CALIFORNIA STRATEGIC GROWTH COUNCIL

Climate Change Research Program

QUARTERLY PROGRESS REPORT

2021

QTR 1

Progress Report # 6 **For the reporting period:** January 1, 2021 **to** March 31, 2021

Grantee Institution: University of California, Irvine **Agreement #** CCR20021

Research Grant Title Innovation Center for Advancing Ecosystem Climate Solutions

Signature Line (authorized representative): Erika Blossom

RESEARCH GRANT PROGRESS SUMMARY

Provide information for each task in the research grant's scope of work, noting zero if work has not been started on a specific task:

Task # or Description	Description	Percent of Work Completed for this Period	Percent of Work Completed to Date	Reimbursement Amount Charged for this Period	Reimbursement Amount Charged to Date
1.1	Collect and homogenize data layers	5%	70%	$12,000.00	$262,786.23
1.2	Test, improve, and update data layers	10%	60%	$38,000.00	$221,623.72
2.1	Prepare data analysis	10%	65%	$35,143.37	$169,546.77
2.2	Analyze historical and current data	5%	40%	$15,000.00	$109,035.26
2.3	Extend data analysis via data science and machine learning	5%	25%	$5,000.00	$26,000.00
3.1	Actively engage stakeholders	10%	55%	$42,000.00	$229,244.11
3.2	Produce decision-making tools	15%	35%	$45,000.00	$81,000.00
3.3	Communication	10%	55%	$10,000.00	$88,000.00
4.1	Develop valuation framework	10%	60%	$12,000.00	$78,000.00
4.2	Develop and implement valuation tools	10%	15%	$18,000.00	$20,000.00
4.3	Develop financing strategies	10%	15%	$4,000.00	$6,000.00

PROVIDE A SUMMARY STATEMENT DESCRIBING THE MILESTONES (INCLUDE GO/NO GO MILESTONES), ACCOMPLISHMENTS, SUCCESSES, BARRIERS, AND OBSTACLES THAT HAVE OCCURRED WITHIN THE CURRENT REPORTING PERIOD:

The CECS Project team continued to make great progress in Q1 2021. Subgroups working on Tasks 1, 2, 3, and 4 have met frequently to discuss strategy and make steps toward deliverables, and cross-task collaboration to bring all project components together into a working web tool are well underway.

For Task 1, we developed a new dataset that maps the fractional cover for several plant functional types using time series of Landsat remote sensing data.

For Task 2, we built out the framework to run the updated Ecosystem Integration Model on UC Irvine's High-Performance Computing Cluster (HPC). The HPC will enable us to easily store and run analyses on data layers for all of California. We also extracted and summarize GPP for fire footprints across California, examined the impact of drought on insect-induced tree mortality on fire behavior, and began to incorporate on-ground validation in chaparral ecosystems.

For Task 3, the CECS Executive Committee and outreach team engaged with 11 CA forest experts in half-day event on January 15 to present our work thus far, and to get feedback on direction and room for improvement. This was crucial in helping us to identify next steps. We also hosted agency representatives in 2 additional needs assessment workshops. We then analyzed the survey and workshop data, and compiled a short overview of results to share with stakeholders. We continued to build and strengthen our partnerships with state and regional agencies, NGOs, and other research consortia through numerous listening sessions, data sharing opportunities, and synergistic discussions.

One of our largest successes of Q1 was developing and refining a beta version of our decision support tool, the Ecosystem Solutions Toolbox, on which we made substantial progress. This preliminary version has the capability to visualize more data layers produced by CECS and will soon be shared with stakeholders in informal feedback sessions.

As part of Task 4, a perspective paper was nearly completed. Additionally, work continued on developing the CECS framework that provides a broad perspective and backbone for mapping and valuing key ecosystem services with forest restoration activities in California. Different frameworks were developed specifically for carbon storage, water resources, carbon-water balances, recreational services, and air quality.

Several papers on CECS research are in the works, many to be submitted in Q2 2021.

Aside from a slight delay in our timeline in some instances due to COVID-19, significant progress continues to be made.

ACHIEVING PROGRAM GOALS

1. Briefly discuss any successes the research has achieved in furthering the Climate Change Research Program's Program Goals:

   One of CECS' goals is to develop and share geospatial data layers that can be used by land managers, decisions makers, the general public and scientists to better understand and manage the effects of climate change on California's ecosystems. CECS is combining data analysis and machine learning with mechanistic models to explore the current conditions, vulnerabilities, and potential benefits of alternative management options across the state. CECS has built a new ecosystem analysis model - the CECS Ecosystem Integration Model - to analyze the complete Landsat satellite record since 1984, and

to produce state-wide, 30m resolution maps of ecosystem carbon budgets, vulnerability to drought stress, runoff amount, fuel load, and the potential benefits of management for fuel reduction and forest restoration. These data layers are being built into web-based visualization tools for easy access, which we call the CECS Ecosystem Management Toolbox, and will be freely shared once finalized. This Ecosystem Integration Model and associated Ecosystem Management Toolbox are helping CECS integrate across the various areas of expertise on our science team, and will ultimately provide one of our most impactful deliverables to the State.

