**Carbon Balance in California Deserts:
Impacts of widespread solar power generation**

**A proposal by the University of California, Riverside
Center for Conservation Biology**

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Our goal is to measure carbon balance of our southern California desert ecosystems, with a particular focus on teasing apart weathering of inorganic C and mineralization of organic C, versus sequestration by native desert communities in the face of soil and vegetation disturbances to place solar electricity-generating projects. **We will:**

1) **develop techniques to assess caliche layering and amounts,**
2) **assess exchange dynamics and rates of inorganic and organic C using natural abundance ratios of C and O in the dominant ecosystems of southern California deserts that are potentially subject to solar power development,**
3) **and design baseline datasets and models to quantify C exchange between soils and atmosphere in southern California deserts that are potentially subject to solar power development.**

Goals 1 and 2 will be undertaken in conjunction with the project proposed by Dr. Cameron Barrows on the Niche modeling for identifying potential impacts of renewable energy projects and the monitoring to asses those impacts across the region, and goal 3 will focus on quantifying exchanges in a well-characterized site (Boyd Deep Canyon) so as to be able to utilize a broader database background, and a site proposed for study by Dr. Alfredo Martinez-Morales, where we would be able to asses in an integrative way, the performance of solar PV and understand the potential impacts of solar development on the carbon balance including the species of the Salton Sea.

Introduction.

California deserts have vast stores of carbon (C) stored as inorganic caliche, or $CaCO_3$, of up to 8kg C/m^2 (Schlesinger 1985). Data and models measuring estimating weathering and accumulation are inconclusive as to the impacts of vegetation disturbance on caliche stocks. Models use atmospheric C (currently between 390 and 400ppm). But initial d^{13}C data show that $CaCO_3$ is more dependent upon rhizosphere-respired CO_2 than atmospheric accumulation (Schlesinger 1985) and rhizosphere CO_2 is far higher than atmospheric CO_2, (Allen and Jenerette unpublished data) making it essential to get more accurate estimates of rhizosphere activity to accurately model soil C exchanges. More recent data suggest that caliche is more dynamic than older modeling efforts reported. Caliche is known to degrade, especially on disturbed lands (Hirmas and Allen 2007) and d^{13}C of caliche shows re-equilibration through time as vegetation changes (Knauth et al. 2003).

Rhizosphere-respired CO_2 is dependent upon the vegetation composition and activity. Further, a large, but relatively unknown amount of CO_2 is fixed and stored as organic C in deserts, with estimates ranging from 60 to 600g/m^2/y, but dependent upon the particular ecosystem perturbed. Woody legumes, in particular, have roots and associated microbes more than 3m deep, sequestering organic C where it is only slowly respired back to the atmosphere. Respired CO_2 in the presence of water (H_2O) and calcium (Ca) is converted to $CaCO_3$ and H^+ or caliche. Creosote bush also has deep roots, and exists in soils with deep caliche depositions, or in soils with little to no caliche in soils.

Our goal is to provide a comparative measure of C fluxes and natural sequestration of organic and inorganic C in deserts that are proposed for solar electrical power development. **We will develop techniques that can measure baseline caliche C as areas for development are proposed, develop newer assessment models which can be used to model organic C and inorganic C sequestration, and**

determine if different vegetation types have different exchanges and potential loss rates of inorganic C.

Electricity Generation Environmental Challenges: Carbon and vegetation removal.
Large-scale solar development in desert ecosystems has the potential to generate electricity, thereby reducing fossil carbon (C) accumulation in the atmosphere, and in turn, lessening the rates of global warming. However, both caliche and organic matter losses compromise the value of solar energy as an alternative to fossil C burning by destroying the ability of the deserts to sequester C and potentially releasing large amounts of stored inorganic C into the atmosphere. We propose to develop measurements and adapt models to measure stored inorganic C, organic C balances of differing vegetation types and changing soil temperature (T), moisture (q), and atmospheric CO_2 levels to determine of there are particular vegetation types that should be protected from disturbance, or others that, from a perspective of C balance, are less sensitive.

