Center for Ecosystem Climate Solutions- Year 2 Annual Report

California needs new datasets and improved decision support tools to prepare its natural lands and forests for climate change. Powered by a team of nearly 50 scientists at 8 major research institutions, with partners in state and federal agencies, nonprofits, and the private sector, the Center for Ecosystem Climate Solutions (CECS) is developing open-source, California-wide datasets and tools to support ecosystem management. Over the last year, CECS has built scientifically rigorous data products that document California's current and recent ecosystem conditions, assess ecosystem vulnerabilities, and evaluate the effects of management options on water supply, vegetation health, wildland fuels, fire hazard, and carbon stocks.

CECS has also spent much of the last year developing a suite of stakeholder-driven web tools called the CECS Ecosystem Solutions Toolbox. End-users will include decision makers and planners, land managers and owners, and researchers in agencies, NGOs and the private sector; users may work with CECS tools online or download CECS data layers to use in their preferred software or prioritization framework. These groups have been crucial to our iterations on CECS data layers and our suite of tools over this last year, and we have had dozens of listening and feedback sessions to better understand their needs and potential uses, and have tailored our datasets and tools accordingly.

In the following sections of this report you will find additional information on the buildout of our data layers, preliminary analyses, a description of our stakeholder engagement efforts, and details about progress made on the CECS Ecosystem Solutions Toolbox. We also highlight some of the challenges and opportunities we encountered in this work, how our work furthers SGC's goals and priorities, and how we plan to focus our efforts over the next year.

Research Progress

CECS has four separate but interrelated goals, as outlined in our project proposal:

1. Mapping ecosystem properties and services
2. Determining land management effects
3. Communicating and informing adaptive management
4. Valuing ecosystem services

Progress has emphasized the first three goals, though work on the fourth goal has picked up substantially in the last year. In this section we describe progress toward the objectives set for each of these four goals.

1. Mapping Ecosystem Properties and Disturbances in CA

CECS is creating new geospatial datasets that fill key gaps, including statewide maps of disturbance, water balance, vegetation stress, fuels and ignition probability. CECS tracks water, vegetation stress, fire, and carbon as a holistic web of tightly-linked ecological conditions, and quantifies ecosystem properties in transparent physical units that allow apples-to-apples comparisons across space and time. The table below summarizes the data layers that CECS has created, is in the process of creating, or will soon create. Highlight color denotes the current status of each data layer.

Datasets are 30 m rasters for all CA wildlands x 37 years x ~100 ecosystem properties. August 2021 progress: First draft complete; Developing prototype; Exploratory data analysis		
	Current and recent conditions and vulnerabilities: Annual observations for 1985-2021	**Alternative conditions and vulnerabilities: Predicted effects of management**
Ecological conditions (water, fuel, carbon pools and fluxes)	Disturbance and management history: Type (fire, die-off, management) and severity (% tree and shrub canopy removed)	Disturbance and management scenarios: Type (fire, die-off, management) and severity (% tree canopy removed x % shrub canopy removed x % surface fuel removed)
	Water pools and fluxes: Evapotranspiration, runoff, plant moisture deficit (mm yr^{-1})	Water pools and fluxes after disturbance or management: Immediate effects and over recovery trajectory
	Wild fire fuel loads: Dead and live fuel (1, 10, 100, 1000 hr., live herb, shrub, canopy, g m^{-2})	Fuel load after disturbance or management: Immediate effects and over recovery trajectory
	Carbon pools and fluxes: Stocks (leaf, wood, roots, detritus, g m^2) and fluxes (production, mortality, decomposition, g m^{-2} yr^{-1})	Carbon pools and fluxes after disturbance or management: Immediate effects and over recovery trajectory
Vulnerability and hazard (water supply, vegetation die-off, wildfire, carbon)	Water supply vulnerability: Sensitivity of water supply to drought or disturbance (change in water supply with drought or disturbance, mm yr^{-1})	Water supply vulnerability after management: Avoided water shortfall during drought, immediate and over recovery trajectory
	Vegetation vulnerability: Probability of vegetation die-off with drought (long term % yr^{-1})	Vegetation vulnerability after management: Avoided die-off, immediate and over recovery trajectory
	Wildfire hazard: Rate of spread, intensity/flame length, probability (long term % yr^{-1})	Wildfire hazard after management: Avoided fire, immediate and over recovery trajectory, Ros, intensity and probability
	Carbon vulnerability: Probability of C loss from fire or die-off (long term based on disturbance probability and effect, g yr^{-1})	Carbon vulnerability after management: Avoided carbon loss from fire or die-off, immediate and over recovery trajectory