The manuscript on the recovery of primary production following wildfire in California forests, by Stanford postdoc Kyle Hemes, UC Irvine grad student Carl Norlen, UC Irvine postdoc Jon Wang, CECS Director Mike Goulden, and Stanford PI Chris Field, is complete and nearing submission. This paper makes the clearest ever case for the impacts of fire on the time course of changes in primary production following fire and is an important element of understanding the impacts of wildfire on California's overall carbon balance.

Additionally, UC Merced postdoc Jian Lin developed a workflow that examines the impact and efficacy of forest management on carbon outcomes. The workflow examined time-series carbon densities after forest management activities, and extracted relevant metrics, such as carbon levels following management activities, magnitudes of carbon recovery, and how long it takes to recover carbon stores, to quantify the efficacies of land management activities.

At UC Davis, postdoc Bin Chen's research has advanced our understanding on fire ignition, and Yuhan Huang's work has provided insight on the impact of drought- or insect-induced tree mortality on fire behavior. These findings will help prioritize fire-fighting resources and further identify core areas for wildfire research in the next step.

2. Describe any successes made in advancing the objectives of the applicable research focus area (i.e., carbon dioxide removal, methane reduction, or heating, cooling, and thermal storage):

The paper on fire regeneration, noted above, provides a detailed picture of the impacts of wildfire on a critical aspect of the carbon balance of California's forests. As such, it advances the state of knowledge on the carbon storage potential of California's natural and working lands.

Additional proposed research will examine carbon outcomes of individual forest management activities, and how they are affected by attributes of forest management (e.g., activity types and management intensities), and other external factors (e.g., wildfire severities). The knowledge gained will enhance our understanding of different land management options and help integrate the natural and working lands into California's carbon neutrality goal.

Additionally, Yuhan's work at UC Davis promotes the understanding of fire risks and impacts in urban and WUI areas of California. Recent fire events have been found to be expanding into the human residential areas and were mostly fueled by houses or landscapes which were not commonly included in previous models. His research will provide insights for fire resistance and risk management.

3. Summarize efforts taken during this report period to conduct Meaningful Engagement:

On January 15, CECS hosted an external project review, engaging Chris Keithley, Christy Brigham, Eli Ilano, Jennifer Smith, Jerry Bird, Kayanna Warren, Leah Fisher, Loretta Moreno, Malcolm North, Michele Slaton, and Nicole Hernandez. These individuals represented the CA Forest Management Task Force, CAL FIRE, California Natural Resources Agency (CNRA), the National Parks Service, the CA Strategic Growth Council, and various facets of the US Forest Service (USFS). During this half-day event, CECS Executive Committee members and the outreach team shared about CECS progress to date with a panel of CA forest experts. We also hosted an open discussion, where panelists provided feedback to the CECS team, discussing both areas where we seem to be doing well, as well as opportunities for improvement/ areas to focus on moving forward. Panelist feedback was very valuable, and we have already begun to incorporate this feedback into our research, as well as into the Beta version of the decision support tool.

On January 26, CECS Director Mike Goulden, Co-Director Roger Bales, PIs John Battles, Toby O'Geen, and Yufang Jin, as well as postdocs Jon Wang and Kyle Hemes, Stakeholder Engagement Specialist Jaquelyn Lugg, and Project Coordinator Raiven Greenberg attended the 2nd Annual Statewide Forest Science Research Coordination, hosted by CNRA, SGC, and Governor's Forest Management Task Force). Mike Goulden presented on CECS research to date, focusing on the CCDC algorithm that we used to create a new historical disturbance dataset, our work on predicting ecosystem recovery curves, and our plans for the Ecosystem Integration Model. All attendees from CECS benefited in learning from other related efforts across the state, and engaging with colleagues in meaningful discussion during breakout sessions.

On February 4, Mike Goulden and John Battles met with Pete Stine at USFS to discuss FORSYS model and integration with CECS. That same day, Mike, along with PI Jim Randerson, UC Irvine postdoc Jon Wang, and Project Coordinator Raiven Greenberg, met with Carlos Ramirez and Leland Tarnay of the USFS Region 5 Remote Sensing Lab (RSL) to discuss for data sharing and feedback between our two groups.

