CALIFORNIA STRATEGIC GROWTH COUNCIL

Climate Change Research Program

QUARTERLY PROGRESS REPORT

2021

QTR 4

Progress Report # 9 **For the reporting period:** October 1, 2021 **to** December 31, 2021

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

Research Grant Title Innovation Center for Advancing Ecosystem Climate Solutions

Signature Line (authorized representative):

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%	85%	$25,000.00	$297,786.23
1.2	Test, improve, and update data layers	5%	85%	$40,000.00	$326,623.72
2.1	Prepare data analysis	5%	80%	$45,000.00	$247,546.77
2.2	Analyze historical and current data	10%	70%	$85,000.00	$253,035.26
2.3	Extend data analysis via data science and machine learning	10%	50%	$35,000.00	$75,059.07
3.1	Actively engage stakeholders	5%	80%	$65,000.00	$375,244.11
3.2	Produce decision-making tools	15%	75%	$270,000.00	$455,000.00
3.3	Communication	5%	80%	$45,000.00	$145,000.00
4.1	Develop valuation framework	5%	85%	$30,000.00	$135,000.00
4.2	Develop and implement valuation tools	15%	50%	$80,000.00	$143,388.13
4.3	Develop financing strategies	10%	40%	$44,676.19	$71,676.19

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:

In Q4 2021, the CECS team made significant progress on our Natural Climate Solutions (NCS) Toolbox, the main technology deliverable of our project. In addition to having a soft public release of the Data Atlas tool (which can be found online at https://cecs.ess.uci.edu/data-atlas/), we also created a beta version of the Data Bridge tool. This tool allows users to extract their layers of interest from the CECS-created Data Atlas layers, as well as complementary data from other sources, and combines this into a "one-stop shop" where users can utilize this data to look at pre-treatment evaluation, pre-treatment planning, prioritization, and post-treatment evaluation for their area(s) and variable(s) of interest. While this tool is only in a beta version now, we are preparing to start to share it with a select group of stakeholders who have expressed interest in testing the capabilities of the tool, and seeing how well it functions in their analysis of specific geographic areas of the state. Their testing of the tool will provide us with valuable information on its usability, as well as areas where we can continue to make improvements, prior to a full public release of our suite of tools in spring/ summer 2022.

In preparation for these "test cases" CECS team members held numerous meetings with stakeholders, and strengthened relationships with CAL FIRE, the California Natural Resources Agency (CNRA), and the Department of water Resources (DWR) in Q4. The team hosted close to 20 meetings this quarter with State and regional groups, as well as nonprofits, and other research consortia. Stakeholder engagement and analysis of user experience with our NCS Toolbox has become a main focus of our work, and will become an even larger part of our project going into Q1, 2022.

One additional development of note is that our analysis of ecosystem services was deepened this quarter, and that we have started to develop a mock-up of an ecosystem services valuation tool, which will be expanded upon and hopefully added to the larger NCS Toolbox in early 2022.

Dozens of papers on CECS research are in the works, and 13 papers were either submitted, under review, or 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:

   Our main focus in Q4 was creating a beta version of the Data Bridge tool, the final unifying piece of our Natural Climate Solutions (NCS) Toolbox. We made great strides in operationalizing the NCS Toolbox. A particular improvement was developing the capacity to evaluate the post-treatment impact of all the common forest and fuel treatments applied on public and private lands in California via a crosswalk table created by UC Berkeley PI, John Battles, and Research Tech, Elliot Kuskulis. Explanation of further improvements to our NCS Toolbox can be found in section 4 of this report.

   Additionally, UC Merced postdoctoral researcher, Jian Lin, continued the task of synthesizing the impacts of forest management activities on carbon outcomes across different time scales. Through a literature review and meta-analysis, he is working to reveal a comprehensive interaction between forest management types, carbon outcomes, and time post-treatment. This work will also contribute to the understanding of the management efficacy of a variety of forest carbon pools under different environmental conditions.

