CALIFORNIA STRATEGIC GROWTH COUNCIL

Climate Change Research Program

QUARTERLY PROGRESS REPORT

2021

QTR 3

Progress Report # 8 **For the reporting period:** July 1, 2021 **to** September 30, 2021

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

Research Grant Title Innovation Center for Advancing Ecosystem Climate Solutions

Signature Line (authorized representative):

Grace J. Park, Assistant Director, SPA

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%	80%	$5,000.00	$272,786.23
1.2	Test, improve, and update data layers	10%	80%	$36,000.00	$286,623.72
2.1	Prepare data analysis	5%	75%	$18,000.00	$202,546.77
2.2	Analyze historical and current data	10%	60%	$32,000.00	$168,035.26
2.3	Extend data analysis via data science and machine learning	5%	40%	$8,000.00	$40,059.07
3.1	Actively engage stakeholders	10%	75%	$43,000.00	$310,244.11
3.2	Produce decision-making tools	10%	60%	$62,000.00	$185,000.00
3.3	Communication	10%	75%	$6,000.00	$100,000.00
4.1	Develop valuation framework	10%	80%	$15,000.00	$105,000.00
4.2	Develop and implement valuation tools	10%	35%	$25,388.13	$63,388.13
4.3	Develop financing strategies	5%	30%	$13,000.00	$27,000.00

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 Q3 2021. Subgroups working on Tasks 1- 4 have met frequently to discuss strategy and make steps toward deliverables, and cross-task collaboration to bring all project components together into a Natural Climate Solutions Toolbox are well underway.

For Task 1, analysis of vegetation and disturbance datasets was extended into looking at the impacts of changes in vegetation on the fire regime in California. Field measurements at Sky Oaks Field Station continued.

For Task 2, a literature review and meta-analysis of previous forest management practices and results was conducted in collaboration with CARB. We published analyses on climate risks to ecosystems and carbon storage in California, and also continued to push on creating machine learning algorithms to predict ecosystem recovery post-disturbance.

For Task 3, one of our largest successes of Q3 was rapid iteration on our beta version of our set of decision support tools, the Natural Climate Solutions Toolbox, which will be ready for public release in Q4. Additionally, our Carbon Vulnerability Tool, which can be viewed at https://cecs.ess.uci.edu/carbon-vulnerability/ was released for public view and use in August. This is just one piece of the larger Natural Climate Solutions Toolbox. We also began to develop a Data Bridge Tool to extract user-selected data from the Data Atlas for export as a timeseries for analysis, or as data files to use in prioritization software, such as ForSys

The CECS Executive Committee held numerous meetings with stakeholders, and strengthened relationships with the North Coast Resource Partnership and Vibrant Planet. One of the first use cases of our data was by Valley Water in Santa Clara County, who contacted CECS to request data to determine how much water Santa Clara County uses and to address concerns about fire and water shortfall. We hope this will serve as a model for ways that our data can be used to support local and regional efforts.

We also hosted another successful summer internship cohort of 3 undergraduate students who produced valuable science communications products.

As part of Task 4, a perspective paper was submitted. Researchers also examined how forest clearcutting and commercial thinning change economic values of carbon storage and water production. Preliminary analysis has been done for the TCSI area, and will be extended to other areas of California. We also began writing manuscripts from our recreational ecosystem services mapping analyses, and completed a preliminary study for hydropower generation within California.

Several papers on CECS research are in the works, with 6 submitted and 4 published during this reporting period.

ACHIEVING PROGRAM GOALS

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

   The extent to which forest management activities affect carbon outcomes is not uniform in the literature, and evidence of the impacts is moderated by many factors such as activity types, forest types, location, disturbance history, and climatic conditions. To inform effective forest-related management in the future, a comprehensive evaluation and comparison of past practices and case studies is necessary. UC Merced postdoc, Jian Lin, is performing a literature review and meta-analysis

to synthesize the evidence from the existing studies. This work receives additional funding support from the California Air Resources Board (CARB).

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):

Jian Lin's work contributes to the research focus area of carbon dioxide removal by: (1) identifying the most frequently employed forest management activities; (2) differentiating the impacts of forest management on carbon outcomes by activity types, carbon pools (e.g., total carbon, live tree, dead tree, and forest floor), and time periods (e.g., short-, medium-, and long-terms); and (3) quantifying the magnitude ranges of the impacts for different activity types by the meta-analysis.

Additionally, UC Merced Project Scientist, Max Eriksson, continued working with past stakeholder workshop data, and has gotten closer to identifying potential human needs, barriers, and solutions to addressing land management issues.