On February 12, PI John Battles attended a review for the Sierra Nevada Conservancy (SNC) with Ashley Conrad-Saydah from SNC and Steven Ostoja from USDA Climate Hub. John provided input on how CECS products might help SNC develop management priorities across their jurisdiction. The same day, he attended the Fire Factor Project Launch Meeting, organized by First Street Foundation, and participated in discussion on how CECS might inform CONUS wide fire risk modeling. On February 25 John attended the UC Berkeley Climate Readiness Institute meeting and explained how CECS products would inform/monitor carbon removal schemes floated by the Biden-Harris administration. On February 26, John attended a meeting with Thom Porter (CAL FIRE), Jessica Morse (CNRA), Helge Eng (CAL FIRE) and discussed lessons learned from CECS effort to collate and integrate spatial and modeled data layers for CA. And finally, on March 24 John attended the CA-NY Climate Innovation Highway Summit 1 and shared insights from CECS effort to transition science to solutions.

Additionally, Roger Bales met with Qin Ma, Assistant Professor at Mississippi State University about collaboration on ET & biomass recovery after disturbance. Roger also met with Tahoe Central Sierra Initiative (TCSI), French Meadows & Blue Forest Conservation, continuing to build CECS' relationships and collaboration with these important partners. Roger also met with the North Coast Resource Partnership regarding measuring water-related metrics.

CECS recognizes that collaboration with other research consortia is important, and Roger engaged in bi-weekly meetings with the CNRA-funded California Foresite team, led by Safeeq Khan, to see how we can share data and further define user groups.

We also continued to engage CECS stakeholders through interactive workshops. We held 2 additional workshops in January with Regional Forest and Fire Capacity Program (RFFCP)-funded watershed coordinators. This included individuals from the Sierra Nevada Alliance, Feather River RCD, Burney Basin Fire Safe Council, Fall River RCD, and the Sierra Institute for Community and Environment.

During Q1, Shane Coffield, PhD candidate at UC Irvine, met with federal legislators, including Representative Katie Porter of the House Natural Resources Committee, to discuss priorities for issues around climate change, wildfires, and natural resources in the new Congress. Shane is now part of the ComSciConLA 2021 science communication conference, where he is working on a write-up of his future carbon manuscript for a public audience. Shane, along with UC Irvine graduate students Nicole Hemming Schroeder and Carl Norlen, is developing a lesson for local 6th graders about our work on California fire and drought ecology as part of the CLEAN program, further translating CECS' research into a format that is engaging and easy for younger generations to understand.

We also distributed the 2nd edition of the CECS quarterly newsletter sent to ~100 contacts, keeping them updated as to recent project developments and additional opportunities to engage with us.

CURRENT STATUS OF THE RESEARCH

4. Summarize the efforts taken during this report period to accomplish the task objectives for each project in the grant:

As part of Task 1, UC Irvine postdoc Jon Wang further developed a new dataset that maps the fractional cover for several plant functional types using time series of Landsat remote sensing data. These datasets provide spatiotemporally continuous data related to the dynamics of ecosystem structure across California, and are an essential component in the ecosystem and fuels model CASA that is being developed. These data were developed by combining the existing dataset from the National Land Cover Database, which has a single map for the year 2016, with machine learning and Landsat spectral data. With these datasets, Jon has started an analysis of the changes in plant cover across California, including a comparison of how these functional types have changed due to climate change, natural disturbances, and other human activity. There has been a notable shift in the distribution of California ecosystems, including a net reduction in tree cover and a large increase in shrub cover. Jon is halfway through drafting a manuscript describing these data, in addition to the disturbance data, with an expected submission to a scientific journal in the summer.

As part of Tasks 1.2-2.3, Sand Diego State University (SDSU) graduate student, Kyle Lunneberg, as well as others from Walt Oechel's lab extracted soil samples in January (winter season) and March (early growing season) from chaparral stands at the Sky Oaks field station at depth of 0-15 cm and 15-30cm, and measured the soil organic content, soil water content, and fine root biomass. Additionally, soil respiration survey measurements have been done every month to increase the number of replicates and understand the spatial variability of the site. Preliminary results suggest soil respiration variability is associated with water content and after-precipitation pulses. The team also processed, cleaned, and partitioned CO_2 flux data from three varying aged chaparral stands in Southern California and identified temporal trends. They are currently analyzing the relationship between multiple meteorological variables and CO_2 flux collected by these flux towers, and conducting statistical to determine the effects of drought, fire, and stand age on carbon sequestration in chaparral ecosystems. Additionally, Kyle collected multispectral drone imagery of six chaparral stands throughout Southern California and began using drone imagery to validate spatial data imports to the CASA model.

For Task 2.1, UCI Project Specialist Mahnoor Khan prepared input data layers for the Ecosystem Integration Model on the UCI High Performance Computing Cluster (HPC). This included different interpolation techniques as well as data cropping solutions. She organized the file path and structure for inputs and outputs as well as code for the Ecosystem Integration Model and wrote a report sharing step-by-step instructions for preparing data as input for the Ecosystem Integration Model. As this data is not easily downloaded at this time, UC Irvine graduate student Carl Norlen created a visualizer and download tool in Google Earth Engine for Ecosystem Integration Model data.

