



February 15, 2022

Jennifer Norris
Deputy Secretary for Biodiversity and Habitat
California Natural Resources Agency
1416 Ninth Street
Sacramento, CA 95814

Re: Inland Desert Region Comments on the Draft 30x30 Pathways Report

Dear Deputy Secretary Norris:

We continue to appreciate the hard work the California Natural Resources Agency (CNRA) and sister agencies have provided in an effort to design a pathway that conserves at least 30 percent of California's land and waters by 2030 as specified in E.O. N-82-20. We are writing to provide our reactions and recommendations on the 30x30 Pathways Draft Report as it relates to the Inland Desert region specifically. Our signatories represent community members and non-profits working throughout the area on issues of conservation, biodiversity, access and equity, specific to our region.

Our coalition would first like to commend the CNRA for its support of diversity and equity issues as well as working with indigenous communities throughout this process. We urge the state to fund 30x30 work with frontline communities, people of color, and indigenous peoples as one of its top priorities for achieving an inclusive 30x30 initiative.

Our comments in this letter are in addition to the letters sent to CNRA prior to the release of the Pathways draft report which include:

1. Sept. 3, 2021, To: Jennifer Norris, Re: Implementation of Executive Order N-82-20 (30x30 Strategy)
2. Nov. 24, 2021, To: Amanda Hansen, RE: Desert Concerns with the Natural and Working Lands Climate Smart Strategy Draft Report

We trust that the final Pathways report will characterize the California desert as a contiguous whole and as an integral element in the state's biodiversity, carbon sequestration and climate resilience portfolio. Additionally, we hope the final Pathways report will acknowledge the desert's sacred meaning and cultural resources to Indigenous Tribes. These acknowledgments and actions are essential to the health and economic sustainability of our communities, and we look forward to working closely with CNRA to further advance the conservation needs in the next revision of the Pathways Report.

Key Issues

It was our understanding that the various 30x30 topical workshops and public input, comments and letters would be informing the draft Pathways report. However, in reviewing the report, we found little to no mention of our coalition's most pressing concerns that we have been voicing since CNRA started its public input process. The seven foundational concerns we wish to highlight here are:

1. Lack of consultation with California Desert Experts and Scientists
2. Ecological Fragmentation of the California Desert
3. Benefits of Desert Carbon Sequestration Are Omitted or Inconsistent
4. Desert Biodiversity Missing
5. Access & Equity
6. Imminent Threats
7. Definition of Conservation

Lack of Consultation with California Desert Experts and Scientists

The Inland Desert region in the Pathways report should be informed by experienced experts and scientists who have a history of dealing with and understanding the complexities of the California desert. That team of experts and/or scientists may already exist, but we would not know. If such a team already exists, we respectfully request CNRA consider introducing our team of scientists and experts to them in an effort to build scientific collaboration that may shed new light and a better understanding of the desert. Additionally, we request CNRA's science team's curriculum vitae or relevant desert science experience be listed. Furthermore, we request that the collective decades of scientific peer-reviewed publications on desert carbon sequestration ([see Appendix A](#)) provided by the University of California -affiliated researchers be included in the analysis to provide scientific transparency and analytic depth. We hope CNRA will acknowledge that scientists working in desert ecosystems have recognized and published on the importance of deep organic carbon since the International Biological Program (IBP) of the 1960s and 1970s. Simply focusing on above-ground

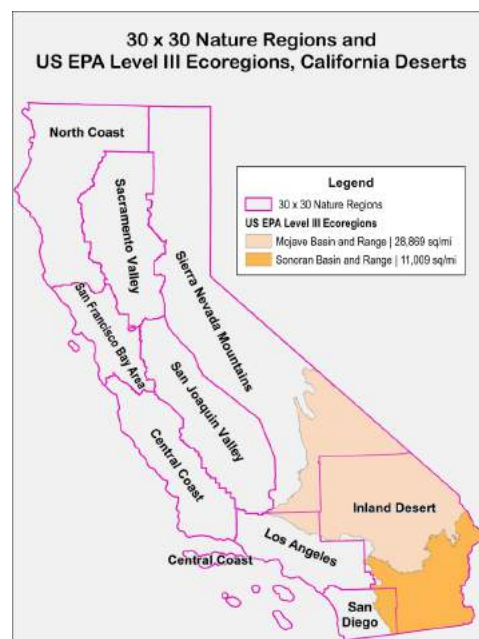
carbon is well known to be inadequate¹. In addition to being inadequate, exclusive focus on above-ground carbon biomass is an inaccurate representation of the global carbon pool which includes below-ground carbon storage.

Ecological Fragmentation of the California Desert

As defined by the CNRA, the “Inland Desert Region” consists of Imperial County, eastern parts of Riverside, and most of San Bernardino County. Based on CNRA’s current regional maps, 21% of the Sierra Nevada region is Desert, including Death Valley, which one would expect to be categorized in the Inland Desert region. At the outset, we note the definition and boundaries above present a considerable obstacle to effective science-based land management. Mapping defined by human-constructed borders rather than ecosystem-driven borders does not allow the intent of 30x30 efforts to be fully developed.

Interestingly, the draft Pathways Report, Appendix B, page 5 references the SC Wildlands California Desert Connectivity Project map which shows a larger California desert; however, this map is not reflected in the Pathways Inland Desert boundary map for 30x30 purposes. Both from an ecological and Native cultural perspective, the California desert does not align with the “Inland Deserts” borders defined by CNRA. Effective stewardship of wildlife connectivity, air quality, cultural resources, and similar issues mandates the entire desert region be depicted in its contiguous whole as shown by numerous government agencies and experts. The US Department of Agriculture, the US Environmental Protection Agency and the US Bureau of Land Management’s “California Desert Conservation Area” maps all show the California desert encompassing a larger area as compared to CNRA’s Inland Desert map ([see Appendix B](#)).

The real threat is not necessarily that we move artificial boundaries on a map, but rather that the lens through which the map is viewed will overlook aspects of that region because they do not resemble what the regional category is named after. For example, other than to state that 21% of the Sierra Nevada is desert, there is no further mention of any desert species or desert iconic landscapes within the Sierra Nevada region. The desert is forgotten or overlooked in the Sierra Nevada and San Diego regions. If not corrected, important and iconic species and landscapes such as the Western Joshua Tree, Death Valley National Park and Anza Borrego State Park remain unaccounted for in CNRA’s Inland Desert Region and sadly, don't show up in any consequential manner in any of the other CNRA 30x30 Regions. We respectfully request the state correct the current Inland Desert mapping system so that the regions accurately reflect their ecological contents, and so that land management prescriptions are correctly placed within their appropriate regions.



¹ S G Bai et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 100 012129

Benefits of Desert Carbon Sequestration Omitted or Inconsistent

We are glad to see that in the Pathways report, Appendix A, page 67, under the title “Potential Nature-Based Solutions”, one of the bullets shown is “Land Management that Promotes Carbon Sequestration in Desert Soils”. While somewhat accurate, this statement is not reflected or expanded at all in the actual report. The fact is that the word “desert” is only mentioned once in the report and only when describing the varied landscapes in the state. An example of an opportunity to **not** overlook the desert is shown on page 16 of the draft Pathways report:

“Intact ecosystems, like forests, grasslands, wetlands, and coastal habitats, remove carbon from the atmosphere, safeguard important resources such as clean water, and can protect people and nature from the impacts of climate change...”

The CNRA could make this statement complete by adding “deserts” to this list.

A complicating factor in desert carbon modeling is that the desert ecosystem is not homogeneous, but instead is a mix of varied topographic and geologic features, habitats, microhabitats, and climatic variations depending on elevation and location. One model for the entire desert may not correctly predict the carbon processes for every acre of the desert. It is our understanding that currently, CNRA is using the California Air Resources Board (CARB) modeling system for quantifying carbon in California. It is our assertion that the CARB model lacks the appropriate systems to record the amount of carbon sequestration taking place below ground. It’s also our understanding that CARB’s modeling systems require them to fit within Intergovernmental Panel on Climate Change (IPCC) protocols -- which are deficient in desert carbon sequestration studies and modeling systems.