Figure 1- This table denotes the current state of each dataset that CECS is developing. Green highlighted layers have a first draft completed, yellow highlighted layers are currently being created and tested, and orange highlighted layers are in the very early stages of development.

Producing Revised Data Layers

The State of California recently set a goal to treat 1-million acres of forestland annually by 2025 in an effort to reduce the risk of catastrophic wildfire in forests and restore valuable forestland. As part of a team interested in helping the state understand their progress towards this ambitious goal, Dr. Clarke Knight (previous CECS team member, and current Postdoctoral Researcher at the USGS) assembled an integrated dataset of California's historic forest management treatments, joining federal and state silviculture databases to provide a benchmark of monitoring progress. In addition to setting up the integrated dataset, Clarke and team checked the archival record against remotely-sensed changes in forests to create a "refined" dataset. They found that the State is currently treating about 300,000 acres annually and is thus 30% of its way to the million-acre goal. They also show how remote sensing and

archival data can complement each other in the pursuit of better forest monitoring strategies. Their case study in California has wider application in the US because the same federal tracking forest systems with the US Forest Service exist in other states. Outside of the US, their work also provides a roadmap for how to fruitfully combine aerial detection and archival data.

Testing Revised Data Layers

Collect Earth Online

Clarke also led the validation of refined historical management and disturbance layers via Collect Earth Online, a free, open source tool for landscape monitoring. It allows multiple analysts to look at plots and satellite images and answer questions pertinent to land-use change or management events that take place over time. For this project, analysts assessed data from remote sensing images and compared it to data from known historical datasets and the CCDC algorithm output for past management events. Analysts also visually compared the historical datasets, CCDC outputs, and the remote sensing images to determine how closely they match, which served as an important check on the validity of the algorithm as well as the historical datasets, which have since been updated in a second version.

Field Validation

In the past year we also expanded our understanding of chaparral carbon flux and vegetation characteristics. As one of the most distinct, yet prevalent, vegetation communities in California, our work identifies the distinctions of chaparral carbon cycling compared to forest and grassland systems. This work included completing a two-year survey of leaf-level photosynthetic measurements and microsite soil respiration, multispectral drone measurements of plant-health-indices, and continued measurement of overall carbon flux via three eddy covariance towers. These combined datasets created a holistic system for assessing climate-related stressors and tying those measurements to larger remote sensing efforts. Continued work focuses on connecting these datasets into the state-wide model of GPP and using the unique drone-based efforts to provide validation for predicted vegetation characteristics in chaparral ecosystems, coming from the CECS Ecosystem Integration Model.

Producing New Data Layers

In addition to our focus on refining historical management layers and classifying disturbance types, we identified key needs for more accurate information on surface fuels and detrital carbon stocks. Salo and others are already making a push to improve information on canopy and live fuels, and we identified the need for a parallel effort on surface fuels and dead, combustible material. Likewise, Lemma, eMapR, CARB and others are already making a push to improve information on the carbon in live biomass, and we identified the need for a parallel effort on detrital and dead carbon stocks. To accomplish this, we have built a new diagnostic model, the Ecosystem Integration Model, to derive monthly surface fuels, detrital carbon stocks and carbon and water exchanges across California since 1984. The model extends the Carnegie-Ames Stanford Approach (CASA), pioneered by CECS PI, James Randerson. The approach ingests monthly remote sensing imagery, precipitation, temperature and disturbance at 30 m resolution across the full state, which are then used to calculate monthly photosynthetic and water fluxes. These

photosynthetic rates are then fed into a biogeochemical model that predicts the surface fuels and detrital carbon stocks over time.