Also as part of Task 2.1, Carmen Tubbesing improved and streamlined the analytical workflow to extract and summarize GPP for fire footprints across California. This workflow is performed in Google Earth Engine (GEE), using scripts she created in R, to perform the GEE calculations in a more reproducible, easy to follow way. Carmen then altered the analysis to extract GPP for individual high-severity fire polygons, rather than entire fire footprints. This narrows the focus of the analysis to areas where all the dominant vegetation was killed by the fire. Thus, the preliminary results show sharper dips in GPP following fire. In order to use high-severity polygons, she first cleaned publicly available fire severity polygons from the USFS. She buffered each polygon to include only areas >120 m from the polygon edge, since high-severity patch interiors are the most susceptible to delayed post-fire recovery, and then uploaded them to GEE and performed GPP calculations. Lastly, she plotted the GPP results across all fires and looked for patterns and outliers. This analysis is still ongoing.

For Tasks 2.1-2.3, UC Davis postdoc Bin Chen has finalized the ignition risk mapping and modeling for the whole state of California. A manuscript has been drafted on the patterns and drivers of human and lightning caused ignition respectively. He has also further refined the method to modeling the ignition dynamics and a manuscript is in preparation.

Additionally, at UC Davis graduate student Yuhan Huang continued to examine the impact of drought- or insect-induced tree mortality on fire behavior. A few interns have been hired to help with visual interpretation of the NAIP high resolution imagery for high resolution dead tree labels and phases. He is developing a deep learning models to map dead trees since 2015. This high-resolution tree mortality will refine the fire behavior analysis at the daily and fire line scale. Yuhan has also started to analyze the linkages of fire behavior and probability of building damage in the wildland-urban interface areas. Yuhan examined the interactions between wildfire patterns and building patterns from 2012-2020 using multi-source geospatial datasets of building footprints, fire survey, urban facility, human, climatic, and biophysical information. He also used deep learning computer vision model to improve the accuracy and completeness of current building footprint dataset and analyze the factors relating to fire damage with machine learning models.

As part of Task 2.3, UC Merced postdoc Jian Lin tested the workflow on one Landsat tile by preparing relevant layers for forest management activities and carbon stores, overlaying different data layers, examining time-series carbon curves after management activities, and extracting relevant metrics that quantify the efficacies of forest management. The initial results showed that carbon densities reduced by 43.7% for selection and 35.3% for commercial thinning the year following management activities, and the carbon density curves did not level-off during the study period (1984-2017). Once the workflow is tested with the refined forest management data, it will be applied to all forested areas in California.

For Tasks 2.2-2.3, UC Irvine PhD Candidate Shane Coffield, and UC Irvine undergraduate researcher Cassandra Vo are making progress on their project using remote sensing to evaluate forest carbon offset projects, including carbon trends and disturbance histories. This work will offer new insights into the strengths and weaknesses of the offsets program and could inform revisions to the forest offset protocol in the coming months. They expect to submit a manuscript for publication this summer.

For Task 2.3, this past quarter Ved Bhoot focused mostly on improving the curve fitting methodology on postfire change in GPP. He also worked on improving performance of prediction of the time to recovery of change in GPP using machine learning (currently using random forest) and assessing importance of features used for prediction.

For Task 3.1, stakeholder survey reporting is underway, with a high-level initial report for stakeholders complete, which will be shared in the April 2021 newsletter. Additional virtual workshops were hosted in January, and discussions with stakeholders continued in smaller group meetings, as well as in the lager contexts of our Jan. 15 External Review Panel, and the 2nd Annual Statewide Forest Science Research Coordination on Jan. 26. More information on our takeaways from these meetings in Section 6, below.

Additionally, Stakeholder Engagement Specialist Jaquelyn Lugg built out a roadmap for stakeholder engagement in 2021, including informal and formal feedback sessions for decision support tool to be held in Q2 and Q3. Additionally, Jaquelyn wrote descriptions/summaries for most of the CECS-created data layers, to be incorporated into the decision support tool.

For Task 3.2 we continued to work on developing and refining a beta version of our decision support tool, the Ecosystem Solutions Toolbox, and made substantial progress. This preliminary version has the capability to visualize more data layers produced by CECS. We spent a substantial amount of time coding for the tool to optimize the presentation of layers and to facilitate the terra bites of data transferred from the Ecosystem Integration Model to the tool. Previous work on the tool was constrained to a region in southern California. The tool now has state-wide coverage for over 28 different data themes with the option of interacting with multiple data years for each theme, for all years between 1985 to 2019. The current data themes that are active in the tool include: 1. vegetation type; 2. surface fuels (including fine, herbaceous, and 2 different fuel types); 3. Carbon stocks (including live, dead, shrub biomass, tree biomass, herbaceous detritus, fresh woody detritus, coarse woody detritus and fine woody detritus); 4. Carbon fluxes (GPP, NPP tree, NPP shrub, NPP herb); 5. Water fluxes and supply (Actual Evapotranspiration, runoff, water shortfall, soil moisture); 6. Effect of drought on tree stress; 7. Effect of Drought on water supply; 8. Fire weather severity; and, 9. Ecosystem services. Each of these data themes contains 34 data layers, one for each year. To host this massive data set we had to migrate the tool over to UC Irvine's HPC.

