ecological disasters, nurture plants for food and medicine, and preserve their cultures.[123] Similarly, the Amah Mutsun Tribal Band is working with California State Parks to return good fire and restore coastal prairies and healthy forests to the ancestral lands of the Amah Mutsun, Muwekma Ohlone, and Awaswas people.[124]

In 2022, the Yurok Tribe reintroduced California condors to Yurok ancestral lands in partnership with Redwoods National and State Parks.[125,126] The Karuk Tribe recently teamed up with the California Department of Fish and Wildlife and UC Berkeley to reintroduce elk to their ancestral homelands.[126,127] And the Maidu Summit Consortium and the Tule River Tribe are working to reintroduce beaver on their ancestral lands.[126,128] These species have great cultural and ecological value.

*California condor*

*Roosevelt elk by Terry Feuerborn*

Meaningful collaboration between agencies and Tribes and incorporating traditional ecological knowledge and Indigenous science in land preservation and management would synergize efforts to combat the climate crisis, increase community resilience and protect biodiversity.[126] Such efforts benefit everyone.

## *WILDFIRE RISK*

Conservation purchases and commitments to permanently protect habitat in areas designated as "high fire hazard severity zones" in Southern California, where chaparral and coastal sage scrub are most vulnerable to development, have led to biodiversity conservation and reduced wildfire risk.[129,130] Proper land-use planning that prohibits development in intact shrubland and grassland habitats in high fire-prone areas can reduce the number of wildfires accidentally ignited by people in the wildland urban interface. Wildfire risk management saves lives while offering the co-benefits of efficiently maintaining biodiversity, facilitating carbon storage, avoiding carbon release due to habitat removal, and preventing toxic air pollution from burning structures.

## *CLIMATE RESILIENCY*

California's native landscapes also help make communities more resilient to climate change by helping to regulate our climate, purify our air and water, pollinate our crops, and create healthy soil. These habitats, along with properly designed and managed urban green spaces, can help ameliorate the impacts of heat waves, flooding and wildfire.[131–134] And when properly designed and managed, urban green space can potentially reduce energy use and associated costs.[135]

The preservation and enhancement of diverse habitats in California offer many direct and indirect benefits to wildlife and people. These benefits emphasize the need to account for these habitats as critical carbon sinks and incorporate their protection as mitigation for GHG emissions.

*Griffith Park, Los Angeles*
*photo by diliana/Flickr*


California chaparral in Silverado canyon by Shannon1/Wikimedia

# RECOMMENDATIONS FOR SEQUESTRATION STRATEGIES

Nonforest habitats present an additional nature-based opportunity to strengthen our fight against climate change. At a minimum, strategic land-use planning should prioritize the following:

- Ensure that during the project approval process, policymakers fully consider the climate impacts from habitat loss. If environmental review under CEQA or other applicable environmental laws is required, it should include comprehensive and accurate accounting of the carbon storage and sequestration loss from the destruction of diverse habitats. When habitats are paved over for development, carbon calculations should include the loss of currently stored carbon as well as potentially sequestered carbon if the habitats were to remain.
- Promote the conservation and restoration of existing intact, connected, heterogeneous habitats (to be managed by local stakeholders, including Tribes) as a viable mitigation strategy for reducing GHG emissions. Prioritize such mitigation over ambiguous carbon "offsets" in faraway places so that local communities affected by the proposed projects are appropriately compensated.
- Discourage tree-planting schemes that replace nonforest habitats with tree plantations. Instead, prioritize the preservation and restoration of local habitats, especially in and near polluted communities, and incentivize the planting of appropriate vegetation with appropriate management in urban areas that lack green space and in communities that have been historically excluded and underserved.
- Incentivize more research on the carbon storage and sequestration capacity of diverse habitats. This report provides regional and statewide estimates of the carbon storage contributions from shrublands, grasslands, deserts and riparian habitats. However, there is great diversity within habitats that must be considered when calculating carbon impacts and offsets. As more research is conducted and new information is made available, we can deepen our understanding of the carbon cycle and how nature-based solutions can help combat climate change.