Michael Goulden was the main architect of this model, and spent much time over the last year refining and iterating on inputs, and producing draft data layers. As of August 2021, the program has been completed and run state-wide, and a first version of most output data layers are now complete, or otherwise prototyped. Refer to Figure 1 for details on these layers. Many layers are near ready for sharing with stakeholders and will be housed on a cloud-based download platform linked through the CECS Ecosystem Solutions Toolbox in the coming months. In the meantime, Michael and other CECS researchers are able to run ad-hoc analyses for personalized areas of interest at the request of our stakeholders.

2. Determining Management and Disturbance Effects

CECS Ecosystem Solutions Toolbox

The Toolbox will allow users to:

1. Visualize and download data: Interactive maps and downloadable data layers to explore and track conditions and the predicted impact of climate change on ecosystem benefits.
2. Identify, explore and prioritize projects: Compare effects of management alternatives (thinning, prescribed fire, etc.) on benefits and resilience pillars (water production, vegetation health, fire protection, etc.) at local (30-m pixels to inform specific projects) or regional scales (prioritize and balance portfolio of projects across a river basin or the whole state).
3. Value ecosystem services: Site-specific tools for valuation of land management outcomes.

As of September 2021, this Toolbox includes a suite of 3 different tools- the Fire Progression Visualization Tool, Carbon Vulnerability Tool, and the Ecosystem Services Mapping Tool. The first two tools are publicly available, and the latter is in a beta version, which is currently being shared with stakeholders before broader release. All tools will eventually be linked to the CECS website for public viewing and use by all interested parties.

Fire Progression Visualization Tool

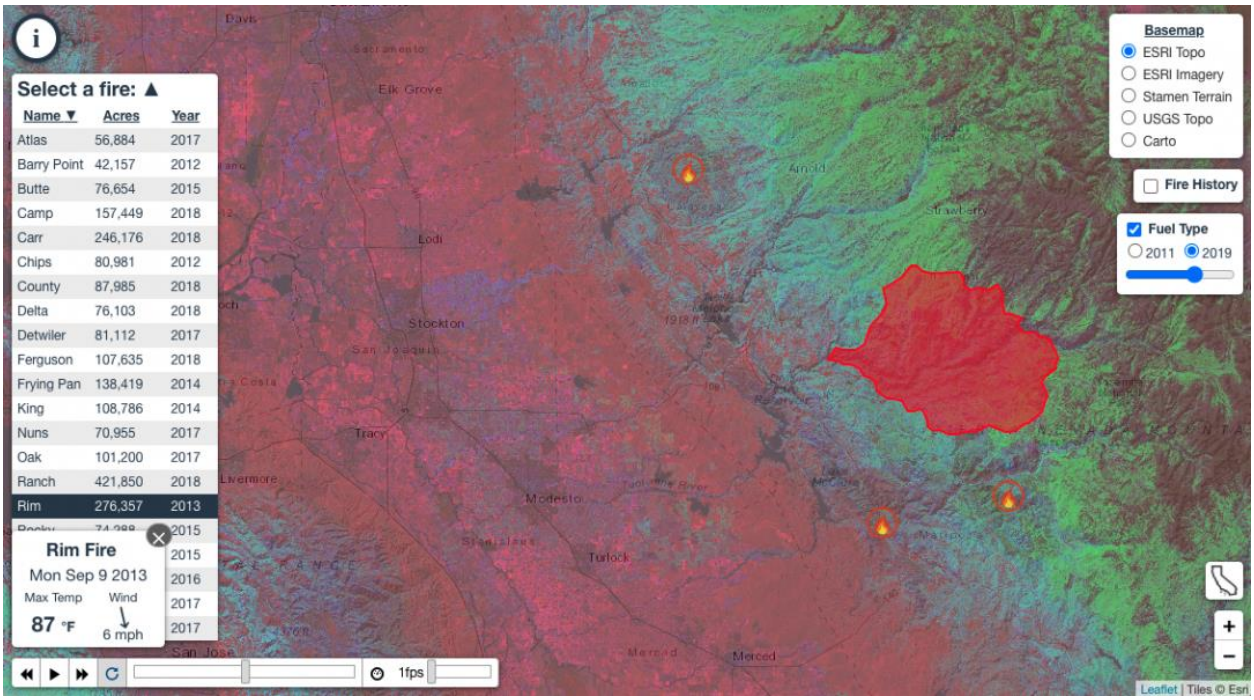

Figure 2- Fire Progression Tool interface. This screen capture shows the perimeter of the Rim fire on Monday, September 9, 2013, over the 2019 fuel type layer. Users can select any fire from the list on the left side of the screen to see the day-by-day progression, accompanied by meteorological data.