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

CECS Co-Director Roger Bales helped plan for the second and third symposia of the 2021 UC Wildfire Symposium Series on July 28 and September 22, and gave a talk and served on panel at symposium on the 22nd (recorded presentation is available here). Roger also provided an in-depth briefing on CECS' work with water to California Natural Resources Agency (CNRA) Assistant Secretary Jessica Morse, and Loretta Moreno on Sept 23. Roger conducted a site visit with Yuba Watershed partners Aug 3-4 and continued biweekly meetings with Blue Forest.

On August 16, UC Davis PI Toby O'Geen gave the virtual presentation "Effects of catastrophic fire on soil" at the Wildfire: Weather, Water, Weeds and Wildlife event sponsored by the Counsel for Watershed Health and UC ANR.

On August 19, CECS Director Mike Goulden, UC Irvine Project Coordinator Raiven Greenberg, UC Davis PI Yufang Jin, and Roger Bales met with Siskiyou County Supervisors Brandon Criss and Nancy Ogren, Matt Parker, North Coast Resource Partnership (NCRP) Director Karen Gaffney, and Ore-Cal Resource Conservation and Development Executive Director, George Jennings to demonstrate parts of the CECS decision support tool, and to discuss how our work can be most helpful and how we can collaborate. They were very interested and we followed up to share HUC-12 level data for their watersheds of interest, and will continue to collaborate.

Mike and Roger met with Patrick Wright of the California Wildfire and Forest Resilience Task Force, Keali'i Bright Assistant Secretary, Dept. of Conservation, and Loretta Moreno on Aug 26 to share the tool and inform these agencies on CECS progress and the types of data we can provide to stakeholders.

Mike, Raiven, and Roger met with Dan Winterson of the Moore Foundation on August 27 to share a demonstration of the CECS tool capabilities, and to learn about the Moore Foundation's current and future funding priorities.

Mike and Roger met with Pat Manley & USFS colleagues regarding data and tool development & sharing between CECS and the Tahoe Central Sierra Initiative (TCSI) on September 10, and discussions will continue in the coming months.

Roger also met with Pete Stine regarding data and tool development and sharing between ACCEL and CECS on Sept 15, and discussions will continue in the coming months.

Roger also briefed staff in offices of Representative Costa and Representative Blumenthal about the work of CECS and its applications to their constituencies.

UC Berkeley PI John Battles helped with the coordination between CECS and Pyregence in developing wildfire hazard projections, with data layers and models being actively shared between our two groups. Collaboration with Pyregence will continue to grow through fall 2021.

Walt Oechel's lab at San Diego State University met with chaparral land managers for a second round of input on drone measurement usefulness for stakeholders.

Mike and Roger followed up with Karen Gaffney of NCRP again on September 24 to see how we may be able to partner for future funding proposals.

We reconnected with and further engaged with Vibrant Planet and their Land Tender tool through a series of calls between July and September. The CECS Executive Committee, along with postdocs Jon Wang and Min Gon Chung, and PhD student Carl Norlen, met with Vibrant Planet to learn about and gain access to their Land Tender tool. In subsequent meetings, CECS researchers provided feedback on Land Tender, showed some of the data layers that CECS has created, and discussed how we may be able to collaborate going forward. Conversations with Vibrant Planet are ongoing.

Valley Water in Santa Clara County contacted CECS to request data to determine how much water Santa Clara County uses and to address concerns about fire and water shortfall. Mike Goulden sent Valley Water Associate Engineer, Kaho Kong, CECS' precipitation and evapotranspiration layers for 2015. Valley Water loaded these layers into their GIS and removed isolated areas served by local realtors, removed areas associated with country clubs and golf courses, and summed up the calculated water shortfalls in these areas to estimate the water need to keep trees healthy, prevent die-off, and minimize fire risks. Based on the calculated water shortfall across the area, Valley Water identified 17,000 acre-feet of water supplies needed to reduce fire risks in the Santa Clara County. They will report this information to the State to try to receive proper water allocation. This is just one success story in the early stages of CECS' data usage by on-the-ground agencies and projects. We hope to serve other organizations in similar means in the coming months.