At San Diego State University (SDSU), PI Walter Oechel's lab further characterized carbon flux in a semi-arid chaparral system. Students conducted data analysis of completed long-term data sets on net ecosystem exchange of carbon, species-level photosynthetic rates with variable water stress, and micro-site-level soil respiration. This data analysis revealed the effects of drought, fire, and stand age on CO_2 flux in chaparral ecosystems. Results also allowed for a better understanding of how climate change and extreme weather events influence the source-sink relationship of chaparral ecosystems.

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 "post-treatment monitoring" function under the CECS Data Bridge could allow for time-series analyses to reveal the impacts of past management on a variety of ecosystem conditions including carbon outcomes. Jian's work complements this by looking at ground-observed field plot datasets. In addition to examining the impacts of past management based on historical observations, he also examines the future impacts of management by summarizing the modeling projections under different climate and management scenarios.

Additionally, John Battles contributed to an assessment of the climate benefits of California's forest offset program.

In our work with stakeholders, UC Merced Project Scientist, Max Eriksson, finished work on the participant workshop data, enabling analysis of potential human needs, barriers, and solutions to address land management and disturbance issues in California.

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

PI John Battles' main effort this quarter was to help develop the NCS Toolbox for stakeholder use. He took the lead in developing a case study of how the Toolbox could be used to evaluate treatment alternatives in a particular watershed in the Klamath Mountains. His lab was also the chief "beta" tester of the Data Bridge. He and Research Tech, Elliot, helped develop hands-on demonstrations and presentations, which we shared with stakeholders.

We continued to interact with Vibrant Planet, and a group including UC Irvine PhD candidate, Carl Norlen, UC Merced Postdoc, Min Gon Chung, and Project Coordinator, Raiven Greenberg met with Scott Conway on 10/4 to provide feedback on technical components and UX of Land Tender. CECS Director, Mike Goulden, had additional follow up conversations with Scott to discuss data and potential for collaboration.

On 10/4 Mike, Roger, and Raiven met with Bobby Fishkin and Claudia Brenner of the nonprofit organization CrowdDoing to learn about their wildfire prevention derivatives project, to introduce CECS, and to see if there is room to collaborate.

We also continued our collaboration with the Pyregence consortium, with Mike, Raiven, UC Davis PI, Yufang Jin, and UC Irvine PI, Jim Randerson meeting with David Saah and team members on 10/19. We further discussed surface fuel layers, as well as the and potential for running fire models at UCI, and sharing runs. We expect our collaboration to deepen in Q1, 2022.

Charity Nyelele, UC Irvine postdoctoral researcher, gave a "Half-Baked" talk on November 5 to the Department of Earth System Science at UCI. She also gave a seminar presentation to the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) team on November 19. In both

presentations, which focused on her work modeling and mapping nature's contribution to humans. Charity also talked about the CECS project and how we are using machine learning and social media data to improve our mapping of cultural ecosystem services.

CECS Co-Director and UC Merced PI, Roger Bales, attended and/or hosted several meetings with region-specific stakeholder interest groups in Q4, 2022. He first presented the CECS Data Atlas tool at annual Yosemite hydroclimate meeting on 10/14, as well as at a subsequent French Meadows partners meeting on 10/25. He hosted two meetings to further collaborate with CECS partner, Blue Forest, on 10/28, and 12/17, further discussing our multi-benefit ecosystem services framework paper, as well as how CECS' data may support Blue Forest in their project efforts. Roger also met in person with the El Dorado Resource Conservation District and others while on a tour of Caldor Fire burn area on 11/5.

One of our most interested regional collaborators to date has been the North Coast Resource Partnership. On 11/8 Mike, John Battles, Roger, Raiven, and Stakeholder Engagement Specialist, Meghan Cook, met with NCRP Director, Karen Gaffney. We provided Karen with a quick overview of Data Bridge, updates to the Data Atlas, and discussed about uses for these tools in the North Coast region (including a potential test case). Mike, John, Raiven, and Meghan, along with UC Davis PI, Toby O'Geen, and Research Tech, Elliot Kuskulis, followed up on this conversation and met with NCRP's geospatial analyst, Mark Tukman on 12/8. We showed Mark some of the more technical components of the Data Atlas, introduced him to the Data Bridge, and discussed how NCRP could use this for analyses. Mark will update his collaborator, Chris Dunn, and get back to us for follow-up on sharing data and running a test case in the new year.