A considerable amount of effort was expended processing these themes and the associated years for each theme. Each individual file needs to be processed to become a viewable image. Legends need to be created and the ideal color ramp needs to be applied to view data trends appropriately. We created a customizable color ramp to help users better visualize these data. Essentially, the color ramp allows the user to change the number of visible classes within a map.

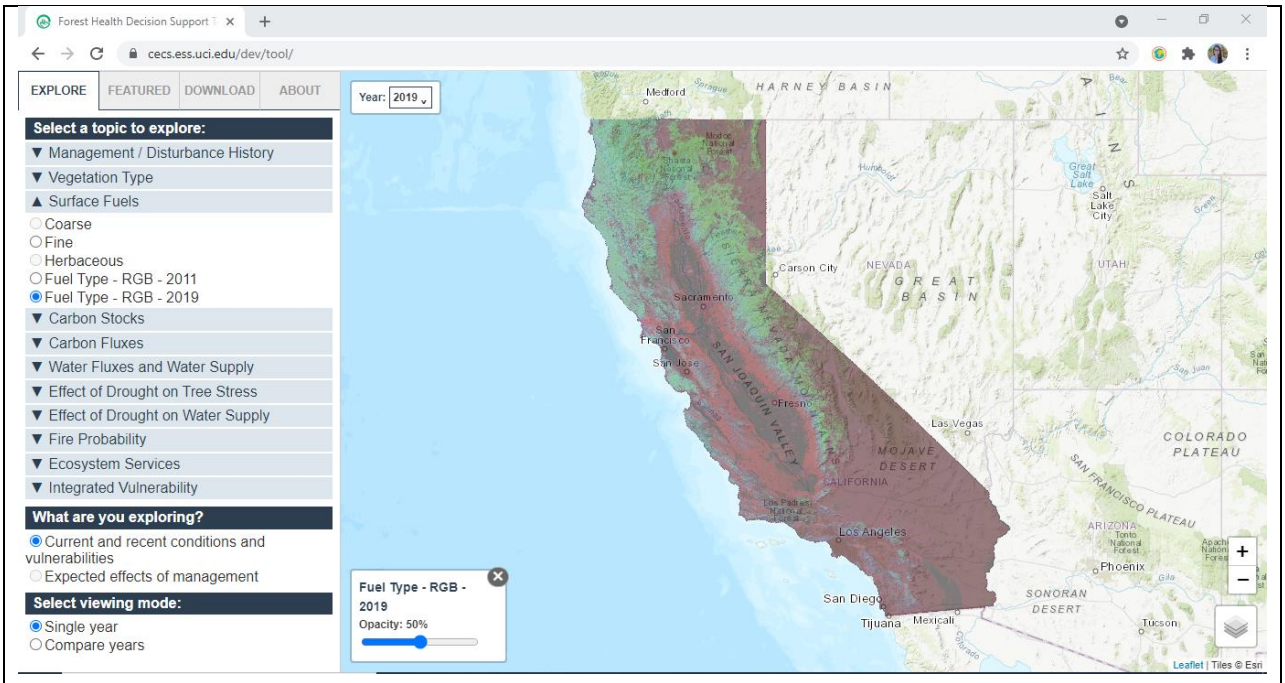

Figure 1: Beta version of the CECS Ecosystem Solutions Toolbox. This screenshot shows the CECS-created fuel type surface fuel layer for 2019 across the entire state.

The Ecosystem Solutions Toolbox will continue to be refined through Q2, especially after the first round of informal feedback sessions with stakeholders. There are also plans for CECS to host science communications interns again this summer, who will contribute to writing up explanations of how different user groups can best utilize the Toolbox. 35 applications were received for this internship, and 4 candidates will be selected from this pool once interviews are completed in mid-April.

For Task 3.3, we distributed the 2nd edition of the CECS quarterly newsletter sent to ~100 contacts, keeping them updated as to recent project developments and additional opportunities to engage with us. We also completed and distributed two video clips focused on ecosystem restoration completed, in partnership with The Chronicles Group. These clips are part of a larger film, called *California's Watershed: Healing*, which is being produced produced by The Chronicles Group and serves as a sequel to *California's Watershed: Beyond the Brink*, which debuted in early 2020.