This new app, which is publicly available at https://cecs.ess.uci.edu/fire-progression/, shows daily fire spread for 32 of the largest multi-day fires in California from 2012-2020. The underlying dataset, built by UC Irvine Project Scientist Stijn Hantson, and other CECS researchers, captures daily fire spread for all large, multi-day fires in California from 2012-2020 using active fire detections from the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi-National Polar-Orbiting Partnership (S-NPP) satellite. There are 274 individual fires currently included, spanning 3984 total fire days (the sum of days with active detections for each fire). This standardized database includes both daily fire spread rate and fire radiative power, the radiative energy emitted from fire. It will be regularly updated to include more recent fire years.

The app also visualizes fuel loads for 2011 (before visualized fires) and 2019, derived from CECS Ecosystem Integration Model, an original product that integrates geospatial data on physical conditions and a diagnostic model of pools and fluxes in order to generate data on carbon pools, water balance, die-off, and surface fuels. The Ecosystem Integration Model is evolving and will be refined over time, and it will also underpin much of the broader CECS Ecosystem Solutions Toolbox.

This visualization tool and the underlying data add to our understanding not only of area burned but also fire behavior. Paired with climate data and information about a fire's cause, this data allows scientists to fill in gaps about overall ecosystem impacts of fire. For example, a team led by Stijn Hantson found that

human caused fires are exhibiting more explosive growth in the first few days after ignition than those caused by lightning, leading to higher tree mortality. This work was featured in Science magazine.

Carbon Vulnerability

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 CECS Carbon Vulnerability web tool at https://cecs.ess.uci.edu/carbon-vulnerability/.

Figure 3- 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.