Our largest stakeholder engagement effort in Q4 was our 'soft release' (first public opening) of the online Data Atlas tool and sneak peek of the Data Bridge tool to State agencies on 11/16. The full CECS Executive Committee team (Mike, Roger, John, Toby, Yufang, Meghan, and Raiven) engaged Tadashi Moody (CAL FIRE), Klaus Scott (CARB), Nic Enstice (SNC), Alan Talhelm (CARB), Chris Kiethley (CARB), Adam Moreno (CARB), Patrick Wright (Forest Mgmt. Task Force), Nadia Tase (CAL FIRE), Shelby Livingston (CARB), Dave Sapsis (CAL FIRE), Nicole Hernandez (SGC), Alex Yiu (CARB), and Loretta Moreno (CNRA) in this call. We received an overwhelmingly positive response from agency representatives, as well as a few good points of feedback, and quickly scheduled follow up calls with certain subgroups who were interested in further exploring the capabilities of the NCS Toolbox.

As they were unable to attend the 11/16 agency tool release call, Andrew Schwarz, Cassandra Evenson, John Yarborough of the Department of Water Resources (DWR) met with Mike, Roger, Meghan, and Raiven on. In addition to answering questions based on their review of the 11/16 meeting recording, we discussed DWR's needs in the Feather River Watershed, and how our data might be able to help. The CECS team followed up on a call with Andrew and Cassandra on 12/14 to further discuss the science and technical capabilities of the tool, and to determine what is needed for a case study starting in Q1.

On 12/8 Mike, Raiven, Elliot Kuskulis, and UC Irvine postdoc, Jon Wang, met with Nadia Tase (CAL FIRE) and Kendal DeLyser (American Forests) to further discuss details of the Data Atlas tool post- agency tool release call. They were especially the CCDC algorithm behind the historic management and disturbance layers. We talked through their data needs and what we can share with them, and explained our matrix of management actions and how those show up in our tools and analyses. We scheduled follow up for January to further discuss the management matrix and our expected effects of management on flame length data.

Following the agency tool release, we also met twice with Loretta Moreno of CNRA, first with Mike and Raiven on 12/3 to discuss a potential test case for using CECS tools for AB 2551 area analysis, and what

setting up a formal process to work through this would entail. The second discussion on 12/10 engaged Mike, John, Meghan, Elliot, and Raiven, who discussed steps needed in setting up a test case/ audit starting in January, and discussed some of the science and technology details and needs, as well as documentation/ user guides for the NCS Toolbox.

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

Mike Goulden compiled additional complimentary datasets, such as CDWF's ACE data, as well as Pyrologix's complete wildfire analysis data, into our Data Bridge tool. He also edited the code of the CECS Data Engine to improve CECS-created data layers. Final homogenization and improvement of data layers will happen in Q1 2022 alongside our 2020-2021 water year updates to the data layers.

In the field, Walter Oechel's lab at SDSU collected and analyzed data focusing on how fire and drought affect CO_2 and H_2O flux in chaparral ecosystems. They analyzed long term data focusing on soil respiration in a chaparral ecosystem, while also maintaining three eddy covariance towers, measuring photosynthetic performance for three dominant shrub species within the tower footprints. To compare species-level carbon flux measurements with various spectral indices, they also collected multiple, spatially comparable drone-based orthomosaics. Each image consisted of Landsat-type bands at 1-6cm^2/pixel.

The CECS research team at SDSU also completed a draft for a research paper focusing on drought and its effects on CO_2 flux in semi-arid chaparral ecosystems, and another focusing on the disappearance of fog and other biogeochemical events in CA's hydrology. And lastly, they sent two abstracts focusing on soil respiration and the effects of drought, fire, and stand age on CO_2 flux in chaparral to the 10th Biennial Education and Science Forum.