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:

Task 1

This quarter UC Irvine postdoc Jon Wang, former CECS researcher (now USGS postdoc) Clarke Knight, and colleagues revised and resubmitted the manuscript, "Accurate tracking of forest activity key to multi-jurisdictional management goals: A case study in California" to the Journal of Environmental Management. They also developed their analysis of vegetation and disturbance datasets into a full manuscript, titled "Remote sensing reveals multi-decadal losses of tree cover in California driven by increasing fire disturbance and climate stress". The manuscript will be submitted in October for peer review and publication to the journal *Science Advances*. Additionally, Jon pushed ahead with a potential analysis of the impacts of changes in vegetation on the fire regime in California. For this work Jon contacted UC Santa Barbara Professor Max Moritz, and his graduate student, Shane Dewees, who is

working on a study of historical changes in shrub cover in California. Jon plans to combine this information with fire spread data or models to develop an analysis linking vegetation change and fire severity.

Meanwhile, for Task 1.2, Walt Oechel's lab at San Diego State University, including PhD student, Kyle Lunneberg, continued their field-based measurements at the Sky Oaks Field Station. They repartitioned ecosystem respiration and gross primary productivity for the period of 2015 – present with new instrument corrections, as well as completed a two-year dataset of photosynthetic performance and water stress for common chaparral shrub species. They measured soil organic content, soil water content, and fine root biomass for various shrub species and control sites. Additionally, they began statistical analysis of EC carbon dioxide fluxes from the years 2015 to 2020 to determine the effects of drought conditions on CO_2 flux in chaparral ecosystems. They also continued monthly measurements of high-resolution multispectral drone imagery to validate our data layers.

Task 2

In July a team including UC Irvine PhD candidate Shane Coffield, UC Irvine PI Jim Randerson, Mike Goulden, and previous CECS researcher Kyle Hemes, published a paper in AGU Advances about the climate risks to ecosystems and carbon storage in California, which received an editor's highlight and articles in UCI News and the LA Times Daily Pilot.

Shane, Jim, and Mike, along with Jon Wang, and CECS undergraduate researcher, Cassandra Vo, are finalizing a manuscript with collaborators from CarbonPlan and plan to submit for peer review in early November. They have used a few remote sensing datasets to analyze the patterns of carbon accumulation and harvest in California forest carbon offset projects relative to other forests, in an effort to evaluate the additional climate benefits of these projects. This fits into overall CECS goals of using geospatial data layers and evaluating the impacts of land management on carbon stocks.

Additionally, UC Berkeley postdoc Carmen Tubbesing conducted preliminary analyses on the rate of recovery following wildfire with a particular focus on measuring the time to replace shrub dominance with tree dominance. This research builds off of previous work of Kyle Hemes.

For Task 2.2, Jian Lin performed a literature review and meta-analysis of previous forest management practices and results in collaboration with CARB. He began this analysis by: (1) searching papers using pre-defined keywords in the Web of Science, as well as using seed papers; (2) screening papers by title and abstract; (3) extracting relevant attributes (e.g., forest types, management activities, carbon outcomes, methods, temperature, precipitation, study periods, and locations) from each identified paper; (4) extracting quantitative information regarding the impacts of forest management on carbon from the tables and figures of the identified papers; and (5) performing meta-analysis. This analysis will continue in Q4. Deliverables will be the literature database and the tables that record the relevant qualitative and quantitative information. Specifically, steps 1 and 2 produce a database of 1445 and 140 articles, respectively. The output from step 3 is a table that records all relevant attributes, while step 4 produces a three-dimensional matrix organized by activity types, carbon pools, and numbers of years post-treatment.

As part of Task 2.3, UCI PhD student Ved Bhoot focused on producing intersection layers using FRAP fire perimeters. These layers will be used for identifying key areas within the state that have low and high burn frequencies. They will also be used in conjunction with Kyle Hemes and Carl Norlen's recovery analysis. Ved is working with Carl Norlen to produce R scripts for data extraction. The R script is nearly ready to be run on UC Irvine's High-Performance Computing Cluster (HPC3), with the plan

to send out runs on the cluster in the coming few weeks. The current forecast for producing a trained random forest model on the recovery data is approximately two months.

Over the next two months Ved will get data ready to train a model with the data from the fire perimeters, fit recovery time on a pixel inside the perimeter, get the climate/burn severity/classification/etc. data for that pixel, and then train the model with the climate/burn severity/classification/etc. data; because the total volume for each pixel would be too much to train on, a subset will be taken. After that, we will obtain future climate data from climate models and determine different burn scenarios for the state to predict recovery times using the trained model.

Task 3

As part of Task 3.1, Max Eriksson spent much of the last quarter engaging with the stakeholder workshop data and writing reports in order to be able to distribute our findings back to participants. He also completed a report on the stakeholder workshop findings. In further working with the stakeholder workshop data, Max gained an understanding of how natural resource professionals in California perceive management, with the main take away being that fire-related management is dominating everyone's view of the system.