For Task 4.1, Several CECS team members, including UC Merced PI Catherine Keske, UC Irvine PI Benis Egoh, UC Irvine postdoc Charity Nyelele, and UC Merced graduate student, Nicholas Goncalves, collaborated with Blue Forest to edit the draft framework paper evaluating the multiple benefits of forest restoration to enable financing. This is under heavy revision and it is being reworked by Blue Forest. Catherine, Benis, and Charity, along with Roger Bales and UC Merced postdoc, Min Gon Chung, met bi-weekly to further develop the multi-benefit framework, and to start on a travel cost paper. Min and Charity had notable individual contributions, described below.

Working toward Task 4.2, Min Gon Chung started to perform analyses to examine changes in forest biomass, ET, and NDVI with different forest management (i.e., clearcut and commercial thin), wildfire, and ownership (i.e., public and private lands) in the Tahoe Central Sierra Initiative (TCSI) area. His programming codes can directly adopt Ecosystem Integration Model data for identifying changes in carbon stock, water production, and surface fuel due to restoration activities in CA. Additionally, Min continued to develop valuation tools for carbon stock and water diversion, writing code to estimate the social costs of carbon (SCC) for restoration activities, as the SCC is widely used for climate policy analysis

to calculate the benefits (or costs) of changing carbon emissions. Next quarter he plans to integrate his biophysical analyses with valuations tools for changes in values of carbon stocks and water diversion with forest restoration activities.

Also as part of Task 4.2, Charity Nyelele's focus this past quarter was on recreational ecosystem services in the TCSI area, our initial case study site. Building up on the conceptual models developed in the previous she and Benis decided to split the analysis into three parts. The first component focuses on mapping the potential recreational ecosystem services using biophysical variables that have been shown to influence recreational activities in the literature, machine learning techniques and Flickr geotagged images as a proxy for recreational visits. They also began on analysis which values the recreational ecosystem services using the travel cost method. They have also had discussions on how to tackle the third component, which assesses the impact of forest management and wildfire on the recreational ecosystem services and benefits.

These analyses will continue to evolve in Q2, as more data becomes available from the Ecosystem Integration Model output.

5. Summarize by task any deliverable or outcome completed during the current reporting period:

The fire regeneration manuscript, led by Kyle Hemes, with additional CECS contributors, is complete as a near-final draft, including all analysis, figures, and text. It is undergoing final edits prior to submission, which is planned for the first few weeks of Q2.

Additionally, Bin Chen's ignition maps have been shared with Pyregence and the UC Berkeley/NCAR's fire modeling group, furthering collaborative data-sharing, and freeing up this data for additional analyses and uses.

As noted in Section 4, the Beta version of the decision support tool was a major focus of Q1 2021 and is now considered an official "Version 1", which we will start to share with stakeholders in Q2 for feedback and further refinement.

6. If applicable, what short-term value, interim findings or success stories can you produce as a result of your work?

Success Stories:

Semi-Annual Meeting

We hosted an internal "Semi-Annual" half-day meeting on January 7, and 33 team members attended. Over 20 individuals provided updates on their work on both science developments and outreach efforts to the full CECS Group. This meeting helped to get everyone updated and in alignment as we move into the next stage of our project.

External Review Panel

This was a very helpful meeting, and we thank the reviewers for their candid and thoughtful comments. The reviewers generally supported our direction and progress to date, but pointed out areas that could use further emphasis. Based on this feedback, as well as our internal discussions and the work presented by other groups at the Jan 26 Statewide Forest Science Research Coordination Meeting, we will further emphasize five areas moving forward.

1. Finish creating statewide geospatial data sets that use new approaches to fill key gaps, including: 1) history and intensity of management/disturbance across all land ownerships; 2) forest health, stress and die-off vulnerability to drought; 3) litter and woody debris carbon pools; 4) soil/rooting depth and soil carbon stocks; 5) fire model inputs of ignition probability and dead surface fuels; 6) water fluxes, runoff, and soil moisture; 7) predictions of disturbance recovery rate and the longevity of management effects.

2. Increase interactions and collaboration with parallel efforts at the USFS and elsewhere, such as the R5 Remote Sensing Lab (RSL) and also groups working on management prioritization frameworks.

3. Build-out the planning tool and get it in front of a range of potential users for feedback and iterative improvement. Expand the tool to create output that can feed directly into existing planning software, such as fire spread models (lcp files for surface fuels and shape files for ignitions as input to models such as FlamMap), and prioritization software (shape files for input to models such as FORSYS, LTD or EMDS).

4. Collaborate on wildfire probability predictions. Work with Pyregence and Salo on a collaboration for wildfire predictions, with CECS contributing data layers for ignition probability and surface dead fuels, Salo contributing layers of live canopy fuels, and Pyregence developing and running fire spread models.