Ecosystem Services Mapping Tool

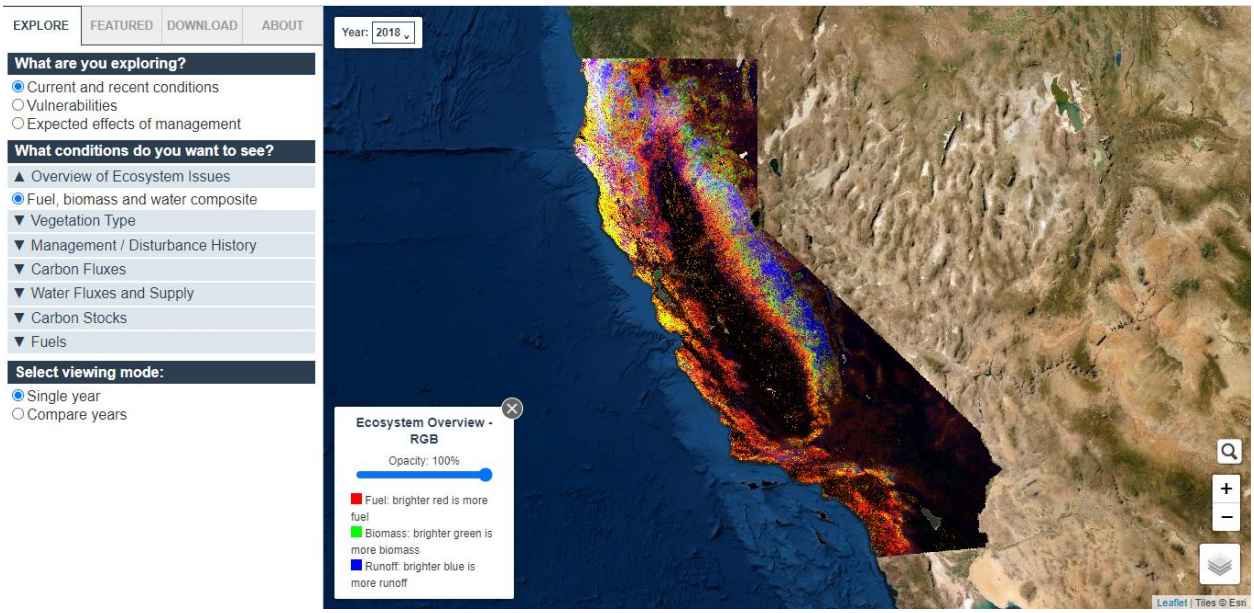

Figure 4- CECS Ecosystem Services Mapping Tool. The layer shown here is the "Fuels, biomass, and water composite" layer. This layer denotes the most important ecosystem services per geographic area, with red pixels representing areas that are important to manage for fire, green pixels representing areas that are important to manage for carbon sequestration, and blue pixels representing areas that are important to manage for water. The brighter pixels show higher ecosystem services values, whereas darker areas represent low ecosystem services values.

The Ecosystem Services Mapping Tool has been our most substantial effort to date, and encompasses many of the data layers highlighted in green in Figure 1. As of the writing of this report, the tool has 3 data themes to explore: current and recent conditions, vulnerabilities, and expected effects of management.

Within the theme of Current and recent conditions, seven sub categories exist: 1. Overview of Ecosystem Issues (shown in Figure 4); 2. Vegetation type; 3. Management / Disturbance History; 4. Carbon Fluxes; 5. Water fluxes and Supply; 6. Carbon Stocks; and, 7. Fuels. Each subcategory contains multiple years of geospatial data.

There are five active subcategories within the theme of Vulnerabilities. These include: 1. Overview of current vulnerabilities, 2. Effect of drought on tree stress; 3. Effect of drought on water supply; 4. Predicted wildfire flame length; and 5. Predicted wildfire rate of spread. In both of the drought vulnerability subcategories, the user can select different drought severity scenarios to visualize a response (i.e. tree stress or water supply).

The theme of Expected effects of management has four subcategories of data exploration: 1. Overview of effect of management; 2. Effect of management on tree stress; 3. Effect of management on water supply; 4. Effect of management on flame length; and 5. Effect of management on rate of spread. To observe scenarios of effect of management, the user selects options to describe a hypothetical % reduction in tree and/or shrub canopy. The display shows a comparison of current conditions with the simulated canopy removal for each subcategory (e.g. change in surface fuels after management).

When combined, all of these data layers provide a fairly comprehensive view of ecosystem services and management effects, all in one place. This tool can be used in powerful ways by land managers and policymakers to see the previous effects of management actions and disturbances, and to predict how similar changes to the landscape in the future may positively or negatively impact local communities and ecosystems. As we continue to share this tool with stakeholders, we will outline in more detail some of the most impactful potential uses of the tool, as well as create a comprehensive user guide.

Post-disturbance ecosystem recovery

Gross Primary Productivity (GPP)

Some components of these CECS Ecosystem Solutions Toolbox require more of a scientific understanding before we are able to generate new data. This is particularly relevant when looking at how long it takes ecosystems to recover from management and disturbance. In that vein, UCI PhD candidate Carl Norlen worked with CECS researchers Michael Goulden and Kyle Hemes over the last year to develop early parts of the Ecosystem Integration Model (EIM) using Google Earth Engine to produce monthly and annual measurements of GPP across California. Carl also worked with Michael Goulden, Jon Wang, and UCI Project Specialist Mahnoor Khan, to build the High-Performance Computing (HPC) infrastructure to be able to run the full EIM. He presented a poster at the AGU Fall Meeting 2020 based on work looking at how wildfire history affects vulnerability to forest die-off. The results will contribute to better prioritizing management to mitigate the effects of future droughts on forests.

Carl also focused on finalizing a manuscript with Kyle Hemes about GPP recovery after wildfires and a manuscript on the impact of multiple droughts on forest health and drought resistance that uses many of the CECS geospatial datasets, including ET, die-off, and precipitation. He initially submitted the multiple

drought manuscript in summer 2021. The findings should provide useful information for managers on how drought disturbance will impact future resistance to drought. Both manuscripts should be submitted or resubmitted by early October 2021.