For Task 3.2, we developed the Carbon Vulnerability app, which is now publicly available at https://cecs.ess.uci.edu/carbon-vulnerability/ (more on this is section 5). For the Data Atlas (formerly referred to as the Ecosystem Services Mapping Tool), most work was related to restructuring the code to accommodate a significant change in the format of the CECS data layers. The layers were changed from a mosaic of individual "ARD" tiles to statewide layers. The tool was adapted to display data on the map using these new statewide files, which provided several benefits: 1) better performance when loading data layers on the map; (2) streamlined workflow for when data layers are updated; and (3) most researchers on the project prefer using the statewide layers for their analyses. Additionally, we made some minor changes to the user interface. For example, we added the ability to compare years for the "Vulnerabilities" layers.

We also made some minor updates to Fire Progression tool, which is publicly available at https://cecs.ess.uci.edu/fire-progression/. Updates included adding the ability to view fuel type layers for all years from 2011 to 2019, rather than just 2011 or 2019, and fixes to minor bugs, and interface improvements.

Mike Goulden also began to develop a Data Bridge Tool to extract user-selected data from the Data Atlas for export as a timeseries for analysis, or as data files to use in prioritization software, such as ForSys. Developing this tool will be the main focus of our team's work in Q4.

For Task 3.3, John Battles began to develop a portfolio of forest management scenarios for California based on an analysis of treatments applied during the last ten years (2010-2019). This portfolio includes explicit cross-walks between silvicultural (e.g., shelterwood harvest) and restoration techniques (e.g., hazardous fuels reduction) applications and their impact on modelled responses in the Natural Climate Solutions Toolbox. This crosswalk will be key in making sure our terminology is reflective of what is used in the field and will also be key in sharing tools with stakeholders.

Task 4

One of the larger successes for Task 4 this quarter was that the manuscript, "A multi-benefit framework for funding forest management in the Western USA" was successfully submitted to *Conservation Biology* and is under consideration.

In addition, Min Gon Chung, a postdoctoral researcher at UC Merced, examined how forest clearcutting and commercial thinning change economic values of carbon storage and water production. His results for initial analysis of the TCSI area showed that forest clearcutting in public lands produced $54,030/km^2 of water production annually for 20 years but also cost $230,674/km^2 in carbon losses before and after the actions. With different thinning activities and policies, clearcutting in private lands had 73.3% more water production values than that in private lands, while commercial thinning in private lands had 47.1% lower carbon values than that in public lands. With these findings, Min has extended this research to examine how landowners and water rights holders leverage sustainable and efficient management strategies for California's natural lands

Charity Nyelele, postdoctoral researcher at UC Irvine, spent much of this quarter writing manuscripts from our recreational ecosystem services mapping analyses. She completed an initial draft of the first paper on how machine learning offers new opportunities for mapping currently understudied cultural ecosystem services including recreation, and is in the process of revising the paper based on comments from colleagues. She also started drafting the second paper on the economic valuation of recreational ecosystem services in the TCSI area. Charity also attended the Alpine Biomass Collaborative July Meeting which focused on a presentation of a report on the "Value of Ecosystem Services and the Risk to Alpine County's Economy from Climate Change" by the Eastern Sierra Sustainable Recreation Partnership (ESSRP), from which she was able to glean information that informed her analyses.

Additionally, UC Merced PhD student Han Guo completed a preliminary study for hydropower generation within California. Based on the annual runoff data for each HUC8 basin and hydropower generation data, two hydropower generation maps, including 142 HUC8 basins and 274 hydroelectric power plants, were developed to complement the CECS data. One is the annual generation map for each HUC8 basin, and the other is the amount of hydropower generation generated per unit of runoff at the HUC8 scale. The next step will be for further refinement of the maps within the HUC8 basins, as the more upstream sub-basins will generate more power per unit of water, as well as monetize hydroelectric generation, due to differences in location and path of hydroelectric generation. With such maps, we can know how hydropower, as one of the ecosystem services, is distributed spatially and can help in forest management decisions.

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

Carbon Vulnerability Tool

At UC Irvine, PhD candidate Shane Coffield has undertaken research to quantify climate change impacts on California forests' carbon storage capacity. Shane along with CECS researchers James Randerson and Michael Goulden published a study in AGU Advances, which was highlighted in UCI News. Results are publicly-available to explore on the Carbon Vulnerability web tool at https://cecs.ess.uci.edu/carbon-vulnerability/.