5. Rapidly prepare and submit publications.

Decision support tool progress

As noted in Section 4, we continued to work on developing and refining a beta version of our decision support tool, the Ecosystem Solutions Toolbox, and made substantial progress. This is arguably the largest deliverable of the project, and we are happy to have a working version coming into the end of Year 2 of the project so that we can start to get feedback, refine the tool, and make it as useful for stakeholders as possible over the remaining 2 years of the project.

Research Findings:

In Q1, UC Berkeley PhD candidate Clarke Knight prepared a journal manuscript that will be imminently submitted to the *Journal of Environmental Management*. Along with Jon Wang, John Battles, Robert York, Ryan Tompkins, and Mike Goulden, she analyzed archival silviculture treatments on public and private lands through time. She found that newly treated "footprints" of land have been decreasing since 2008, despite the long-standing goal of expanded pace and scale in forest treatments. This finding has important management implications for California because the State is actively working to achieve 1,000,000 acres treated/annually in an effort to modify fire behavior on the landscape. Our results suggest the State but may be falling short of its goal. Additionally, in this manuscript, she compared the timing and intensity of archival treatments to CCDC algorithm harvests and found close matching on private lands but large overestimation in federal archival data.

At UC Davis, Yuhan Huang analyzed the effects of wildfire, spatial patterns of buildings, environmental conditions, and socioeconomic factors on building damage. He found that spatial arrangement of buildings, fuel loading, and the rate of fire spread are key factors relating to the amount of the damaged

buildings within the fire day. These findings will help prioritize firefighting resources and further identify core areas for wildfire research. He is developing a deep-learning based model for building footprint extractions which also has the potential to be extended to classify damaged levels of postfire buildings.

Stakeholder Survey and Workshop Findings:

As noted in previous reports, the stakeholder needs assessment survey data show that stakeholders have a need for spatially mapped data related to forestry and fire data. Respondents also perceived lack of funding and social capital as major barriers to their work and mentioned a need for collaboration and standardization of data collection efforts across the state. Finally, our results also indicate that natural resource management believe the risk of negative natural events, such as wildfires and droughts, are likely to increase in the future.

Adding to this, our workshop data clearly show the importance of accounting for interaction between ecosystem services when evaluating benefits or costs. We find that air quality, fire protection, recreation, provision of habitat, and carbon storage group in a separate community compared to other ecosystem services. According to our results, fire protection is the most interaction-dependent ecosystem service while energy production is the least sensitive to interactions. The measured interactions also have an impact on management efficiency suggesting that some management actions such as replanting and meadow restoration might be overvalued, while ecosystem services with salient negative impacts, such as clear cutting, is somewhat undervalued.

In sum, our ongoing work has identified a set of stakeholder needs which largely corresponds with the overall aims of this project, which suggests that the overall scope of our work is likely to be highly relevant for stakeholders. In the workshop we also found evidence of potential knowledge gaps among current managers that will be very relevant for our continued communication. As the project progresses we will reconnect with survey respondents to ensure the relevance of our final products, such as the interactive web tool and other information.

Papers:

The role of fire in primary production is not well known, and the study by Kyle Hemes and Carl Norlen et al. as part of this project is the first study to explore the impact over a large number of fires. The paper is targeted for a high-profile journal (Proceedings of the National Academy of Sciences). It will highlight an important aspect of the carbon balance of natural and working lands, hopefully with some media and public attention.

Carl Norlen also submitted a manuscript about the impact of multiple droughts on forest health and drought resistance that uses many of the geospatial data sets we are preparing for the CECS project (ET, die-off, precipitation). The findings should provide useful information for managers on how drought disturbance will impact future resistance to drought.

Shane Coffield and Cassandra Vo's manuscript "Climate-driven limits to future carbon storage in California's wildland ecosystems" has been resubmitted and is in review for publication at AGU Advances. In this paper they explore several statistical approaches to project end-of-century vegetation and carbon storage across the state, quantifying uncertainties arising from different approaches and climate projections. This research may inform land management for maximized carbon storage in different parts of the state, especially in forest carbon offset projects which are required to verify carbon stocks for 100+ years. All data and model output will be shared on a public repository and some will be available via the CECS decision support tool.

Presentations:
Kyle Lunneberg at SDSU presented research findings on how drought, fire, and stand age can affect carbon sequestration in chaparral ecosystems at The American Meteorological Society 101st Annual Meeting in January 2021. He will be presenting similar findings at The Global Monitoring Annual Conference in May.

7. Describe any challenges and/or opportunities encountered when accomplishing this portion of the Scope of Work:

Kyle Hemes, the Stanford postdoc leading the post-fire ecosystem recovery effort, has accepted and started a new position with New Forests, a sustainable real assets investment manager. Kyle is taking concepts developed in this project and applying them in the real world, generating additional impacts form the work. We cannot replace Kyle's skills directly, but his main project is essentially complete. Next phases of the research, will be taken up by UC Berkeley postdoc Carmen Tubbesing and a new postdoc that will be hired on at Stanford.