Solicitation Objectives: Determining Carbon Balance of Potential Sites
We envision three goals to explore developing carbon budgets for desert ecosystems likely to be impacted by placement of solar power generation systems. We will:

1. assess if we can determine caliche and root distribution using soil pits and ground-penetrating radar (GPR) to survey vegetation. This will provide a tool for an immediate assessment of the potential C lost to the atmosphere with perturbation.
2. analyze $d^{13}C$ and $d^{18}O$ of both inorganic C (caliche) and organic C (SOM) to determine the relationships between climate, vegetation, and soil C balance. These more accurate models can then be used to rapidly assess different vegetation types in different regions, and their roles in C sequestration and weathering.
3. measure C fixation, respiration and allocation for different vegetation types, under variable climates. This will include determining the relationships between aboveground vegetation type, climate, and rhizosphere CO_2 levels. From these relationships, we can more accurately model directionality and rates of caliche formation and weathering and C sequestration within soil organic matter.

Together this information can be used to rapidly assess the impacts of solar electricity generation on different communities and ecosystems.

Proposed Research: State of Knowledge
Desert soil carbon (C) is comprised of stored inorganic C (as caliche), vegetation and soil organic C (as buried organic matter). But, we know little of C sequestration and release, especially under conditions of global and regional temperature increase. Solar power has the potential to dramatically reduce C release to the atmosphere by reducing fossil fuel burning for electrical generation. Understanding how different vegetation types turn both organic and inorganic C over, in the context of regional C budgets and CO_2 savings from solar power is the largest unknown question facing solar development in California.
Soil is the largest global terrestrial pool of Carbon (C) at 1500Gt compared with the atmosphere at 800Gt and plants at 600Gt, but is extremely dynamic and variable spatially. In contrast to the $50 g/m^2/y$ anthropogenic source of C, and the sinks in desert soils range from 39 to 622g/m2/y. Even year-to-year variation is high, ranging from sequestration during wet periods to weathering and mineralization during dry. For all biomes we have a poor understanding of the longer-term allocation of net primary production (NPP) to and retention (sequestration) of soil C (e.g., Treseder et al. 2005, U.S. DOE 2010).
Our deserts have large amounts of CO_2, stored as caliche ($CaCO_3$). The amount of C in caliche, when accounted globally, may be equal to the entire C as CO_2 in the atmosphere and as much as 30% of global soil C. Inorganic C remains a huge gap in understanding stored C pools (e.g., Schlesinger 1985, Mielnick et al. 2005, Serrano-Ortiz et al. 2010). $CaCO_3$ formation has been modeled on a strictly geochemical basis using varying atmospheric CO_2 levels (e.g., Hirmas et al 2010). But, we have shown that $CaCO_3$ is also a