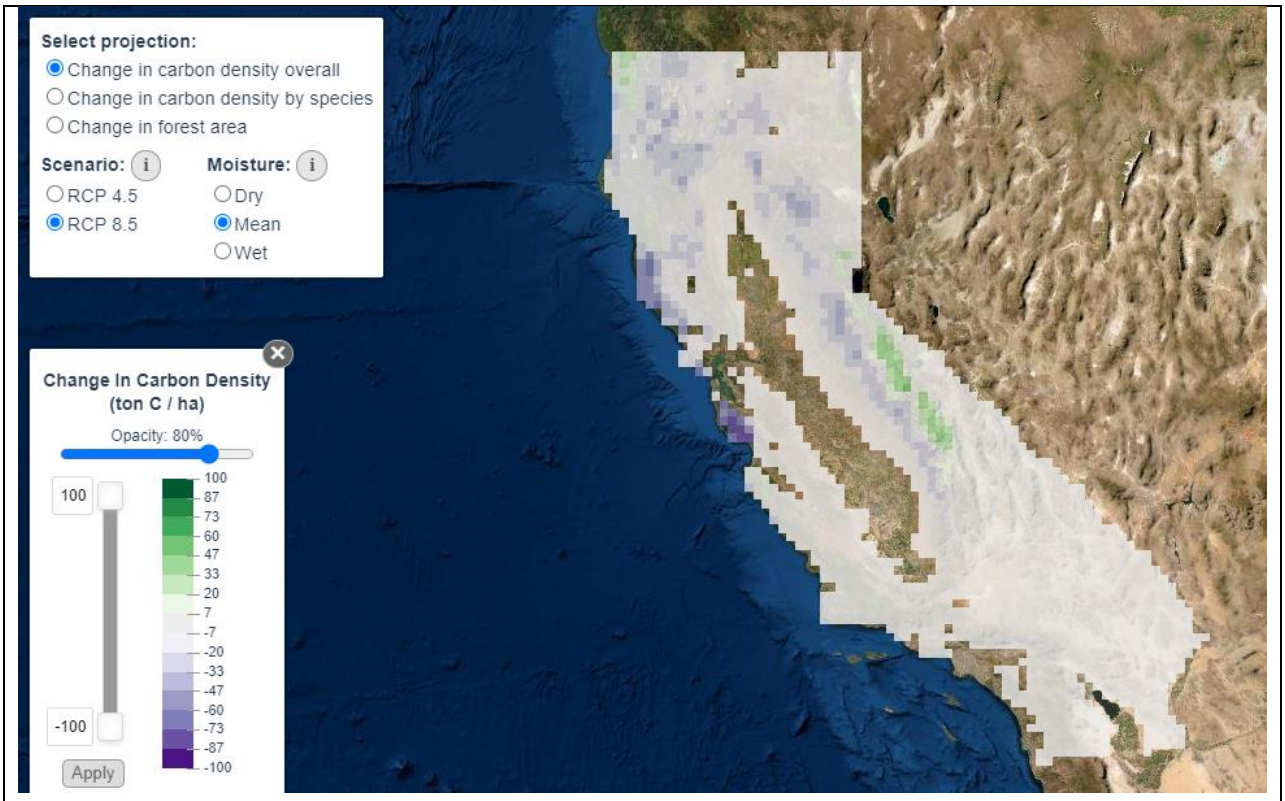

Figure 1- CECS Carbon Vulnerability Tool. This screenshot shows the predicted change in overall carbon density for the most extreme warming scenario (RCP 8.5). Darker purple pixels indicate a greater loss of carbon, while green pixels indicate carbon removal from the atmosphere.

This visualization tool shows projected changes to aboveground carbon stocks across California over this century based on both moderate and extreme climate change scenarios. These projections, which are based on random forest models, using four seasons of temperature and precipitation as input, identify which parts of the state are most vulnerable to future carbon loss due to changing temperature and precipitation patterns. Projections also include changes in tree versus shrub spread across the landscape and maps vulnerability for 20 tree species statewide. Data and code are also available for download in a public repository at https://doi.org/10.7280/D1568Z. This tool and its underlying data on the vulnerability of California's carbon stocks can directly inform land management by anticipating the effects of climate change and targeting efforts to protect existing carbon stocks.