Based on scientific evidence, it is our position that:

- Up to 10% of carbon sequestration in California stems from below-ground activity in its deserts ([see Appendix C](#)).
- California’s hot deserts contain a large pool of inorganic carbon in the form of calcium carbonate (caliche), derived from biological processes. Because of carbon’s potential to remain sequestered in mineralized form for eons, it is often considered that carbon stored underground in caliche does not affect greenhouse gasses, so it should not be included in carbon models. Although this mineralized carbon can be stored underground for many thousands of years, it can also be released back into the atmosphere if weathered upon exposure when disturbed.
- Carbon is patchy across California's deserts and can be distributed between 1 meter (3 feet) and 60 meters (197 feet) deep, below depths commonly surveyed. Most research involving carbon storage in desert soils has been conducted to depths of 1 meter or less, but carbon capture in hot desert ecosystems occurs mostly below those depths.
- Inorganic carbon is fixed but dependent upon bio-weathering of calcium. While the chemical steps are well known, the temporal and spatial interaction patterns are complex.

Therefore, we urge you and your colleagues to implement the research and analysis presented in [Appendix A](#), a white paper authored by Dr. Michael Allen, Distinguished Professor Emeritus, Department of Microbiology and Plant Pathology University of California, Riverside as a means to properly model carbon sequestration in the California desert.

Dr. Allen's white paper compares various models for relative success or shortfalls in tracking carbon across the desert landscape. Highlights from his white paper (with citations) that can serve as a roadmap include:

Models of carbon accumulation ~

- **DayCENT**: Parton et al. 1998. Global and Planetary Change: 19:35
- **Hydrus**: Šimůnek, & Suarez. 1993. Water Resources Research, 29:487
- Šimůnek et al. 2005. University of California, Riverside, Research Reports, 240.
- *Empirical data of groundwater access is critical* to accurately model carbon accumulation: Kitajima et al. 2013. Journal of Geophysical Research- Biogeosciences 118:1561, data underlying Allen et al. 2014. In M. Tausz, N.E. Grulke (eds). Trees in a changing environment.

Model of calcium carbonate sequestration ~

- **SLIC**: Hirmas et al. Geoderma 154:486. *But actual rhizosphere CO₂ concentration empirical data* are needed as inputs: Allen et al. 2013. CEC-500-2013-063.

We urge the CNRA to acknowledge the importance of a holistic study of all available carbon sequestration. Above-ground carbon sequestration won't identify most of the stored carbon captured in the desert underground. There are both modeling and measurement research approaches that California's ecological research community have applied over several decades that can and should be undertaken.

It is our hope to shed light on the intricate but largely unacknowledged sequestration processes that work together to capture and store carbon deep in hot desert soils. For elucidation on this process, we are mailing you and your CNRA colleagues a hardcopy of "*The Desert Underground*", a book by biologist and former Bureau of Land Management botanist for the California Desert District, Robin Kobaly. We are hoping to get this book more widely circulated and hope you can appreciate it as much as we have in explaining desert carbon sequestration to the layperson. We appreciate your review of our material and welcome further conversations with you and your colleagues. The health of our planet and our communities deserve to have our "lungs" in the desert protected and conserved.

Desert Biodiversity Missing

The Inland Desert Region includes over 17.9 million acres² of some of California's most spectacular public lands and waters. These public lands and waters are part of the most intact terrestrial ecosystem in the lower 48 states and are of incalculable value to plants, wildlife, and people. The California desert region supports extremely high biodiversity: 38% of native plant species within the state can be found here, owing to the rich diversity of geologic and climatic patterns. Currently, there are 2,450 species of native plants³. To facilitate this plant biodiversity there are up to 600 species of native bee pollinators in the Joshua Tree National Park region alone⁴. Bees love the desert and its variety of wildflowers. Additionally, 2.4 million acres are designated as Important Bird Areas by the National Audubon Society within the Colorado and Mojave Deserts.

When driving on highways through the California desert, it can be difficult to see the amount of biodiversity and fragile ecosystems in place. We gaze at thousands of acres of intact lands with evenly spaced creosote bushes rolling into the distance, but what you don't see is what's underground and hiding in plain sight. If we only took the step needed to slow down the normal flow of time to investigate and observe, we would find a system teeming with both fragile and robust life that also doubles as a natural climate healing system for our planet and medicine for our health and mental well-being.

Access & Equity

Many in our communities, including those in the Greater San Bernardino and Riverside Counties, and Eastern Coachella and Imperial Valleys, are lacking the access and financial means to visit and benefit from many of our public lands and open spaces. Much work must be done to increase public transit access and improve facilities, including multilingual signage and reduction of park fees to make sure these places are available and welcoming for regional community members as much as it is for visitors from afar. Additionally, we support green space investments in climate-vulnerable neighborhoods --including farmworker communities at the East Coachella and Imperial Valleys and urbanized areas of the Inland Empire, which all lack access to nature and healthy, biodiverse environments.

The initiative to provide appropriate access to public spaces starts with access to the 30x30 process for people who have been historically marginalized and/or remain disadvantaged. Providing the final Pathways report in both English and Spanish would be a positive step towards accessibility (Spanish is the 2nd most common language in the state of California)⁵.

California's tremendous biodiversity owes greatly to Indigenous stewardship, and many of our most biodiverse areas are also culturally important areas. We appreciate that the draft Pathways Report includes "...partnering with California Native American tribes" as one of three guiding principles.

² California Natural Resources Agency, Natural and Working Lands Climate Smart Strategy Draft Report, Page 94

³ Kara A. Moore and James A. Andre in FREMONTIA Vol. 42, No. 1, January 2014. California Deserts, Part 1 Biology and Ecology.

⁴ www.nps.gov/articles/a-preliminary-report-on-the-bees-of-joshua-tree-national-park-with-special-focus-on-anthophora-digger-bees.htm

⁵ <https://www.milestoneloc.com/the-top-languages-spoken-in-california/>

However, the report lacks specific recommendations to ensure that this principle is honored. For example, there should be funding specifically provided to support tribal engagement in 30x30 and for the establishment and administration of tribally protected areas.

Imminent Threats

Due to the logistics industry expansion into the Inland Empire, warehouse development and accompanying truck pollution has not only swallowed up desert lands, it has contributed to a long list of health ailments in desert communities⁶.

Communities surrounding the Salton Sea, the inland body of water straddling California's Riverside and Imperial counties, show high rates of asthma due to high aerosol dust levels resulting from the sea shrinking over time⁷.

Given the state's laudable decarbonization goals, the CNRA should design policy recommendations that avoid harming nature in pursuit of climate goals by discouraging renewable energy development on lands with intact ecosystems. This is especially true in the desert — where it takes hundreds of years to fully restore native vegetation and where massive amounts of carbon stored over millennia are released when the soil is disturbed. Instead, the state should promote distributed energy resources that can be located on rooftops, parking lots, canals, road and utility rights-of-way, and other areas that have existing infrastructure, which will minimize the societal costs and environmentally-damaging impacts of long-distance energy transmission.

We fundamentally agree that the future prosperity of our state is dependent on mitigating climate change and advancing clean energy development. As an equal priority to the deployment of clean energy, we must protect and restore wild places and build resilient habitats that can help species and ecosystems survive climate change. Areas unsuitable for development for either commercial renewable energy projects or other energy projects should be identified, defended, and protected.