biological process, forming along roots and hyphae (e.g., Jurinak et al. 1986). Soil CO_2 levels are not equilibrated with atmospheric levels, but are a result of P_s, and even in arid regions, can range from 600 (in dry) to 10,000ppm (following rainfall) (Jenerette and Allen unpublished data). Most of the caliche in our deserts was formed during the ice ages, when vegetation was more productive. These deposits may have been stable since (Schlesinger 1985). Being stable, though, means that inputs equal exports. Carbon in caliche may in fact be released, especially when vegetation and soils are disturbed. Mielnick et al. (2005) reported losses of up to 145g $C/m^2/y$. Additional research is needed to understand and quantify these exchanges (Schlesinger et al. 2009, Serrano-Ortiz et al. 2010), as there are C exchanges in desert ecosystems that we do not understand. Previous data show that caliche layers were largely formed during the Pleistocene. ^{14}C data show formation averaging 20,000 years ago (Schlesinger 1985). An analysis of $d^{18}O$ shows that the caliche came from water from Pleistocene conditions. Further, analysis of $d^{13}C$ shows that the C came from root and microbial respiration from C_3 vegetation that dominated during that period. It does not resemble the ^{13}C ratio of atmospheric C, again supporting the need to understand C sources (goal 2). Just as importantly, $d^{13}C$ of caliche in Arizona can shift around indicating continuous exchange and equilibration through time (Knauth et al. 2003).
But, back of the envelope calculations suggest that the amount of C lost due to land disturbance is on the same order as gained by the C gained by using large solar arrays instead of fossil fuel burning. Complicating this picture even more is the changing respiration with global warming. California deserts are predicted to increase as much as 5 to 6°C, which could have dramatic impacts on C balance across all vegetation types. Respiration (R) is a key indicator and driver of biogeochemical processes and CO_2 is the end product of aerobic metabolism. The vast majority of soil processes from decomposition to microbial growth to N transformation produce CO_2 and each of these process rates have been mechanistically linked with respiration rates. Q_{10} estimates of response of R to changing T, in the face of changing q, are critical to quantifying and predicting C sequestration in soils by both primary producers and decomposers. Importantly, CO_2 fixation by plants has a relatively flat Q_{10} in contrast to R where the Q_{10} ranges from 1.5 to 3, depending upon a host of biotic and abiotic variables. Obtaining accurate estimates of carbon sequestration means separating the small difference between fixation and R. **Thus, under warming environmental conditions, desert soils could shift from a sink to a source of C, negating the value of some vegetation types, and supporting a need for increasing solar development.**

Proposed Research: Technical approach and methods.
1. Measure caliche using soil pits and GPR. One of the difficult issues is measuring the amount of caliche and how much C might be lost with removal of vegetation and surface soil layers. However, recent studies have used GPR to distinguish depth and layering of caliche below the soil surface. Wilson et al. (2005) used GPR to characterize caliche depth and fractures as a means to study CO_2 leakage through soil. We previously used GPR in the Yucatan to describe fractures and soil layers within limestone $CaCO_3$ (Estrada-Medina et al. 2010). We will test a number of locations in different vegetation types to determine the distribution of caliche depths, roots, and soil of soil pits. We believe that this approach will provide a rapid means of assessing potential C balance.
2. We will take caliche and soil and vegetation samples from multiple vegetation types, regions, and soil depths to determine the exchange rates of ^{13}C-^{12}C (from CO_2) and ^{16}O-^{18}O (from water) from the original deposition. $d^{13}C$ and $d^{18}O$ will be analyzed in the UCR CCB stable isotope facility (FIRMS) using standard techniques and appropriate standards. Additional detail can be found in our website (http://ccb.ucr.edu/firms.html).
3. Measure C fixation, respiration and allocation. Model SOM and $CaCO_3$ dynamics under varying vegetation, soils and climate conditions. **A networked environmental observatory – continuous sensors, manual measurements, experiments, and soil surveys.** Networked environmental observatories provide new approaches for understanding ecological dynamics through the dual capabilities of high temporal resolution and continuous observations (Allen et al. 2007). We are currently running CO2 sensor networks at the James Reserve in the San Jacinto mountains, and at Deep Canyon, in a desert shrubland. Each location is instrumented with solid-state CO_2, soil temperature, and soil moisture

sensors at 2, 8 and 16 cm soil depths. The CO_2 sensors are calibrated every six months after deployment to ensure the quality of the measurements. We measure soil CO_2 using Visala soil CO_2 sensors (Vargas and Allen 2008, Kitajima et al. 2010). These provide accurate CO_2 inputs to caliche modeling in comparison with simply using atmospheric CO_2 values (Hirmas et al. 2010). From these data, we calculated soil respiration from the soil using a CO_2 gradient flux method based on concentrations of CO_2 in the soil profile (Vargas and Allen 2008).

Eddy Covariance (EC) will be used for monitoring the fluxes of CO_2, H_2O, and energy of whole ecosystems at a spatial scale of hectares (Goulden et al. 1996, Baldocchi 2003).