Shane and colleagues' main findings in their paper, which are also clearly visible when using the tool interface, are that rising temperature and changing rainfall patterns will most likely act to decrease the total amount of carbon stored in California's forests by 9-16% depending on our emissions pathway. This adds to the management challenges associated with meeting the State's goal of increasing the amount of carbon stored in natural lands. In particular they found that the low-elevation coastal and mountain areas, including where many forest carbon offset projects are located, are most vulnerable to climate change. Now a similar team, along with CECS intern Cassandra Vo, are writing up a research paper about California's improved forest management carbon offset projects specifically, using a variety of remote sensing tools to evaluate the offset projects' effectiveness since the program began in 2012.

Annual Mtg.

We hosted our CECS 2nd Annual Meeting on August 16 and 18. During this time, our summer interns presented on their work (more information on this in section 6), and CECS researchers gave individual

brief science updates to get folks up to speed with the current state of the project research and analyses. We also held two discussion forums on the Natural Climate Solutions Toolbox, and on project plans going forward. More than 80% of the team was in attendance, and this led to a revitalization of collaboration between project researchers.

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

Success stories:

Internship Program

CECS hosted its second Ecosystems & Climate Change Summer Internship cohort virtually this summer for 8 weeks between June 21 and August 13. There were over 35 applicants to the program, and we selected 3 interns from a very diverse pool.

This summer's interns focused on science communication. Mentored by UC Davis PI Toby O'Geen and Project Coordinator, Raiven Greenberg, the interns learned about core science communication concepts like attention to audience, distilling complex information, eliminating jargon, and more. Their tasks revolved around documenting CECS-created data layers, explaining the findings and implications from upcoming CECS publications through blog posts, and creating use cases for the Natural Climate Solutions Toolbox. Each week, interns worked together and with their mentors to revise their products, all of which will be featured on the CECS project website and/or within the Ecosystem Solutions Toolbox interface. All interns presented their work at the CECS 2nd Annual Meeting, to a virtual audience of over 30 individuals.

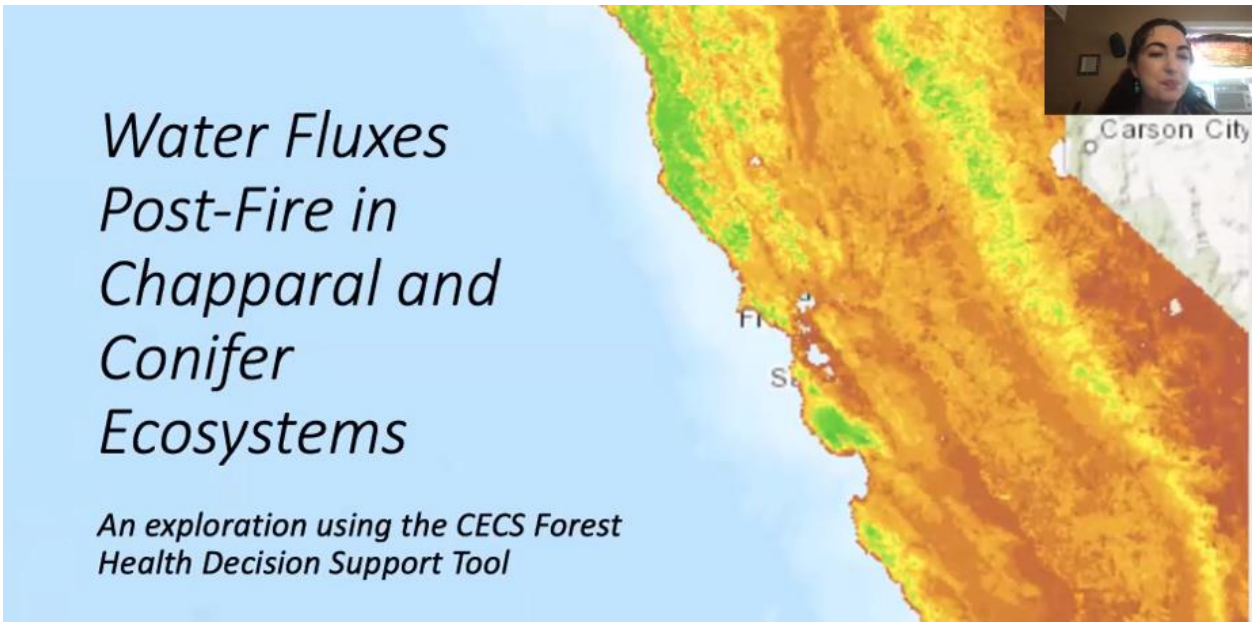

Figure 2 - One of our summer interns, Claire Tauber, presenting her findings on the impacts of fire on several data layers in the CECS Ecosystem Solutions Toolbox during our 2nd Annual Meeting.