It is incumbent on the state's 30x30 leadership to pursue the goals above by:

- Re-initiating the state portion of the Desert Renewable Energy Conservation Plan (DRECP), and provide funding to desert Counties for necessary planning on disturbed land
- Ensuring that the California Public Utilities Commission (CPUC) does not jeopardize rooftop solar as it's threatening to do by slashing net metering programs and greatly increasing connection fees; not only would this burden all future ratepayers with unnecessary capital costs and ongoing transmission/delivery charges at billions a month – this would also cause unnecessary destruction of the desert, flying in the face of 30x30 goals
- Collaborating with key state agencies such as the CPUC, CARB and the California Energy Commission to deliver a successful 30x30 program for all Californians

⁶<https://www.nbcnews.com/tech/tech-news/treated-sacrifices-families-breathe-toxic-fumes-californias-warehouse>

⁷<https://news.usc.edu/159380/salton-sea-shrinking-asthma-respiratory-health-air-quality/>

Definition of Conservation

We appreciate the CNRA for defining “conservation”. We would like to bring up a point of clarification – would protections created through administrative action be considered enduring – and thus meet the definition of conservation? If so, we would point out that lands and waters protected by administrative actions are time-limited and reversible by administrative reconsideration or redesignation and therefore, should not be considered “conserved” for purposes of 30x30. This is particularly important in our region, rich in public lands, where designations such as Areas of Critical Environmental Concern could be easily reversed. Additionally, the definition should include an explicit goal to sustain biodiversity.

Conclusion

Please do not overlook the deserts of California and their benefit to biodiversity, Tribal equity and climate resilience when generating your final report; not doing so severely compromises the intentions of the 30x30 initiative.

We look forward to working with you to implement Governor Newsom’s ambitious effort to ensure that all Californians will enjoy access to a healthy and climate-resilient environment in which biodiversity and people thrive. Thank you for taking our cumulative recommendations from past writings and those in this letter. We look forward to the ongoing collaborations with CNRA and other state entities on this important work.

Sincerely,

Signatories:

Mason Voehl, Executive Director
Amargosa Conservancy

Sendy Hernández Orellana Barrows, President
CactusToCloud Institute

April Sall, President of the Board and Executive Director
California Desert Coalition

Andrea Williams, Director of Biodiversity Initiatives
California Native Plant Society

Francisco Moreno, Executive Director
Consejo de Federaciones Mexicanas

Elyane Stefanick, California Program Director
Conservation Lands Foundation

Jora Fogg, Policy Director
Friends of the Inyo

Shanna Edberg, Director of Conservation
Hispanic Access Foundation

Rebecca T. Zaragoza, Regional Policy Manager | Eastern Coachella Valley
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Kelly Herbinson
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Joint Executive Directors
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Dr. Rebecca R. Hernandez, Wild Energy Initiative
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Chris Clarke, Ruth Hammett Associate Director, California Desert Program
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Kim Floyd, Conservation Chair
Sierra Club, San Geronimo Chapter

Jim Dice, Reserve Manager
Steele/Burnand Anza-Borrego Desert Research Center

Robin Kobaly, Executive Director
SummerTree Institute

Jack Thompson, California Desert Regional Director
The Wildlands Conservancy

Sam Easley, Executive Director
Transition Habitat Conservancy

Janessa Goldbeck, CEO
Vet Voice Foundation

Laura Cunningham, California Director
Western Watersheds Project

Chris Krupp, Public Lands Attorney
WildEarth Guardians

cc: Wade Crowfoot, Secretary, California Natural Resources Agency
Amanda Hansen, Deputy Secretary for Climate Change, California Natural Resources Agency
Moisés Moreno-Rivera, Assistant Secretary for Equity and Environmental Justice, California Natural Resources Agency
Lauren Sanchez, Senior Advisor for Climate, Office of Governor Newsom
Tom Gibson, Office of Governor Newsom
Mindy McIntyre, Office of Governor Newsom

APPENDIX A

NOTES ON MODELS OF CARBON DYNAMICS FOR THE CALIFORNIA DESERTS

(content begins on next page)

Notes on Models of Carbon Dynamics for the California Deserts

Prepared By Michael F. Allen, Ph.D., Distinguished Professor Emeritus,
Department of Microbiology and Plant Pathology, UC Riverside

Production of organic Carbon (C_{organic}) is generally low in hot desert ecosystems. Net primary production in the Mojave desert generally ranges from 10 to 30gC/m²/y (Rundel and Gibson 1996), with a pool of 0.9 to 1.1kgC/m² (Evans et al. 2014). Photosynthesis is limited by temperature and moisture, and decomposition can remain high. Q_{10} values for RuBP Carboxylase is generally credited as a bit over 2 for ten degree increments between 10 and 40°C. Above 30°C, rates of photosynthesis decline rapidly. In deserts, however, soil respiration rates indicative of enzymatic activity can remain high up to 60 to 70°C (Cable et al. 2011). For this reason, C in desert ecosystems has been overlooked or even criticized as a crucial element in global and regional models.

Importantly, there are reports of very high rates of net ecosystem exchange of C (e.g., Xie et al. 2009, Wohlfahrt et al. 2008). These have been criticized as being unreasonable (Schlesinger and Amundson 2019), but no one has provided an alternative explanation for the measured values. While scientists continue to study the patterns and mechanisms of C_{organic} in deserts, we know that California deserts have been accumulating inorganic C ($C_{\text{inorganic}}$) for millennia (Schlesinger 1986). While some measurements of the rates of input are controversial, including localized, temporal values equal to those of forest ecosystems (e.g., Schlesinger et al. 2009, Schlesinger and Amundson 2019), ***a large pool of stored C has the potential to be lost through anthropogenic disturbance and exposure***. The mechanisms of C dynamics in desert ecosystems are outlined here with a focus on southern California.

- Cable, J. M., K. Ogle, D. G. Williams, J. F. Weltzin, and T. E. Huxman. 2008. Soil texture drives responses of soil respiration to precipitation pulses in the Sonoran Desert: Implications for climate change. *Ecosystems* **11**:961-979.
- Evans, R. D., A. Koyama, D. L. Sonderegger, T. N. Charlet, B. A. Newingham, L. F. Fenstermaker, B. Harlow, V. L. Jin, K. Ogle, S. D. Smith, and R. S. Nowak. 2014. Greater ecosystem carbon in the Mojave Desert after ten years exposure to elevated CO₂. *Nature Climate Change* **4**:394-397.
- Rundel, P., and A. Gibson. 1996. *Ecological communities and processes in a Mojave Desert Ecosystem: Rock Valley, Nevada*. Cambridge University Press, Cambridge.
- Schlesinger, W. H. 1985. The formation of caliche in soils of the Mojave Desert, California. *Geochimica Et Cosmochimica Acta* **49**:57-66.
- Schlesinger, W. H., and R. Amundson. 2019. Managing for soil carbon sequestration: Let's get realistic. *Global Change Biology* **25**:386-389.
- Schlesinger, W. H., J. Belnap, and G. Marion. 2009. On carbon sequestration in desert ecosystems. *Global Change Biology* **15**:1488-1490.

- Wohlfahrt, G., L. F. Fenstermaker, and J. A. Arnone. 2008. Large annual net ecosystem CO₂ uptake of a Mojave Desert ecosystem. *Global Change Biology* **14**:1475-1487.
- Xie, J. X., Y. Li, C. X. Zhai, C. H. Li, and Z. D. Lan. 2009. CO₂ absorption by alkaline soils and its implication to the global carbon cycle. *Environmental Geology* **56**:953-961.

What is Caliche?

Caliche is a layer of calcium carbonate (CaCO₃) formed between the soil surface, and accumulating at the depth to which water will percolate carrying calcium (Ca) and to which roots will respire CO₂. CO₂ from respiring roots and microorganisms, plus atmospheric CO₂, dissolves in rainwater forming bicarbonate HCO₃⁻ and hydrogen ions (H⁺). Using the free Ca, the equilibrium reaction results in CaCO₃, and the CaCO₃ crystals precipitate, until the next storm, when the reaction reoccurs and percolates the dissolved CaCO₃ in solution down to that storm's depth.

Caliche forms in bajadas below mountains comprised of high concentrations of Ca, particularly basalts (mineral CaO) and silicates (CaSiO₃) and limestone CaCO₃ formed under the oceans and pushed up geologically, along with its derivatives, dolomite (with added Mg) and marble, limestone's metamorphic derivative. Weathering of well-known mountain ranges, including the Alps and the Himalayas, yields Ca. When in semi-arid to arid regions, deep layering of CaCO₃ forms, such as in most of Mediterranean Europe, and the deserts of the southwestern US and northwestern Mexico. As much C in the form of CO₃ is sequestered in arid to semiarid soils as in plant organic C mass globally, and there remains a large "missing sink of C" somewhere in terrestrial ecosystems.