Task 2

For Tasks 2.1-2.1, UC Irvine PhD candidate, Carl Norlen, worked with previous CECS postdoc, Kyle Hemes, to finalize his manuscript on GPP recovery following fire across California. This manuscript should be ready for submission in early 2022. Carl also worked with UCI PhD student, Ved Bhoot on extending Kyle's work for predicting GPP recovery for future fires. Additionally, Carl revised and re-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). He has been updating his analysis on how wildfire recovery changes forest drought response and is working on a manuscript draft, which he aims to complete by early summer 2022.

For his literature review in collaboration with CARB, Jian completed several efforts after extracting all relevant attributes from identified articles: (1) he classified all forest management actions into 8 LANDFIRE disturbance categories: Thinning, Prescribed fire, Biological/herbicide/chemical, Harvesting, Mastication, Clearcuts, Soil amendment, and Other mechanical; (2) classified all carbon pools into 5 categories: Live aboveground carbon, Dead aboveground woody carbon, Forest floor, Mineral soil carbon, and Fine and coarse root carbon; (3) classified the years post-treatment into 3 categories: short-term (< 5 years), medium-term (>=5 & < 15 years), and long-term (>= 15 years); and (4) calculated the effect sizes by referencing treatment group mean to control group mean. The control group was defined as adjacent untreated plots if the paired-sites study design was employed, and defined as the initial

values of the same plots before forest management actions if the chronosequence design was employed.

As part of Task 2.2, UC Irvine Assistant Project Specialist, Aurora Gutierrez published her paper on fire in the Sierra Nevada (linked in the publications list in section 6 of this report). As part of a new project, she has been labeling trees dead or alive for UC Irvine PhD candidate, Nicole Hemming-Schroder's tree mortality project.

Last quarter, Jon Wang also submitted "Losses of tree cover in California driven by increasing fire disturbance and climate stress" to AGU Advances, and it is undergoing the peer review process. He has started a complementary analysis of fire spread and rangeland shrub expansion as well.

As part of Task 2.3, UC Davis PhD candidate, Yuhan Huang, developed a neural network to improve the current building footprint dataset in the wildland urban interface (WUI) using NAIP aerial imagery. This dataset was then used to augment WUI mapping every two years. The mapping techniques under this development improved the spatial details and captured temporal changes of mixed fuels with WUI areas. Following the initial analysis on building damage by wildfires, Yuhan continued to analyze the linkages among fire behavior, building patterns, and environmental conditions, and the probability of building damage in the wildland-urban interface areas.

In another aspect of task 2.3, Ved Bhoot continued to work on pixel-scale recovery of ecosystems post-fire. The forecast for the trained random forest model had been a bit delayed, as Ved runs tests and makes changes in the curve fit methodology. The trained model should be ready for the next reporting period.

Task 3

As noted in section 3 of this report, we had the soft launch of our data visualization tool, the Data Atlas, on November 16. This tool is now publicly available at https://cecs.ess.uci.edu/data-atlas/. Prior to releasing this tool, we dded the introductory "modal" window when the page loads that includes information about the application and notes on how to use it. We also added the disclaimer modal window which requires users to accept terms of use before proceeding, essentially noting that this is just a beta version of the data that will be updated in the near future, and that the data, while potentially the best available science, should not be used on its own to make important management decisions at this stage.

A major objective of this grant is to get a pilot decision support product. During Q4, CECS Director, Mike Goulden, built out much of this application infrastructure (guides, demonstrations, and documentation) to make the NCS Toolbox operational. He had immense support from PI John Battles, and Research Tech, Elliot Kuskulis, in ensuring that the Data Bridge tool in particular functions on a variety of machines, and that the instructions for using it are well documented. John and Elliot were also instrumental in building out test case examples to share with agency representatives in January.