To ensure that the implementation of such strategies is successful, the following mitigation standards are recommended:

- Prioritize protecting and managing connected, intact habitat in perpetuity. When habitat conservation is used as a mitigation measure, such land should be vulnerable to development so that true carbon storage gains are made. High replacement ratios should be used to ensure a net gain of habitat. Funding should be allocated for long-term monitoring, reporting, and adaptive management with measurable performance criteria. Extractive uses, such as mining, fossil fuel extraction, logging, livestock grazing, agriculture, energy development, and off-road vehicle recreation, should not be allowed in conservation areas.
- Prioritize conservation easements and avoid development in high fire hazard severity zones and flood zones.
- Prioritize the restoration and enhancement of degraded habitats and abandoned agricultural lands to store and sequester more carbon.[62,136] With the passing of the Sustainable Groundwater Management Act in 2014, it is estimated that 500,000 to 1 million acres of agricultural land in the San Joaquin Valley will need to be retired within the next 20 to 30 years to bring groundwater basins into balance.[137,138] California has an opportunity to retire agricultural lands for shrubland and grassland restoration. Doing this strategically will increase carbon storage, reduce air pollution, increase water reliability during drought and support biodiversity that facilitates improved ecosystem function and climate change resilience.[139–142]
- Meaningfully collaborate with Tribes and incorporate traditional ecological knowledge and Indigenous science to re-establish historical fire regimes and adaptively manage ecosystems.
- If GHG emissions reductions from protecting habitat are used for meeting regulatory or permitting requirements, ensure that mitigation measures are real, permanent, quantifiable, verifiable and enforceable. There should be evidence that shows the GHG emissions reductions would not have occurred in the absence of mitigation measures. Similarly, the GHG emissions reductions must be irreversible.

Tree-planting and carbon offset schemes are not the answers to the climate crisis. If we want to take meaningful climate action, we must make smarter land-use decisions that value the carbon storage and sequestration abilities of not only trees and forests, but also California's overlooked shrublands, grasslands, deserts and riparian corridors. As California communities grow, we must mitigate harmful developments with a sound plan that brings real results. Preserving and restoring the native habitats of this golden state protects our rich biodiversity, benefits communities, and gives us a fighting chance to tackle the climate crisis.

*South Fork Kings River in Sequoia-Kings Canyon Wilderness by Tiffany Yap*

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# APPENDIX

There is great diversity within habitats that must be considered when calculating carbon impacts and offsets. Yet existing tools used to calculate carbon losses from destroyed habitat are often insufficient and incomplete. Miscalculations relying on these tools can, for example, underestimate the loss of carbon storage and sequestration from removing native grasslands or shrublands while also leading to systematic over-crediting in California's carbon offsets program.[1] Therefore, it's essential to carefully examine and analyze site-specific carbon storage and sequestration.

This report provides regional and statewide estimates of the carbon storage contributions from shrublands, grasslands, deserts and riparian habitats. There are many ways carbon can be stored in ecosystems.[i] Carbon can be stored in aboveground biomass of living and dead plants, belowground root systems, soils, and leaf litter. This appendix provides additional information and discussion regarding how carbon is stored in various habitats. Accounting for the various carbon sinks within an ecosystem is important when calculating carbon loss from habitats that are bulldozed for development.

The Supplemental Table provides a more detailed summary of the available data in the scientific literature regarding carbon storage and sequestration in shrublands, grasslands, desert, riparian habitats, natural forests and urban trees in California. Although there are gaps in the data that make it difficult to directly compare the habitats, the available information reflects the untapped carbon potential of several nonforest habitats in the state.

Climate science is a growing and dynamic field. Some habitats have more information than others. As more research is conducted and new information is made available, we can deepen our understanding of the carbon cycle and how nature-based solutions can help combat climate change.

[i] Some scientists are even looking into the recovery of baleen whales as a carbon sequestration strategy.[31]