Despite the large amount of CaCO₃ sequestered over the past several thousand years, three assumptions contribute to a view among decision-makers that this C can be ignored in the quest to understand C fluxes between the biosphere and the atmosphere. These are three assumptions that pose serious limitations to global carbon modeling and are at least contributors to the large gaps remaining in closing the global C models. These are: (1) CaCO₃ is patchily distributed globally and not easily mapped, (2) that the processes are geological and, because the dominant form is inorganic (CaCO₃), it is a geological and not biological process. Therefore, no accounting need be undertaken using ecosystem models. And (3), there is an assumption that the rates of transformations and loss are on a geological time scale and not relevant to global change models.

Given that approximately 40% of the increase in atmospheric CO₂ driving global climate change is due to land use change (compared with 60% from fossil fuel burning), it is critical to understand the nature of the largest single terrestrial C pool, especially since much of it is in desert ecosystems.

1) How much and where is Carbon in California deserts?

Surface soil CaCO_3 is distributed widely, but in patches throughout the desert. In the surface layers, we can see, for example large swaths in the southern California (SoCal) deserts, where as much as 5% or more of the surface soil is CaCO_3 (Fig 1).

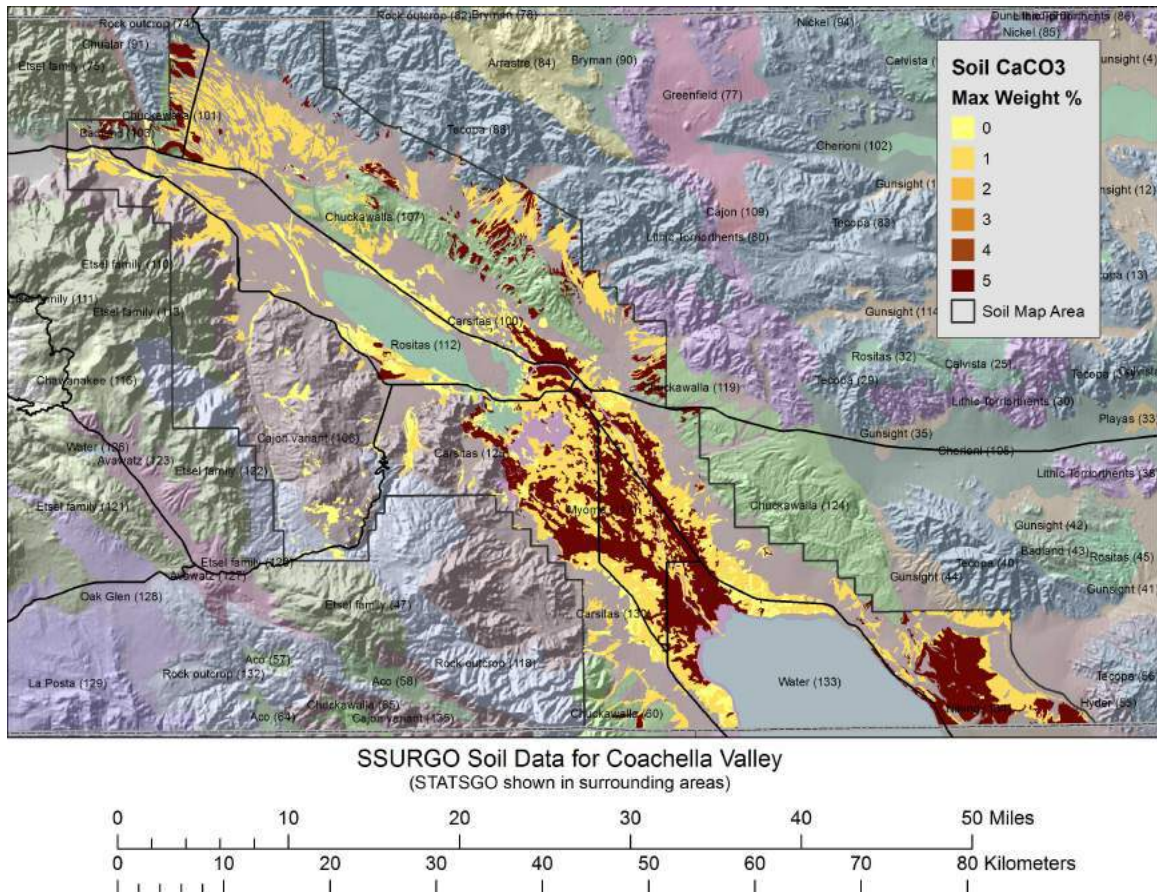


Figure 1. USDA NRS high resolution SSURGO map for surface soil CaCO_3 , adding the STATSGO data for areas surrounding the Coachella Valley, information from (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr12/tr/?cid=nrcs142p2_010596). Map created by the Center for Conservation Biology, UCR.

Schlesinger (1985) found that at depths in the Chuckwalla Valley of greater than a meter, as much as 12% was CaCO_3 , or between 30 and 70 kg/m^2 of CaCO_3 ; or between 4 and 8.4 $\text{kg C}_{\text{inorganic}}/\text{m}^2$, or as much C as is stored in mixed grass prairie as soil organic C.

Schlesinger, W.H. 1985. The formation of caliche in soils of the Mojave Desert, California. *Geochimica et Cosmochimica Acta* 49: 57-66.

Other C forms may also be critical in desert ecosystems. Garvie (2006) reported an accumulation of 2.4 $\text{g C}_{\text{inorganic}}/\text{m}^2/\text{y}$ under saguaro cactus accumulating as much as 40 $\text{g C}_{\text{inorganic}}/\text{m}^2$, through the production and release of oxalic acid. The importance

of oxalic acid rests not only in and of itself, nor its role in P (phosphorus) nutrition of plants (Jurinak et al. 1986), but in an ability to lead to CaCO_3 , or caliche accumulation (discussed below).

Garvie, L.A.J. 2006. Decay of cacti and carbon cycling. *Naturwissenschaften* **93**, 114–118. <https://doi.org/10.1007/s00114-005-0069-7>

It is important to get a better handle on the C distributions and exchanges of both organic and biologically-derived inorganic forms. ***Clearly more extensive surveys of desert C are needed to know how much is actually sequestered.***

2) Do the processes occur only in geologic time scales and, because the dominant form is inorganic (CaCO_3), can we ignore this sequestered carbon because it is a geological and not a biological process? In essence, what is the time scale?

Bioweathering by fungi and lichens, and even by many plants, commonly occurs initially in the California desert mountains, resulting in a source of Ca downslope to the bajadas. The biogeochemical pathways provide for a continuous dance between Ca and atmospheric CO_2 across the landscape from the mountain tops to the desert floor, where C is biotically converted to a form, CaCO_3 that can be sequestered. However, this form also can be rapidly weathered upon exposure.

The BioGeoChemical Pathways for Biologically-derived Inorganic C.

- 1) CO_2 (atmospheric) \rightarrow $\text{C}_6\text{H}_{12}\text{O}_6$ (photosynthesis): plants, lichen algae, cyanobacteria
- 2) $\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{H}_2\text{C}_2\text{O}_4$ (bioweathering): lichen fungi, plants, mycorrhizal fungi
- 3) $\text{Ca} + \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{CaC}_2\text{O}_4$ (calcium oxalate production): desert crusts, rhizosphere, mycorrhizosphere
- 4) $\text{CaC}_2\text{O}_4 \rightarrow \text{Ca} + \text{CO}_2$ (C source, degradation): bacteria, fungal exoenzymes
- 5) $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^-$ (bicarbonate formation): root and microbial respired CO_2
- 6) $\text{Ca} + \text{HCO}_3^-$ (in solution) \leftrightarrow **CaCO_3** + H^+

As the soils dry, the CaCO_3 precipitates, and upon layering, creates a caliche layer.