Stakeholder Engagement Specialist, Meghan Cook, also assisted Mike in completing initial documentation for the Data Atlas and Data Bridge tool, meeting with PIs to collect information on the data and tools in the Natural Climate Solutions Toolbox and summarizing that information for use in tool documentation for users. To further our outreach and communications efforts, Meghan also posted to the project's social media (Twitter) and website blog to promote project research and publications, and interviewed a CECS researcher in preparation for an article featuring their research to be posted on the project website blog in January.

In addition to the development of these tools, and the furthering of our outreach activities, referenced in section 3 of this report, we also continued to bring together the information gathered from our previous stakeholder workshops, for social science research analysis. Data analysis is complete for a second paper on predictors of management capacity and Project Scientist, Max Eriksson, is in the process of completing a draft manuscript. Max is also working on a third paper on collaboration and partnerships between different management organizations.

Task 4

Group 4, focused on ecosystem services, continued semi-regular meetings throughout the quarter to discuss research and progress towards goals. Individual graduate students and postdoctoral researchers also made great strides in their work toward this task.

UC Irvine postdoc, Charity Nyelele, submitted her first manuscript on how machine learning offers new opportunities for mapping currently understudied cultural ecosystem services including recreation. Charity also provided values for recreational ecosystem services for incorporation into the valuation tool that is being developed by Min Gon Chung and Roger Bales. This included average $/acre of forest and annual visitation rates based on USFS National Visitor Use Monitoring Program data for each National Forest within the Tahoe Central Sierra Initiative (TCSI) boundary. Charity also worked on her second draft paper on the economic valuation of recreational ecosystem services in the TCSI area and started developing code to analyze the impact of forest management on recreational ecosystem services.

For last quarter, UC Merced PhD student, Han Guo, worked on valuation of economic benefits of additional water yield arising from proposed forest treatment activities for the Upper Yuba watershed and North Fork American watershed. He used hydropower models and marginal water prices coupled with runoff data from the Data Atlas to estimate those benefits and got some preliminary results. The results show significant water-related economic benefits per acre of treatment. He is also developing methods to estimate the avoided cost of fire risk reduction due to forest treatments, focusing on the costs of property loss and sediment accumulation by using the fire simulation results from Data Atlas coupled with sediment yield model and estimates of potential economic loss. Results from this work should be available in the coming months.

This quarter UC Merced postdoctoral researcher, Min Gon Chung, completed a manuscript entitled “Economic impacts of management activities and carbon sequestration and water production in dry forests, and plans to update his analyses when the NCS Toolbox data are updated in Q1 2022. Information on preliminary findings can be found in section 6 of this report.

In addition to building out these analyses and writing his paper, Min also developed a mock-up of a web-based decision supporting tool that estimates carbon and water values for 20 years after forest management practices in the TCSI area. Users will upload or select their own polygons of interest and input the unit values of carbon and water prices based on their local contexts. Users can choose the types of landownerships, forest management, and ecosystem services. Then tool will then estimate the annual marginal values of carbon sequestration and water production over the next two decades after the selected management practice. Additionally, users can see the list of water agencies that possibly obtain the co-benefits of management actions performed. Shiny packages in R were used to develop the web-based tool, and much of the focus for Task 4 next quarter will be on further developing and testing this application.

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

Our largest accomplishment of Q4 was the "soft release" of Data Atlas tool, which can be viewed at https://cecs.ess.uci.edu/data-atlas/. We also created the beta version of Data Bridge, which is now operational and ready to demonstrate to small groups of stakeholders starting in Q1, 2022. As part of this tool, we completed compilation and analysis of all statewide forest and fire treatment projects over the last ten years. The Data Bridge tool allows users to prescribe specific treatments that align with existing silvicultural and forest practice guidelines, making this immediately applicable for use in State planning.

For Jian Lin's complimentary work with CARB, the main deliverables included (1) a report with 11 figures and 10 tables; (2) A database containing all identified articles; (3) Excel spreadsheets recording all relevant attributes; and (4) the R code that documents the data processing and meta-analysis. Work on this aspect of the project is near complete.