We will provide realistic and continuous measurement of soil CO_2 at all sites, particularly in the desert regions (Deep Canyon to new sites across southern California) with large amounts of caliche C (unpbl observations). In arid regions, HCO_3^-, derived from CO_2 and H_2O in the soil, combines with Ca^{2+} to form $CaCO_3^-$, fixing CO_2 into sequestered inorganic C, and in turn, with additional H^+ ions releasing the CO_2. **$CaCO_3$ formation has been modeled on a strictly geochemical basis using varying atmospheric CO_2 levels (e.g., Hirmas et al 2010). But, soil CO_2 levels are not equilibrated with atmospheric levels, but are a result of P_s, and even in arid regions, can range from 2,000 to 10,000ppm (Jenerette and Allen unpublished data). Our contribution to understanding sequestration of inorganic C is to provide realistic data on soil CO_2 levels. From this change, more realistic evaluations of $CaCO_3^-$ can be derived.**

We have two focal sites to measure C fluxes. The first is alluvial vegetation at the Boyd Deep Canyon UC Natural Reserve. This instrument system is already in place, with an eddy flux tower to integrate C fluxes, maintained by Dr. Michael Goulden, UC Irvine. A soil sensor network is maintained by M. Allen, with sensors under Palo Verde, creosote bush, barrel cactus, and brittlebush. We will put a new sensor node into a desert riparian woodland at a creosote alluvial shrubland, in association with the crucial plant species.

The second site will be associated with the developing solar PV projects in the Salton Sea, led by Dr. Alfredo Martinez-Morales. The unique combination of natural resources and challenging environmental conditions at the Salton Sea require that a feasibility study is conducted to truly determine the potential of developing utility scale energy projects in the area. Potential projects in the Salton Sea will need to present a more attractive alternative to energy project developers in terms of reduced environmental impacts, lessened mitigation requirements, shorter length of the permitting and approval process, and the overall cost of development. The goal of the overall project is to conduct a feasibility study to evaluate the merits of developing utility scale solar projects on the exposed lakebed at the Salton Sea moving into the surrounding alluvial flats. The site has been identified in partnership and support from the Coachella Valley Economic Partnership (CVEP), the Imperial Irrigation District (IDD) and the Torres Martinez Desert Cahuilla Indians. By assessing and monitoring the in-field performance, reliability and robustness of an actual PV system, we will be able to gathered information on the technical, environmental and economic viability of PV solar in the Salton Sea. Using the gathered information we will design a pilot project to demonstrate the feasibility of developing the Salton Sea for the development of utility scale solar projects that will achieve the energy production mandates, lower the regional emissions of green house gases (GHG) and potentially address air quality issues by preventing the exposed lakebed from being a source of particulates affecting the surrounding population.

Conclusions.

Back of the envelope calculations (Allen) shows that the CO2 saved from reducing fossil fuel burning by developing solar-powered electrical generation will be compromised, or even negated by the loss of stores of inorganic and organic C sequestered by desert native ecosystems, among those slated for development. We will develop techniques and models that can be used to judge individual sites based on their vegetation, coupled with measured or projected values of temperature and precipitation. These can form the backbone of individual site selection to identify those areas suitable versus compromised for solar power development.

Principal Investigators (PI) –PI Allen is responsible for overall project management, research and supervision of the staff and students. PI Allen will oversee the continuous soil sensor output coupled with the flux measurements. Allen will also oversee GPR and soil pit measurements of caliche C.

CoPI Jenerette will oversee the experimental flux measurements, equations, and will oversee the modeling.

Co-PI Santiago will oversee natural abundance isotopic measurements.

Graduate Student Researchers – Two graduate students are expected to work on this project. One of the graduate students will be involved in the proposed root and fungal measurements (with Allen), while the second graduate student will be primarily involved with the flux measurement (with Jenerette). Both graduate students will use the outputs as part of their dissertation research.

Undergraduate students – We anticipate two undergraduate student researchers will work with both PIs and staff, and will participate in the data gathering and entry, and modeling activities.

Support is also requested Staff Research Associate Dr. K. Kitajima to maintain sensor networks and the data organization. Dr. Kitajima has been organized and managed sensors and data for James Reserve prototype effort for the past 6 years.

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