- 7) If exposed, with rainfall, $\text{CaCO}_3 + \text{H}^+ + \text{O}_2 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Ca}$
 - 8) $\text{Ca} + \text{HPO}_4^- \rightarrow \text{CaPO}_4, \text{CaSO}_4$ (gypsum)
- cycle back to step 1 and step 4.

Description of Steps: It is important to remember that equilibrium does not equal stasis. Each time CaCO_3 goes into solution, some of the CaCO_3 dissolves into $\text{Ca} + \text{CO}_2 + \text{H}^+$, with a potential for CO_2 to be released back to the atmosphere. This is a

mechanism whereby Ca moves from the mountains into the bajada, and then deeper into the bajada.

1) CO_2 (atmospheric) $\rightarrow \text{C}_6\text{H}_{12}\text{O}_6$, or $\text{C}_{\text{organic}}$ (photosynthesis): plants, lichen algae, cyanobacteria

Photosynthesis and primary production is well understood, and I will not further elaborate. However, it is important to note that photosynthesis is carried on from the tops of desert mountains to the desert floors in plants and desert crusts. These sources of organic C inputs should never be ignored.

2) $\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{H}_2\text{C}_2\text{O}_4$ (bioweathering): lichen fungi, plants, mycorrhizal fungi
Fungi and bacteria produce oxalic acid, among others including citric acid, carbonic acid, and nitric acid. These acids, especially oxalic acid, in particular, allow the fungi of lichens and the mycorrhizal fungi of plants to acquire P from etched rock surfaces (e.g., Gadd et al. 2014).

Gadd, G.M. et al. 2014. Oxalate production by fungi: significance in geomycology, biodeterioration and bioremediation. *Fungal Biology Reviews* 28: 36-55.
<https://doi.org/10.1016/j.fbr.2014.05.001>.

3) $\text{Ca} + \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{CaC}_2\text{O}_4$ (calcium oxalate production): desert crusts, rhizosphere, mycorrhizosphere

Once arriving at the bajada, oxalic acid is also produced by a wide variety of organisms. Cacti produce high concentrations (Franceschi and Nakata 2005). Many of the fungi in desert crust lichens, but also other biotic crusts produce them. Ectomycorrhizal fungi, such as associated with oaks and pines, produce these acids (e.g., Allen et al. 1996) and even the arbuscular mycorrhizal fungi, formed with the majority of desert perennial plants, form Ca-oxalates as a mechanism, when combined with increasing CO_2 respired within the mycorrhizosphere, to obtain limiting P (Jurinak et al. 1986, Knight et al. 1989).

Allen, M.F. C. Figueroa, B.S. Weinbaum, S.B. Barlow, and E.B. Allen. 1996. Differential production of oxalates by mycorrhizal fungi in arid ecosystems. *Biology and Fertility of Soils* 22: 287-292.

Franceschi, V.R. and P.A. Nakata. 2005. Calcium oxalate in plants: formation and function. *Annual Review of Plant Biology* 56: 41-71.

Jurinak, J.J., L.M. Dudley, M.F. Allen & W.G. Knight. 1986. The role of calcium oxalate in the availability of phosphorus in soils of semiarid regions: a thermodynamic study. *Soil Science* 142:255-261.

Knight, W.G., M.F. Allen, J.J. Jurinak and L.M. Dudley. 1989. Elevated carbon dioxide and solution phosphorus in soil with vesicular-arbuscular mycorrhizal western wheatgrass. *Soil Science Society of America Journal* 53: 1075-1082.

- 4) $\text{CaC}_2\text{O}_4 \rightarrow \text{Ca} + \text{CO}_2$ (C source, degradation): bacteria, fungal exoenzymes. Once Ca-oxalate is formed, like any organic material, there are both fungi and bacteria awaiting to use it as a carbon source (Morris and Allen 1994, Gadd et al. 2014).

Morris, S.J. and M.F. Allen. 1994. Oxalate metabolizing microorganisms in sagebrush steppe soils. *Biology and Fertility of Soils* 18: 255-259.

- 5) $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^-$ (bicarbonate): root and microbial respired CO_2

Once rainwater or groundwater reaches the location where respiration occurs, whether from roots or microbes, bicarbonate is formed. This can be in the surface, or tens of meters deep (see model discussion below). It is important to note that

while atmospheric CO_2 is increasing (from 310ppm in 1950 to 410 today), soil CO_2 can be many thousands of ppm, and we have measured over 2,500ppm at the Boyd Deep Canyon Reserve (see below).

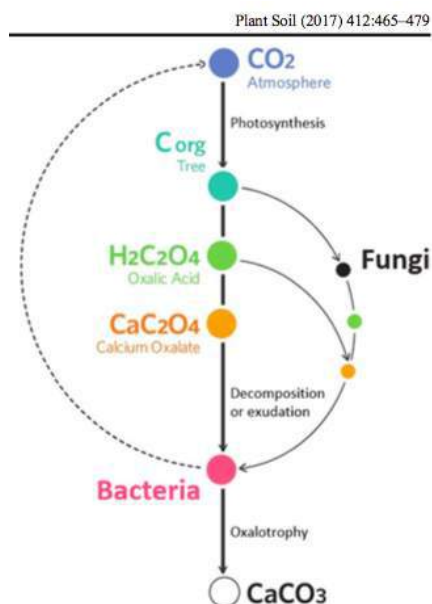


Fig. 1 A simplified model of the Oxalate-Carbonate Pathway (OCP), a process that transfers carbon dioxide from atmosphere to secondary calcium carbonate. As described by Cailleau et al. (2014), the process commences when a calcium oxalate producing species (Tree) organically sequesters carbon during photosynthesis (C org), converting it into oxalic acid and then calcium oxalate. Once released from organic material during decomposition or as exudes, calcium oxalate is subsequently catabolised by oxalotrophic bacteria (Bact.), converting one mol as carbonate and releasing another as respired carbon dioxide. Fungi also assist in the process by either breaking down oxalic rich matter and depositing calcium oxalate for catabolism by bacteria, or by fungal oxalotrophy

- 6) $\text{Ca} + \text{HCO}_3^-$ (in solution) $\leftrightarrow \text{CaCO}_3 + \text{H}^+$

The critical step in Carbon Sequestration!

In a comprehensive synthesis, Mike Rowley, in Lausanne, Switzerland, and his colleagues showed that the Ca-oxalate pathway concentrates Ca temporally and spatially, where C is sequestered through oxalotrophy through free Ca coupled with the high concentrations of HCO_3^- , forming CaCO_3 (Figure 2).

Figure 2. A model showing biotically-controlled CO_2 sequestration focused on the Yucatán Peninsula, from Rowley et al. 2017.

Rowley, M.C., H. Estrada-Medina, M. Tzec-Gamboa et al. 2017. Moving carbon between spheres, the potential oxalate-carbonate pathway of *Brosimum alicastrum* Sw.; Moraceae. *Plant and Soil* 412: 465-479.

Time Scales:

In our efforts to better understand the time scales of C dynamics, we undertook two types of studies. First, we analyzed the $\delta^{18}\text{O}$ signals (Delta-Oxygen-18 is an indication of groundwater/mineral interactions) of caliche across the Coachella Valley. These values showed that caliche was dynamic (Allen et al. 2013). This

conclusion was collaborated by a subsequent study in the Mojave desert (Mills et al. 2020).

At Deep Canyon, my research group further re-ran the SLIC model (see model discussion below) using our empirical CO₂ sensor data to determine the CaCO₃ in solution (Allen et al. 2013, Swanson 2017, Swanson et al. in preparation). Importantly, soil CO₂ can reach as high as 2,500ppm, as compared with atmospheric CO₂ of 395ppm (during the measurements), as soil respiration increased following precipitation events. CaCO₃ in solution tracked the CO₂ and H₂O. As soils dried out, some of the CaCO₃ in solution again precipitated forming new caliche deeper in the profile. However, eddy covariance measurements show a large CO₂ flux from both undisturbed soils and from sites with no measureable organic C (Allen et al. 2013, Swanson 2017).