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

Research findings and applications:

A group of CECS researchers including UC Irvine PhD candidate Shane Coffield, previous UC Irvine student researcher Cassandra Vo, Jim Randerson, Mike Goulden, and Jon Wang have been collaborating with scientists at the non-profit organization CarbonPlan and University of Utah on a remote-sensing based analysis of forest carbon offsets in California. They demonstrated how these new geospatial datasets can be used to compare carbon and harvest trends across California, which is useful for assessing whether offset projects are sequestering more carbon than would otherwise occur. Through their analyses they offer constructive steps forward for improving nature-based climate solutions and offset programs such as California's, which are critical for climate change mitigation. The manuscript titled "Using remote sensing to quantify the additional climate benefits of California forest carbon offsets" has been submitted to Global Change Biology. It was also presented as a poster at the AGU Fall Meeting.

In PI Yufang Jin's lab at UC Davis, the max-Ent based ignition models were finalized to estimate the spatial distribution of both human- and lightning caused ignitions at the state-wide and eco-regional scales. Results showed that the integrated models with both biophysical and anthropogenic drivers predicted well the spatial patterns of both human- and lightning-caused ignitions in statewide and sub-ecoregions of California. Model diagnostics and marginalized response curves showed that precipitation, slope, nighttime light, and road network were the most important variables for shaping human-caused ignition probability, while snow water equivalent, lightning density, and NDVI dominated the spatial patterns of lightning-caused ignition probability. The relative importance of biophysical and anthropogenic predictors differed across various sub-ecoregions. Our findings provided insights for improving localized wildfire risk and land management to reduce the ignition probability.

Min Gon Chung's study developed a new valuation tool to estimate annual marginal values of carbon sequestration and water production at each change in forest management types and landownerships. In the TCSI, results showed that clearcutting in public and private lands produced \$39,803/km^2 (\$22,733-87,003) and \$51,320/km^2 (\$34,078-124,636) of net benefits, respectively. Although clearcutting in private lands produced 73.2% more of water production values than that in public lands, private lands had 29.8% more of net benefits with larger carbon sequestration losses than public lands. In both public and private lands, the ranges of these net benefits were stable for at least 19 years

because the capacity of carbon sequestration after clearcutting were continuously recovered over time while additional water production values were reduced. Commercial thinning had quite different trends of net benefits between public and private lands. With commercial thinning, public and private lands produced \$2,824/km^2 (\$762-7,909) and \$10,593/km^2 (\$9,467-32,082) of net benefits, respectively. Private lands had 275% more of net benefits than public lands. After commercial thinning, public lands only maintained these net benefits for 12 years with low recovery rates of carbon sequestration. These numbers may change slightly, as the newest CECS data is ingested into the model in Q1 2022, but these results are promising, and we believe this tool is well suited to be applied to quantify economic benefits of management actions across the state.

Papers under review or published in Q4 (note that all publications to date can be found on the Publications page of the CECS website):