To create a richer experience for our interns, especially in the fully virtual world of the COVID-19 era, we hosted biweekly virtual workshops on eliminating jargon, targeting messaging toward specific audiences, and giving effective presentations, as well as a Young Professionals in STEM Panel to explore career opportunities. Interns were also able to learn from and collaborate with researchers across all 6 universities involved in the CECS project through weekly sub-group calls.

In an exit survey, 100% of interns reported an increase or strong increase in their interest in both a career in research and/or in science communication, and in attending graduate school. 100% of interns also felt more knowledgeable about science communication, and also reported more knowledge about forest management strategies and ecosystem services. One intern also shared on their exit survey:

> "Interning with CECS has by far been one of my most valuable undergraduate experiences. Over the course of the internship, I not only fostered a greater appreciation for science communication but also gained a better understanding of ecosystem services and land management in California. Through CECS, I was introduced to geospatial analysis, a skill that will undoubtedly help me in my future environmental endeavors. I am so grateful to have joined such a knowledgeable and interdisciplinary team of science communicators and researchers, and I hope other undergrads passionate about sustainability and the environment will have a chance to participate in this internship next summer!"

For this being a fully virtual internship, we considered this a large success, which we hope to replicate again next summer, hopefully in an in-person format.

Research findings:
Clarke Knight and colleagues submitted a manuscript to the *Journal of Environmental Management*, which was conditionally accepted for publication. They analyzed archival silviculture treatments on public (USFS) and private (CALFIRE) lands through time. Overall, they 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. These results suggest the State but may be falling short of its goal. Additionally, in this manuscript, they 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.

UC Irvine Junior Specialist, Aurora Gutierrez, and colleagues submitted their paper "Wildfire response to changing daily temperature extremes in California's Sierra Nevada" to Science Advances. It should be published in early November, just after the submission of this report. Their abstract and findings can be found below.

Abstract:
Burned area has increased across California, especially in the Sierra Nevada range. Recent fires there have had devasting social, economic, and ecosystem impacts. To understand the consequences of new extremes in fire weather, here, we quantify the sensitivity of wildfire occurrence and burned area in the Sierra Nevada to daily meteorological variables during 2001–2020. We find that the likelihood of fire occurrence increases nonlinearly with daily temperature during summer, with a 1°C increase yielding a 19 to 22% increase in risk. Area burned has a similar, nonlinear sensitivity, with 1°C of warming yielding a 22 to 25% increase in risk. Solely considering changes in summer daily temperatures from climate model projections, we estimate that by the 2040s, fire number will increase by 51 ± 32%, and burned area will increase by 59 ± 33%. These trends highlight the threat posed to fire management by hotter and drier summers.

Table 1. Model estimates of changes in fire number and burned area caused by summer climate warming in the Sierra Nevada ecoregion. Percent change for each decade is reported relative to a baseline of the 1980s. Fire observations from FRAP are also shown along with mean surface air temperature from PRISM for 1980s through 2010s. Future estimates of summer temperature, denoted with a * are from the CESM1 LENS project for the RCP85 scenario (24). The uncertainties were estimated using a jackknife approach, denotated with a ± for 1 SD.

Time period	Summer mean temperature (ºC)	Fire number			Burned area		
		n y^{-1}	Δ%	Obs. n y^{-1}	km^2 y^{-1}	Δ%	Obs. km^2 y^{-1}
1981-1990	16.0 ± 3.8	13.7 ± 3.1	0	16.8 ± 1.2	419.6 ± 96.5	0	195.5 ± 27.6
1991-2000	16.6 ± 3.8	15.3 ± 2.5	11	13.3 ± 0.8	504.0 ± 75.3	20	196.7 ± 19.4
2001-2010	17.6 ± 3.6	18.7 ± 2.4	36	20.8 ± 0.8	573.0 ± 72.5	37	315.7 ± 28.5
2011-2020	17.8 ± 3.6	19.4 ± 3.8	41	17.3 ± 0.6	621.1 ± 130.2	48	878.4 ± 103.3
2021-2030*	18.6 ± 3.9	23.8 ± 5.0	73		769.2 ± 162.6	83	
2031-2040*	19.1 ± 3.9	26.3 ± 6.4	91		869.9 ± 205.6	107	
2041-2050*	19.8 ± 3.9	29.3 ± 7.3	114		987.2 ± 251.6	135	