*Owens Peak Wilderness*

***Supplemental Table:*** *Carbon storage and sequestration of different habitat types in California.*

| Habitat Type | Age (years) | Average Aboveground Biomass (metric tons/acre) | Average Belowground Biomass (metric tons/acre) | Average Soil Carbon (metric tons/acre) | Soil Depth (cm) | Average Leaf Litter Biomass (metric tons/acre) | Estimated Average Total Carbon Storage (metric tons/acre) | Estimated Annual Carbon Accumulation (metric tons/acre/year) | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| **Riparian Habitat**[a] | 1-45 | 233.8 | 51.6 | 40.2 | 50 | | | 0.81 | 2 |
| Channel | | 61.8 | 14 | | | | | | 2 |
| Floodplain | | 92.9 | 20.1 | 17.5 | 50 | | | 0.35 | 2 |
| Upper Bank | | 79.1 | 17.5 | 22.7 | 50 | | | 0.45 | 2 |
| **Grasslands** | | | | | | | | | |
| Dominated by *Agrostis halli* (native species) | | 1.34 - 1.7 | 0.85 - 1.66 | 71.2 | 50 | | 71.2[b] | 2.18 - 3.36 | 3 |
| Dominated by *Festuca rubra* (native species) | | 1.41 - 1.5 | 2.02 - 4.09 | 68.4 | 50 | | 68.4[b] | 3.44 - 5.58 | 3 |
| *Nassella pulchra*, *Bromus carinatus*, *Elymus glaucus* mix (native species) | | 1.05 - 1.05 | 1.5 - 3 | 59.5 | 50 | | 59.5[b] | 2.55 - 4.05 | 3 |
| Non-native Grasslands | | 0.49 - 1.13 | 0.57 - 0.81 | 38.4 - 60.3 | 50 | | 38.4 - 60.3[b] | 1.05 - 1.94 | 3 |
| Rangelands | | | | 15.8 - 23 | 40 | | 15.8 – 23[b] | | 4 |
| **Shrubland** | | | | | | | | | |
| Mixed Chaparral | 1 - 30+ | 14 | 5.38 | 5.66 | 100 | 10.3 | 35.3 | 1.73 | 5,6 |
| Chamise Chaparral | 1 - 30+ | 8.55 | 5.13[c] | 3.65 | 100 | 5.17 | 22.5 | 0.45 | 5,6 |
| Coastal Sage Scrub | 1 - 10+ | 6.4 | | | | 5.63 | | | 5,6 |
| **Desert** | | | | | | | 4.17[d] | 0.4-0.51[d] | 7–9 |
| *Ceanothus greggii* (desert shrub) | 21 - 24 | 19.7 | 3.23 | | | | | 2.41 | 5 |
| **Natural Forest**[e] | | | | | | | 48.6 | 1.21 - 3.16 | 10 |
| **Urban Trees**[f] | | | | | | | 3.3 - 6.2 | 1.3 - 2 | 11 |

a Only maximum estimates of carbon storage and carbon sequestration rates are provided.
b Only includes average soil carbon because average biomass data was provided as a range.
c Calculated based on the 0.6 shoot:root ratio provided for chamise (*Adenostoma fasciculatum*) in Bohlman et al. (2018).
d Estimates are based on measurements taken in the northern Mojave Desert in Nevada.
e Estimates include forests in Northern California and Oregon, only includes total tree biomass.
f Only includes total tree biomass.

Coastal scrub by Ileene Anderson

## SHRUBLANDS

California chaparral is primarily made up of evergreen woody shrubs that create a dense, semi-impenetrable cover. It occupies most of the hills and lower slopes of California and is adapted to drought and fire.[12] Long-duration cycles of fire and regrowth sustain the various successional stages of chaparral communities. It also fixes carbon throughout the year with summer and winter depressions.[12]

Named for its preference for the entire coast of California, typically within the fog-drip zone, coastal scrub is occasionally referred to as "soft chaparral" because the shrubs are shorter, less robust, and have a shallower root zone.[13,14] Unlike chaparral, coastal scrub shrubs are typically drought deciduous, which means they lose leaves during the dry season, adding biomass during the rainy season. With this strategy, the majority of the carbon uptake occurs during the rainy season.[13,14]

Aboveground biomass consists of both live and dead vegetation. Even dead vegetation, like stands of shrubs or trees killed during a wildfire, can still serve to store carbon, and some plants can resprout after fire. Researchers found that carbon in above-ground biomass of shrub communities, including mixed chaparral, chamise chaparral, and coastal sage scrub, ranged from 0.49 to 47.7 metric tons of carbon per acre and averaged 6.4 to 14 metric tons of carbon per acre (Supplemental Table).[5,15]

Although researchers found that the amount of carbon stored in shrub communities increased with the age of the stand, the age of an individual plant may not always be indicative of the amount of carbon stored.[5,15] For example, Bohlman et al. (2018)[5] found the lowest reported biomass for an individual chamise (*Adenostoma fasciculatum*) was 0.198 kg of carbon per square meter for a one-year-old individual, while the highest reported biomass was 6.818 kg of carbon per square meter for a resprouting two-year-old individual that had many dead stems. The next highest biomass was from a mature individual (>60 years old) at 4.260 kg of carbon per square meter, of which 3.363 kg of carbon per square meter was alive.[5]

Even leaf litter, which includes accumulated leaves and branches and other once-living matter on the ground that has not decayed, also consists of carbon that is being stored and not emitted into the atmosphere. Though often overlooked, such litter in shrublands has been estimated to store 5.17 to 10.28 metric tons of carbon per acre (Supplemental Table).[5]

Although carbon in belowground biomass is rarely measured or calculated, some shrubland species have been found to have 41% to 47% of their biomass below the surface,[5] and chaparral roots have been found 4 meters

(>13 feet) deep in weathered bedrock.[16] For example, Bohlman et al. (2018)[5] calculated the average reported belowground biomass carbon for mixed chaparral to be 5.38 metric tons of carbon per acre (Supplemental Table).