Similarly, Bin Chen, the UC Davis postdoc who led our ignitions data push, has accepted an Assistant Professor position at the University of Hong Kong, where he will be able to share the work of CECS with the next generation of earth systems researchers.

8. Is the research grant on budget and on schedule (Please refer to the Work Plan/Schedule for Implementation)? Please indicate here if a go/no-go milestone was reached this quarter, if it is behind schedule, and/or will not be met, and provide explanation. If other items are off budget and/or behind schedule, what issues need to be addressed and what steps are being taken to ensure that the grant is completed on time and on budget?

As we received a one-year no-cost extension, the expected date of project completion is now well within schedule. The budget for Year 3 and Year 4 will be refined and submitted to SGC as a budget amendment request.

ADMINISTRATIVE/FISCAL OVERVIEW

9. Provide a brief narrative explaining the grant's financial expenditures and budgeted amounts for this period that includes cash and/or in-kind items.

UC Irvine spent $130,767.76 in Q1, mainly on salaries and benefits for the Project Coordinator, Project Specialist, Postdoctoral Researchers, Project Scientist, and graduate student assistance, in addition to administrative overhead.

UC Davis spent $47,219.30 in Q1, primarily on a Postdoctoral Researcher, Programmer, and graduate student salary, benefits, and overhead.

UC Berkeley spent $34,044.88 in Q1, primarily on graduate student and postdoc salary and benefits.

San Diego State University spent $13,662.64 in Q1 on salary and benefits for a PI and graduate student researcher.

Stanford spent $9,448.72 in Q1 on PI effort and Postdoctoral Researcher salary, administration, and overhead.

UC Merced completed substantial work during Q1, but an invoice had not yet been received from them at the time of submission of this report. Thus, we can expect a substantially larger charge from them in Q2 2021.

Total project spending amounts to $236,143.37 for Q1 2021. $1,291,236.05 has been spent to date.

10. Do you anticipate major modifications to the grant's budget or work plan in the next quarter?

Yes. We are submitting a budget amendment request to SGC soon after this report in order to ask for and explain justification for proposed moving of budget between the prime awardee and subawards for Year 3. This amendment request will not constitute large changes to the workplan, but rather re-balance budget to cover personnel expenses across institutions.

ADDITIONAL COMMENTS

The abstract for the new ecosystem recovery paper is pasted below.

"The magnitude and pace of photosynthetic recovery after wildfire in California ecosystems"
Kyle S. Hemes, Carl A. Norlen, Jonathan A. Wang, Michael L. Goulden, and Christopher B. Field

Abstract:

Wildfire has the potential to greatly modify the short- and long-term fluxes of greenhouse gases between the land surface and the atmosphere, impacting the provisioning of ecosystem services from natural lands. California is at the epicenter of these challenges – experiencing 17 of its 20 largest recorded fires in the last two decades. While historically low-intensity, frequent fires in California's dry forests may have been nearly in equilibrium with climate, contemporary perturbations could result in wildfire legacies that pose new challenges in accounting for net fire and land sector carbon emissions.

To understand the complete impacts of a changing fire regime on ecosystem services and the net benefit of fire mitigation strategies, we need to better characterize the multi-decadal regeneration of ecosystem services after fire. Here, we analyze how the legacy of fire across California has affected gross primary productivity over the last century by applying a chronosequence of more than three decades of medium-resolution remotely-sensed vegetation index to ask: 1.) What is the magnitude and spatial arrangement of foregone carbon uptake associated with recent fires in California? 2.) How long does it take for recently burned areas to recover important carbon uptake capacity? 3.) How has post-fire recovery changed over the past four decades?

Across more than thirteen thousand fires in majority forest and shrub landcover that occurred since 1919, we find significant changes in gross primary productivity, derived by scaling Landsat near infrared reflectance with eddy covariance measurements. The burned area productivity is, on average, reduced by 83.7 ± 1.9 g C m^{-2} $year^{-1}$ (mean ± standard error, n=13092) the year following fire, with mean recovery to baseline conditions after 12 years. The highest severity and largest fires led to a 273.2 ± 5.4 g C m^{-2} $year^{-1}$ (n=1366) and 174.5 ± 4.1 g C m^{-2} $year^{-1}$ (n=2946) productivity deficit in the first year after fire, and recovered carbon uptake over 16 years and 11 years, respectively. Recent increases in fire severity and recovery time have led to a decrease in GPP across California's fire-disturbed landscape, resulting in nearly −9.9 ± 3.1 MT CO_2 forgone uptake due to the legacy of fires on the landscape. Understanding how disturbances like fire influence the state's ability to take up CO_2 in

natural and working lands will be paramount to weighing the costs and benefits associated with ecosystem management strategies for climate change mitigation.