1. Eriksson, M. Safeeq, T. Pathak, B. Egoh, R. Bales. (in review) Using stakeholder-based fuzzy cognitive mapping to assess management effects on wildfire-vulnerable forests. PNAS.
2. Nyelele, C., C. Keske, M.G. Chung, B.N. Egoh. (in review) Machine learning offers opportunities for reducing uncertainty in mapping understudied cultural ecosystem services. Journal of Biogeography.
3. Sam J. A., Preisler H. K., Westerling A. L., Xu Q., Baldwin W. J. and Sleeter B. M. (in review). Estimation of Burn Severity Fractions in California. *Environmental Research Letters.*
4. Qingqing Xu, Anthony LeRoy Westerling, Andrew Notohamiprodjo, Christine Wiedinmyer, Joshua J Picotte, Sean A. Parks, Matthew D. Hurteau, Miriam E Marlier, Crystal A. Kolden, Jonathan A. Sam, W. Jonathan Baldwin, Christiana Ade. (in review). Wildfire Burn Severity and Emissions Inventory: An example implementation over California. *Environmental Research Letters.*
5. Wang, J., C. Knight, and J.B. Battles, M.L. Goulden, and J.T. Randerson. (in review) Remote sensing analysis of land cover change reveals a multi-decadal decline in California tree cover driven by increasing wildfire and drought stress. AGU Advances.
6. Coffield, S.R., C.D. Vo, J.A. Wang, M.L. Goulden, G. Badgley, D. Cullenward, J.J. Battles, W.R.L. Anderegg, and J.T. Randerson. (in review) Remote sensing-based evaluation of California's improved forest management carbon offset projects. Global Change Biology.
7. 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.*
8. Norlen CA, Goulden ML. 2021. Recent drought induced needleleaf conifer mortality episode reduces subsequent forest die-off severity. *Nature Climate Change*.
9. 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. (in review) Tracking extremes in California wildfire spread using satellite active fire detections and an object-oriented classification approach. *Scientific Data*.
10. Hantson, S., N. Andela, M.L. Goulden, J.T. Randerson. (in review) Human-ignited fires are faster, hotter, and kill more trees in California forests. *Nature Communications*.
11. Chen, B. and Y. Jin (2022). Spatial patterns and drivers for wildfire ignitions in California. *Environmental Research Letters*. (under minor revision)
12. 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
13. 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

AGU presentations:

1. Ved Bhoot, Michael Goulden, Kyle Hemes, Carl Norlen, Jonathan Wang. Can Machine Learning Predict Post-Fire Vegetation Recovery?.
2. Shane Coffield, Cassandra Vo, Jonathan Wang, William Anderegg, Michael Goulden, James Randerson. Remote sensing-based evaluation of California's forest carbon offset projects.
3. Jon Wang, James Randerson, Michael Goulden, Clarke Knight, John Battles. Time series remote sensing reveals net declines in California's tree canopy coverage driven by recent increases in wildfire and climate stress.
4. Nicole Hemming-Schroeder, Steven Allison, James Randerson. Modeling Tree Mortality in the Sierra Nevada Under Drought Conditions.
5. Yuhan Huang, Yufang Jin. Understanding the risk of building damage to wildfires at the wildland-urban interface.

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

Distributed computation was a challenge in working with the Data Bridge. We are exploring ways to make data distribution easier, less time consuming, and more streamlined. This may include moving the Data Bridge to an online server and/or having it hosted in a desktop-as-service framework. We should have a better understanding of the technical capabilities by the end of Q1 2022.

In working with ecosystem services and management actions, Max found that there's always hard trade-offs relating to the scale of analysis, and striking a balance between accuracy and generalizability has been a challenge. The open survey answers in the surveys were acronym heavy and took some time to clean for use in analysis and writeup in the paper that was just submitted.

7. 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?

The beta version of the Data Bridge tool was created this quarter, putting us in a good place to start sharing it with stakeholder groups, and essentially beginning the process of closing out the project over the next year. All items are tracking on schedule and on budget.

ADMINISTRATIVE/FISCAL OVERVIEW

8. 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 $117,178.20 in Q4, mainly on salaries and benefits for the Project Coordinator, Postdoctoral Researchers, Project Scientist, and graduate student assistance, in addition to administrative overhead.

UC Davis spent $36,105.32 in Q4, primarily on our Programmer, PI effort, and overhead.

UC Berkeley spent $1,292.45, on postdoc salary and benefits.

Stanford spent $42,987.56 on postdoc and PI salary and benefits, plus overhead.

San Diego State University spent $15,521.91 on graduate student support, PI effort, and overhead.

UC Merced invoiced for $551,590.74, which covered their work completed in Q3 and Q4, 2021, as well as Q1, 2021. This work had been accounted for in the percent complete for each Task and subtask on page 1 in previous reports, and our reimbursement amount charged to date for each of these tasks is just now starting to catch up, as we only now received these older invoices. The vast majority of these expenditures were for postdoc and PI salaries and benefits, as well as stakeholder workshops and communications.

Total project spending amounts to $764,676.19 for Q4 2021. $2,501,388.87 has been spent to date.

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

No

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.