A substantial amount of carbon may also be stored in the microbial communities and mycorrhizal fungi that work in concert with root systems to trap carbon in biomass and soil pores and to suppress decomposition of humic substances.[17,18] One study found 3.65 metric tons of carbon per acre in soils down to 1 meter deep for chamise (Supplemental Table).[6]

Accounting for total biomass (above and below ground), soil carbon (1 meter deep), and leaf litter carbon, mixed chaparral and chamise chaparral habitats have been found to store an average 22.5 and 35.3 metric tons of carbon per acre, respectively (Supplemental Table). In addition, shrubland habitats can continue to sequester carbon as they age. Scientists estimated that mixed chaparral and chamise chaparral sequester on average an additional 1.73 and 0.45, respectively (Supplemental Table).[5]

Intact shrublands with more diverse plant communities have been found to stimulate the formation of soil pores that support optimal microbial functioning and carbon accrual.[17] And increased root surface area supports more mycorrhizae that aid in nutrient uptake and facilitate carbon flow and soil carbon accumulation.[18–20] In addition, semi-arid shrublands have been found to drive the trend and interannual variation of the global carbon cycle.[21,22] Shrublands should be recognized for their carbon storage potential and included in carbon calculations.


*Colorado Desert by slworking2/Flickr*

## DESERTS

Carbon in desert landscapes can be found in vegetation and within the soil. Although desert plant cover is generally low, some desert shrubs can store large amounts of carbon. Desert ceanothus (*Ceanothus gregii*) was found to store up to 41 metric tons of carbon per acre in their aboveground biomass and up to 5.8 metric tons of carbon per acre in their belowground biomass while accumulating 2.4 metric tons of carbon per acre, per year (Supplemental Table).[5] Other areas with vegetation, like Joshua tree woodlands and creosote bush, likely store significant amounts of carbon as well.

There are no soil databases that have data on carbon sequestration capacity of soils below 2 meters,[23] but soil carbon in deserts should not be dismissed. Two different mechanisms can sequester deep soil organic matter in desert soils: preferential flow of dissolved organic carbon and plant rooting behavior.

Preferential flow pathways are stable paths that persist for decades and the transport of carbon into deeper soil horizons depends on soil texture and the homogeneity of surface plant cover. An example of a preferential flow pathway is the vertical cracks of clayey soils that cause an increasing variability of soil organic carbon distribution in lower soil horizons.[24]

Plant rooting behavior plays an important role in carbon storage. As roots move through the soils, they release fluids and slough-off organic material, and at some point the roots die or die back and decompose.[24] Perennial desert plants, including microphyll woodlands, creosote and other deep-rooted desert plants, can have roots that reach 30 meters below the surface where groundwater is located, resulting in the introduction of organic carbon, through plant root behavior, deep into the soil horizons.

Soil organic carbon fluctuates and is tied to rainfall, with greater organic carbon being stored when moisture is available.[25] Large stocks of soil inorganic carbon are mostly found in regions with low water availability (*i.e.*, areas with mean annual precipitation < 250 mm),[26] with deserts having the greatest densities of soil inorganic carbon compared to other ecosystems.[27,28] Soil inorganic carbon and deep soil organic carbon are very stable forms of stored carbon, and they dominate the carbon sink in deserts.[25,29] This highlights the carbon sequestration contribution of California's deserts and the need to protect these landscapes from soil disturbance and degradation from development.

The desert data provided in the report are from studies conducted in the northern Mojave Desert in Nevada, which is different from the more southern portions of the Mojave and other desert areas in California. The Mojave Desert receives almost all of its precipitation in the winter, while the southern desert in California, known as the Colorado Desert, has bimodal precipitation where rain falls in the winter and summer. The summer rainfall is known as monsoon season, when the Colorado Desert gets most of its rain. This bimodal rainfall creates many ephemerally flooded washes that support microphyll woodlands or dry desert wash woodlands. They create an important desert refugia for animals including migratory birds in California's southern desert.

Microphyll woodlands are dominated by leguminous trees with deep roots that extend down several meters and into groundwater.[30] These trees absorb carbon dioxide as they grow, creating sugars that move into the roots and soil organisms. In the desert when carbon dioxide is respired back into the soil, it reacts with calcium in the soil to form calcium carbonate, a very stable material.[30] This process sequesters large amounts of carbon into soils, making it possible that California deserts store and sequester even more carbon than reported here.

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