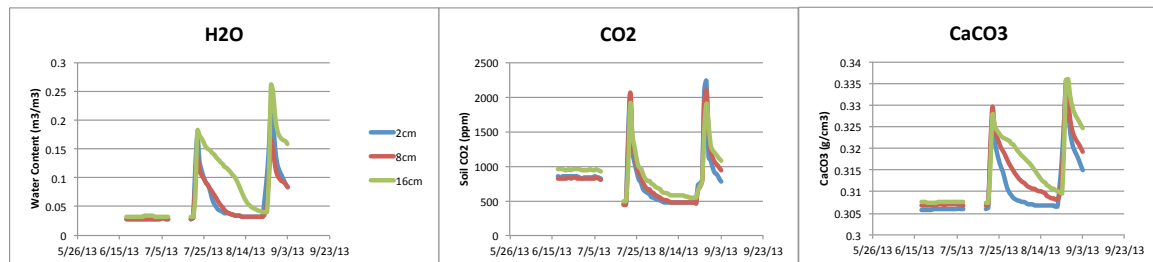


Figure 3. Daily time scales of soil water, CO₂ and modeled solution CaCO₃ (SLIC model) following a precipitation event at Boyd Deep Canyon in July through September of 2013 (Allen et al. 2013, Swanson 2017).

Allen, M. F., G. D. Jenerette, L. S. Santiago. 2013. Carbon Balance in California Deserts: Impacts of Widespread Solar Power Generation. California Energy Commission. Publication number: CEC-500-2013-063.

Swanson, AC. 2017. Disturbance, Restoration, and Soil Carbon Dynamics in Desert and Tropical Ecosystems. PhD. Dissertation. University of California-Riverside.

7) If exposed, with rainfall, $\text{CaCO}_3 + \text{H}^+ + \text{O}_2 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Ca}$

$\delta^{18}\text{O}$ ratios show that in surface soils, CaCO₃ continually turns over (Allen et al. 2013, confirmed by Mills et al. 2020). We do not know where, or how much Ca is redistributed with erosion, but there is considerable wind erosion of Ca, especially as calcium sulphate (Frie et al. 2019).

Allen, M. F., G. D. Jenerette, L. S. Santiago. 2013. Carbon Balance in California Deserts: Impacts of Widespread Solar Power Generation. California Energy Commission. Publication number: CEC-500-2013-063.

Frie, A.L. A.C. Garrison, M. V. Schaefer, S. M. Bates, J. Botthoff, M. Maltz, S. C. Ying, T. Lyons, M. F. Allen, E. Aronson, and R. Bahreini. 2019. Dust Sources in the Salton Sea Basin: A Clear Case of an Anthropogenically Impacted Dust Budget.

Environmental Science & Technology 53 (16), 9378-9388 DOI:
10.1021/acs.est.9b02137

Mills, Jennifer, Laura Lammers, and Ronald Amundson. 2020. Carbon Balance with Renewable Energy: Effects of Solar Installations on Desert Soil Carbon Cycle. California Energy Commission. Publication Number: CEC-500-2020-075

8) $\text{Ca} + \text{HPO}_4^- \rightarrow \text{CaPO}_4$ (bound inorganic P, CaSO_4 (gypsum))

Even though in equilibrium, Ca tends to attach to $-\text{CO}_3$ but some can bind to phosphate or sulphate (forming gypsum), move in solution downstream, or even blow via wind erosion (Frie et al. 2019).

Frie, A, A Garrison, M Schaefer, S Bates, J Botthoff, M Maltz, S Ying, T Lyons, MF Allen, EL Aronson, R Bahreini. 2019. "Dust Sources in the Salton Sea Basin: A Clear Case of an Anthropogenically Impacted Dust Budget." *Environmental Science & Technology*. 53(16):9378-9388. doi: 10.1021/acs.est.9b02137.

(3) What we are missing is an overall synthesis of the rates of CO_2 exchange across the California deserts, both from landscape models, and from local validation measurements. These are crucial for a broad overview of C fluxes in the desert.

The Models: One modeling concept uses the assumption that the rates of transformations are on a geological time scale and not relevant to change models. These are the models that should be used and tested.

DayCENT: Parton, W. J., M. Hartman, D. Ojima, and D. Schimel. 1998. DAYCENT and its land surface submodel: description and testing. *Global and Planetary Change* 19:35–48.

The Century model was designed to estimate long-term soil C accumulation. DayCENT is a version of Century using a daily time-step to better understand short-term C dynamics. It is the most sophisticated model available appropriate to generate long-term understanding of soil C. But there are limitations that require a better incorporation of concepts described below and the data and model inputs specific to California's deserts.

Rao et al. 2010 used DayCENT for studying the impacts of Nitrogen deposition on Net Primary Productivity (NPP -or how much CO_2 vegetation takes in during photosynthesis minus how much CO_2 plants release during respiration) in deserts, mostly as related to fire. But there is one distinct limitation to the current generation of DayCENT models: the ability to access groundwater. During a year

dominated by native forbs, simulated production was 20-40g C/m², but measured production was 60-80gC/m².

Rao, L.E., E.B. Allen and T. Meixner. 2010. Risk-based determination of critical nitrogen deposition loads for fire spread in southern California deserts. *Ecological Applications* 20: 1320-1335.

Using DayCENT, Joshua Tree National Park, the accumulated SOM-C (soil organic matter-carbon) ranged from 668 to 916g/m², depending on N deposition. This compares with measurements ranging up to 2,000g/m² (USDA 2013).

United States Department of Agriculture, Natural Resources Conservation Service, and United States Department of the Interior, National Park Service. 2013. Soil survey of Joshua Tree National Park, California. (Accessible online at: http://soils.usda.gov/survey/printed_surveys/)

Much of these production differences were probably due to accessing of deep-water sources. Furthermore, using DayCENT, we do not know inorganic C, the largest pool of C in California deserts.

Regional expertise for DayCENT- Leelia Rao CARB, G. Darrel Jenerette UCR

Limits to DayCENT 1: Deep water.

Our primary concern was an inability in the model to incorporate deep roots into organic C accumulation due to the model not integrating deep root dynamics. Many shrubs in the microphyll woodlands have deep roots and microbial associations (e.g., Virginia et al. 1986). Roots reaching deep and especially to groundwater level, allow the plant to continue growing and fixing carbon well into the dry periods (Ogle et al. 2004). For example, creosote bush sends horizontal roots through the shallow upland soils to find cracks in caliche. Then they dive deep, obtaining a large fraction of their water from within and below caliche layers (Ogle et al. 2004). In our estimates of deep-water use (Allen unpublished data), as much as 60 to 90% of the plant water in microphyll woodland plants came from the groundwater. Moreover, roots and the mycorrhizosphere (the region around a mycorrhizal fungus colonizing plant roots) contribute to increasing atmospheric CO₂, increasing the partial pressure pushing bicarbonate concentrations (see SLIC modeling below). These plant mycorrhizospheres are producing CO₂ for the creation of HCO₃⁻, binding with Ca to form CaCO₃ deep in the profile at unknown rates.

Ogle, K., R.L. Wolpert, and J.F. Reynolds. 2004. Reconstructing plant root area and water uptake profiles. *Ecology* 85: 1967-1978.

Virginia, R.A., M.B. Jenkins, and W.M. Jarrell. 1986. Depth of root symbiont occurrence in soil. *Biology and Fertility of Soils* 2: 127-130.

In a California conifer-hardwood forest, we initially used DayCENT to characterize NPP (Allen et al. 2014). We also measured ET (EvapoTranspiration, or transpiration plus evaporation) and NEE using eddy-flux measurements (Michael Goulden data, UC Irvine) and our sapflow measurements of water transport. DayCENT failed to identify the extended summer water flux because it did not have a mechanism to acquire deep water (Figure 4).