Overview of CECS publications under review, or published in Q3:

1. Wang, J.A., Knight, C, Goulden, M.L., Battles, J.B. & Randerson, J.T. (in review) Remote sensing reveals multi-decadal losses of tree cover in California driven by increasing fire disturbance and climate stress. *Science Advances.* In review.
2. Hemes KS, Norlen CA, Wang JA, Goulden ML, Field CB. 2021. The magnitude and pace of photosynthetic recovery after wildfire in California ecosystems. *PNAS*. In review.
3. Norlen CA, Goulden ML. 2021. Recent drought induced needleleaf conifer mortality episode reduces subsequent forest die-off severity. *Nature Climate Change*. In review.
4. Chen, Y., S. Hantson, N. Andela, S.R. Coffield, C.A. Graff, D.C. Morton, L.E. Ott, E. Foufoula-Georgiou, P. Smyth, M.L. Goulden, and J.T. Randerson. 2021. Tracking extremes in California wildfire spread using satellite active fire detections and an object-oriented classification approach. *Scientific Data*. In review.
5. Hantson, S., N. Andela, M.L. Goulden, J.T. Randerson. 2021. Human-ignited fires are faster, hotter, and kill more trees in California forests. *Nature Communications*. In review.
6. Quesnel Seipp, Kimberly; Maurer, Tessa; Elias, Micah; Saksa, Phil; Keske, Catherine; Oleson, Kirsten; Egoh, Benis; Cleveland, Rachael; Nyelele, Charity; Wyrsch, Peter; Goncalves, Nicolas; Hemes, Kyle; Lewis, David; Guo, Han; Gon Chung, Min; Gritter, Abby; Conklin, Martha; Bales, Roger. A multi-benefit framework for funding forest management in the Western USA. *Conservation Biology*. In review.
7. Knight, C., Tompkins, R.E., Wang, J.A., York, R., Goulden, M.L., & Battles, J.B. 2022. Accurate tracking of forest activity key to multi-jurisdictional management goals: A case study in California. *Journal of Environmental Management.* doi: 10.1016/j.jenvman.2021.114083
8. Gutierrez, A.A., S. Hantson, B. Langenbrunner, B. Chen, Y. Jin, M.L. Goulden, and J.T. Randerson. 2021. Wildfire response to changing daily temperature extremes in California's Sierra Nevada. *Science Advances*. doi: 10.1126/sciadv.abe6417

9. Coffield, S.R., K.S. Hemes, C.D. Koven, M.L. Goulden, and J.T. Randerson. 2021. Climate-driven limits to future carbon storage in California's wildland ecosystems. *AGU Advances*. doi: 10.1029/2021AV000384.
10. Hantson, S., T.E. Huxman, S. Kimball, J.T. Randerson, and M.L. Goulden. 2021. Warming as a driver of vegetation loss in the Sonoran Desert of California. *JGR Biogeosciences*. doi: 10.1029/2020JG005942.

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

Challenges:

Research progress at UC Davis was stalled in Q3, as the postdoc who was supposed to start this summer accepted a faculty position instead. We are in the process of hiring a new postdoc, and things will speed up after we get the new hire onboard.

Additionally, Max Eriksson found that working with ecosystem services and management actions always involves a hard trade-off relating to the scale of analysis, and striking a balance between accuracy and generalizability has been a challenge in terms of deriving meaning from our workshop data.

Opportunity:

Jian Lin began working part-time with the California Air Resources Board (CARB) this summer to perform a literature review and meta-analysis synthesizing the evidence from past forest management studies. This work bidirectionally supports both CARB and CECS' efforts, and also allows leveraging of Jian's salary for 3 months so we can extend him on CECS.

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?

Budget and schedule are both tracking as planned.

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 $137,579.85 in Q3, mainly on salaries and benefits for the Project Coordinator, Postdoctoral Researchers, Project Scientist, PIs, and graduate student assistance, in addition to administrative overhead.

UC Davis spent $44,404,57 in Q3, primarily on our Programmer, PI effort, and overhead.

UC Berkeley spent $81,403.71in Q3, primarily on graduate student, PI, and postdoc salary and benefits.

UC Merced, Stanford, and San Diego State University all completed substantial work during Q3, but invoices 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 Q4 2021.

Total project spending amounts to $263,388.13 for Q3 2021. $1,736,712.69 has been spent to date.

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

None anticipated.

ADDITIONAL COMMENTS

We thank SGC for your continued support of this project, and look forward to sharing the full Natural Climate Solutions Toolbox with you soon.