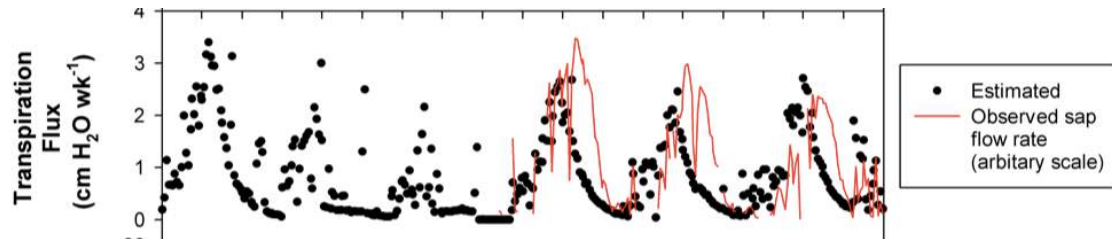


Figure 4. Kitajima and Allen-output from a model run from 2005-2010, from Allen et al. 2014, showing the comparison in Transpiration flux measurements with DayCENT modeling (dots) versus measured sapflow rates (red line). The lag in transpiration (which affects CO₂ fluxes) does not show in DayCENT as there is no provision for access to deep-water sources. As long as there is transpiration, there is fixation.

Allen, M.F., K. Kitajima, R.R. Hernandez. 2014. Mycorrhizae and global change. Pp. 37-59: in M. Tausz, N.E. Grulke (eds). Trees in a changing environment. Springer-Plant Sciences, Dordrecht, The Netherlands.

**Regional Expertise Eddy Covariance calibration measuring NEE: Ray Anderson
USDA Salinity Lab (UCR campus), G. Darrel Jenerette UCR**

HYDRUS: Simunek, J., M. T. Van Genuchten, and M. Sejna (2005), The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media, University of California, Riverside, Research Reports, 240.

For this reason, we shifted to HYDRUS 1D to study seasonal water flux and the role of deep water. Again, we compared modeled output to eddy covariance flux measurements and measured isotopic composition (δD = delta-deuterium, or hydrogen-2, and $\delta^{18}O$, or delta-oxygen-18) to confirm the sources of the water (Kitajima et al. 2013). We modified the HYDRUS 1D to acquire the deep moisture. By making these changes in the model, we could account for the added growing season length and summer water use. Given that the water isotopic composition of many desert species shows that a large fraction to the majority of the plant's water was from groundwater, making these adjustments was critical to overall C budgets, and will be invaluable for any estimates of C fluxes in desert soils.

Kitajima, K., M.F. Allen and M.L. Goulden. 2013. Contribution of Hydraulically Lifted Deep Moisture to the Water Budget in a Southern California Mixed Forest. Journal of Geophysical Research- Biogeosciences 118: 1561-1572

Suarez, D. L., and J. Šimůnek (1993), Modeling of carbon dioxide transport and production in soil: 2. Parameter selection, sensitivity analysis, and comparison of model predictions to field data, *Water Resources Research* 29: 499–513, doi:10.1029/92WR02226.

Regional expertise for HYDRUS: Jirka Šimůnek - UCR Environmental Sciences (author of Hydrus), Tom Harmon UC Merced.

Limits to DayCENT 2: Inorganic C

The inorganic C (C_i) in California deserts is very patchy, but can be quite high. Schlesinger (1985) undertook landmark studies in the alluvial plain outwash from the Eagle Mountains and the Coxcomb Mountains. He measured between 30 and 70 kg of CaCO_3/m^2 , or between 4 to 8.4 kgC/ m^2 of inorganic C or C_i . This would place the soil C in the range of C in the middle of the Great Plains, and even the lower end of the C-rich temperate forest soils.

Schlesinger, W. H. 1985. The formation of caliche in soils of the Mojave-Desert, California. *Geochimica Et Cosmochimica Acta* 49:57-66.

The problem is that caliche is distributed in patches across the deserts, and larger regional measurements do not exist. Thus, there is a need to better determine where and how much caliche is present across the SoCal deserts (see above discussion).

Inorganic C: Two models that should be used:

HYDRUS 1D

The first step in understanding inorganic C is to determine the equilibrium between pore water gas and water. For this determination, we used sensor readings of temperature, water and CO_2 (Allen et al. 2007). Henry's law states that $[\text{CO}_2(\text{aq})] = K_H P_{\text{CO}_2}$, where the P_{CO_2} reading (partial pressure of carbon dioxide, which reflects dissolved CO_2) is the sensor output converted to atmospheres. The second step is to determine local soil pH (how acidic or basic the soil is) that can be measured directly or determined from $\text{CO}_2(\text{aq})$, aqueous carbon dioxide, or the gas dissolved in water, where: $\text{pH} = 3.9 - 0.5 \log P_{\text{CO}_2}$.

Using pH and carbonate equilibrium, we can determine the other species,

$$\text{DIC}_{\text{total}} = [\text{H}_2\text{CO}_3^*] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$$

We can use these sensor data as an input to HYDRUS 1D to simulate the HCO_3^- input and output from a known soil layer (Thomas Harmon and Michael Allen, unpublished data).

Allen, M.F., R. Vargas, E. Graham, W Swenson, M. Hamilton, M. Taggart, T.C. Harmon, A Rat'ko, P Rundel, B. Fulkerson, and D. Estrin. 2007. Soil sensor technology: Life within a pixel. *BioScience* 57: 859-867.

Once the HCO_3^- (bicarbonate) and soil water is known, the soil $\text{C}_{\text{inorganic}}$ can be determined and converted to the form of caliche (CaCO_3) in a known soil layer using the SLIC model (Hirmas et al. 2010).

Expertise: *Thomas Harmon, UC Merced; Jirka Simunik, UC Riverside.*

Soil Landscape Inorganic Carbon model (SLIC): Hirmas, D.R., C. Amrhein, and R.C. Graham. 2010. Spatial and process-based modeling of soil inorganic carbon storage in an arid piedmont. *Geoderma* 154:486-494. doi: <https://doi.org/10.1016/j.geoderma.2009.05.005>

The SLIC model simulates soil $\text{C}_{\text{inorganic}}$ across the landscape. The strength is that the model simulates the exchanges between carbonate HCO_3^- and CaCO_3 , caliche. Caliche exists in a solid form when dry. Following water inputs, some of the CaCO_3 dissolves into Ca^{2+} , plus CO_2 plus protons. Depending upon the CO_2 concentration (using atmospheric CO_2), plus free Ca, CaCO_3 then reforms, the concentration of which depends on the equilibrium chemistry. The fact that dissolution occurs then CaCO_3 reforms means that as soil dries out, solid caliche is formed, deeper in the soil profile. As new Ca arrives from erosion, new CaCO_3 can form in the soil surface layers. Isotopic data using $\delta^{18}\text{O}$, show that there is a continual turnover of the surface layers of CaCO_3 when exposed (Allen et al. 2013, confirmed by Mills et al. 2020).

However, a critical missing element is that the SLIC model, as originally developed, is a chemical model only, building upon the soil atmosphere ($\sim 400\text{ppm}$), and does not integrate biological soil respiration, which isotopic ratios have suggested are the source for deep caliche (Schlesinger 1985). $\delta^{18}\text{O}$ ratios of surface caliche materials clearly demonstrate continuous turnover in the surface layers, with the potential for loss. Those values, even at 16cm depth, can exceed 2,500ppm. We do not know the CO_2 concentrations deep at the groundwater level.

Hirmas, D.R., C. Amrhein, and R.C. Graham. 2010. Spatial and process-based modeling of soil inorganic carbon storage in an arid piedmont. *Geoderma* 154:486-494. doi: <https://doi.org/10.1016/j.geoderma.2009.05.005>

Allen, M. F., G. D. Jenerette, L. S. Santiago. 2013. Carbon Balance in California Deserts: Impacts of Widespread Solar Power Generation. California Energy Commission. Publication number: CEC-500-2013-063.

Mills, Jennifer, Laura Lammers, and Ronald Amundson. 2020. Carbon Balance with Renewable Energy: Effects of Solar Installations on Desert Soil Carbon Cycle. California Energy Commission. Publication Number: CEC-500-2020-075

Regional expertise: *Daniel Hirmas, Environmental Sciences, UCR*

For organic C cycling, an acceptable approach would be to run DayCENT, but integrating the length of C acquisition with access to deep water, extending the time for photosynthesis into each drought period. This requires collection of empirical

data of the timing of active photosynthesis coupled with isotopic data on water sources, as per Ogle et al. 2014.

The best models for inorganic carbon would probably be the newest version of Hydrus 1D combined with SLIC, but again integrating empirical data of mycorrhizosphere CO₂ at the depths where water is acquired and CaCO₃ deposited. Together these models coupled with empirical data, particularly for soil CO₂ and the current 3D spatial distributions of Ca, CO₂, and CaCO₃, should provide for a solid simulation of desert C and the impacts of anthropogenic and climate stressors on sequestration and fluxes.

APPENDIX B

CALIFORNIA DESERT MAPS SHOWING A LARGER FOOTPRINT THAN CNRA'S 30X30 INLAND DESERT REGIONAL MAP

(content begins on next page)

California Desert Maps Showing A Larger Footprint Than CNRA's 30x30 Inland Desert Regional Map

30 x 30 Nature Regions and US EPA Level III Ecoregions, California Deserts



As defined in Section 601 of the Federal Land Policy Management Act, the CDCA is a 25-million-acre expanse of land in California designated by Congress in 1976

USDA Ecoregions



Regions Discrepancy



A sample list of desert features that are within the US Department of Agriculture, California Desert ecosystem but are cut out of CNRA's 30x30 boundary map:

Death Valley National Park (nearly all of it)
 Anza Borrego Desert State Park (nearly all of it)
 California Poppy State Natural Reserve
 Western Joshua Tree Habitat
 Eureka Valley
 Owen's Lake
 Saline Valley
 Amargosa River (much of it)
 Funeral Mountains
 Coso Range
 Argus Range
 Cottonwood Mountains
 Black Mountains
 Kingston Range (part)
 Antelope Valley
 Lancaster
 Palmdale

APPENDIX C

CLIMATE MITIGATION IN CALIFORNIA: THE IMPORTANCE OF CONSERVING CARBON IN DESERTS

(content begins on next page)

Climate Mitigation in California: The importance of conserving carbon in deserts



MBCA

morongo basin conservation association

As climate change continues to accelerate, it is essential to protect natural habitats that act as carbon sinks. When these areas are developed and disturbed, additional carbon is released into the air and the plants and soils in those ecosystems are impacted, reducing their ability to absorb and store carbon. Studies around the world have shown that desert ecosystems can act as important carbon sinks. With desert ecoregions comprising 27% of California, protecting this biome can contribute to securing carbon stores in the state. By limiting development, excessive OHV use, livestock grazing and other activities that disturb desert soils, the state can help ensure these carbon reserves stay in the ground and out of the atmosphere.

Carbon Capture in Deserts

There are several ways in which deserts store carbon. To start, desert plants store carbon in their biomass just as other plants do; through photosynthesis, plants take in CO₂ from the air and convert that into tissue. Many desert plants also have important relationships with underground fungi: roots bond with these fungi in a mutually beneficial relationship. As part of this relationship, the plants transfer carbon to the mycorrhizae, which also store carbon. The majority of stored and sequestered carbon, however, is in soils. Plant or animal excretion and decomposition releases some carbon, which reacts with calcium in the desert soil to create calcium carbonate crystals. Since some desert plants' roots grow to over a hundred feet, these crystals, called caliches, can be deep underground. Caliches build into larger chunks over time and create carbon sinks. Additionally, when the root fungi die, they leave behind their waxy coating, which aggregates and helps keep carbon in the soil. For their storage and sequestration potential, arid-semiarid soils are considered the third largest global pool of carbon (Emmerich 2003).

California Carbon Sinks

The most conclusive evidence of California desert carbon storage potential comes from a 10-year study in the Mojave Desert at the Nevada Desert Free-Air CO₂ Enrichment Facility (NDFE). This study compared plots of desert with current CO₂ levels to plots with projected 2050 CO₂ levels. To do this, they piped extra CO₂ over the plots. At the completion of the study, the researchers compared the carbon between the plots with current CO₂ levels and those with projected CO₂ levels. They found that the plots that received extra carbon were able to store significantly more carbon than those that received current carbon levels. This indicates that as atmospheric CO₂ levels rise, deserts will have increased capacity to sequester in response to projected elevated atmospheric CO₂. Deserts store 9.7% of California carbon and based on the NDFE experiment, and this amount may increase with climate change. A report by the National Parks Service shows that Death Valley and Joshua Tree National Parks and the Mojave National Preserve were within the top 10 park units with the highest annual net ecosystem carbon balance.

Quick take

- Desert ecosystems provide important carbon storage functions now and in the future given climate change.
- Conserving California deserts can help ensure that the stored CO₂ stays in the ground.
- Key results include:
 - Inland deserts account for 10% of the state's total stored carbon.
 - 7% of carbon-rich areas in California deserts may already be impacted by human activities.
 - Ensuring sufficient desert representation in conserved areas will protect unique species assemblages and ecosystem services.

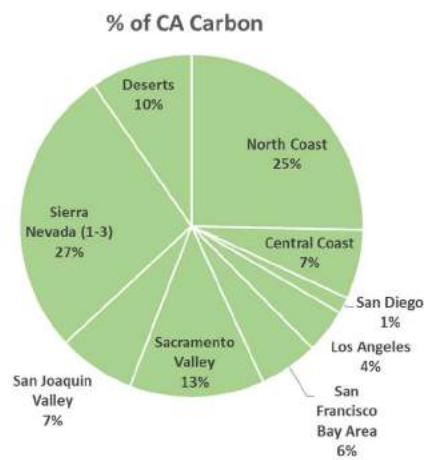
Read more about the desert carbon storage process here: <http://www.desertrep.org/?p=2270>

Read the full scientific article for this experiment here: <https://doi.org/10.1038/nclimate2184>

Results

The data indicate that 27% of lands within the state of California fall within desert ecoregions (Inland Desert and Sierra Nevada-East). These lands alone account for nearly 10% of the total carbon stored in the state. Importantly, the top carbon-rich locations in deserts are less impacted by human activity compared to other ecoregions: 7% overlap with areas of higher human footprint compared to nearly one quarter of carbon-rich areas in the San Joaquin Valley. Currently, 42% of carbon-rich areas in desert regions fall into areas managed for conservation. An additional 35% fall on public lands managed for multiple uses (including extractive activities). Based on these results, California deserts sequester and store a significant amount of the state's carbon. Though desert environments have relatively low sequestration on a per area basis, they represent a large proportion of the state's area and are relatively undisturbed by human activity.

Carbon can be stored in a number of different reservoirs. Here we analyzed total ecoregion carbon in above- and belowground biomass and in soil ([Soto-Navarro et al. 2020](#)). We compared the top carbon-rich areas for each ecoregion with human footprint metrics and the protected areas database of the U.S.



Map highlighting carbon-rich areas (top 20%) within each ecoregion and current coincidence with higher human disturbance. Sierra Nevada – East was combined with the Inland Desert ecoregion to represent California's deserts as a singular unit.

Recommended Actions

Given their carbon storage capabilities, conservation of large, intact desert areas could have a high return on investment for climate mitigation. Decision-makers will need to account for desert ecosystems in short- and long-term conservation planning efforts to ensure the persistence of these ecosystem services under future climate change scenarios. Great opportunity exists for desert protections on public lands, but some carbon-rich areas could benefit from private lands conservation, especially around the Salton Sea. Particular care should be taken in recognizing Death Valley (Sierra Nevada – East sub ecoregion) as a desert ecosystem that is unique and separate from others in the Sierra Nevada ecoregion. Failing to do so results in underestimation of Death Valley's carbon storage potential, which has been noted in other works. Finally, local stakeholders, Tribes and desert communities should be part of the decision-making process to ensure that those groups disproportionately impacted by conservation (or other) efforts in this ecoregion are well represented.

Questions?

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