Carbon

California has devoted tremendous efforts to conserve, restore and manage its forest lands. However, the extent to which these efforts have impacted carbon outcomes and carbon neutrality remains unclear. By utilizing and integrating forest management data and the CECS Ecosystem Integration Model outputs, UC Merced postdoc, Jian Lin, examined time-series carbon densities after forest management activities and compared the impact of forest management on carbon outcomes. The initial results show that the clearcut category (e.g., clearcut and shelterwood) results in initially greater losses of carbon and faster carbon recovery rates than the commercial (e.g., commercial thinning and sanitation salvage) and non-commercial categories (e.g., fuel break and transition). He found that convex curves (namely carbon initially recovers at a relatively stable or slightly upward trend and then increases rapidly at the later stage) generally provide a better fit than concave curves (namely carbon increases at a faster rate initially, then at a slower rate, and finally become relatively insensitive) when looking at carbon recovery, which was an unexpected result. Jian and others' analysis of post-management and post-disturbance carbon recovery will continue in the coming months.

Applying machine learning

In the past year UCI graduate student Ved Bhoot worked on identifying post-disturbance trends in recovery using previous data produced by Kyle Hemes and Carl Norlen. He used an empirical approach to fit curves on metrics of vegetation productivity such as GPP, ET, and others. These curves were then used to approximate the time when the system reaches pre-disturbance levels, also known as time to recovery. The approximated time to recovery is then used to integrate the curves to determine magnitude of ecosystem services recovered. Ved trained a random forest model on climate normals, topography, burn severity, and vegetation type of the different fires in order to predict time to recovery. He is currently working on writing code in R to run on the high-performance computing environment to extract relevant CECS data, with an overarching goal to conduct this analysis on the pixel scale. Recovery curves will be fitted to the data in each burned pixel. Once this is done, a random forest model will be trained with what will likely be a few million rows (each row indicating a pixel). The end goal is for this information to be added onto the CECS Ecosystem Solutions Toolbox for stakeholders to use to estimate a time to recovery, and recovered ecosystem services in a range of different climate and burn scenarios.

3. Communicating & Informing Adaptive Management

The overall goal of the CECS engagement strategy is to co-create transdisciplinary knowledge with diverse stakeholders across the state. Our approach recognizes that integrating science and management is an iterative, multi-directional process, involving stakeholders throughout.

Engagement within the second year of the project centers around three linked efforts: 1.) stakeholder workshops 2.) collaborations with agencies, organizations, and parallel projects, and 3.) broader communications and sharing of CECS data and tools.

Needs Assessment Survey and Stakeholder Workshops

The CECS outreach team engaged with 32 representatives at over 25 agencies, nonprofits, local collaboratives, and private companies for participation in interactive virtual workshops, hosted by our previous Stakeholder Engagement Specialist, Jaquelyn Lugg, and UC Merced Assistant Project Scientist, Max Eriksson. Workshops were held in November, 2020 - January, 2021 and consisted of each participant drawing two cognitive maps: one of weighted connections between ecosystem services, and another of weighted impacts of management actions on ecosystem services. These cognitive maps were then aggregated and analyzed, as well as with other interested stakeholders.

Workshop participants included individuals from the following organizations:

- Blue Forest Conservation
- Board of Forestry and Fire Protection
- Burney Basin Fire Safe Council
- Butte County Fire Safe Council
- Butte County RCD
- CAL FIRE
- California Trails Conference
- California Wilderness Coalition
- California Air Resources Board
- Central Valley Water Board
- Environmental Defense Fund
- Falls River RCD
- Feather River RCD
- Latino Outdoors
- McMullin Area Groundwater Sustainability Agency
- Nevada Irrigation District
- Rabobank
- River Ridge Institute
- San Gabriel and Lower Los Angeles Rivers and Mountains Conservancy
- Sierra Forest Legacy
- Sierra Institute for Community and Environment
- Sierra Nevada Alliance
- Sonoma County Water Authority
- Tuolumne River Trust
- USFS Region 5

Stakeholder Survey and Workshop Findings:

As noted in previous reports, the stakeholder needs assessment survey (conducted in summer/fall 2020) 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 professionals believe the risk of negative natural events, such as wildfires and droughts, are likely to increase in the future.

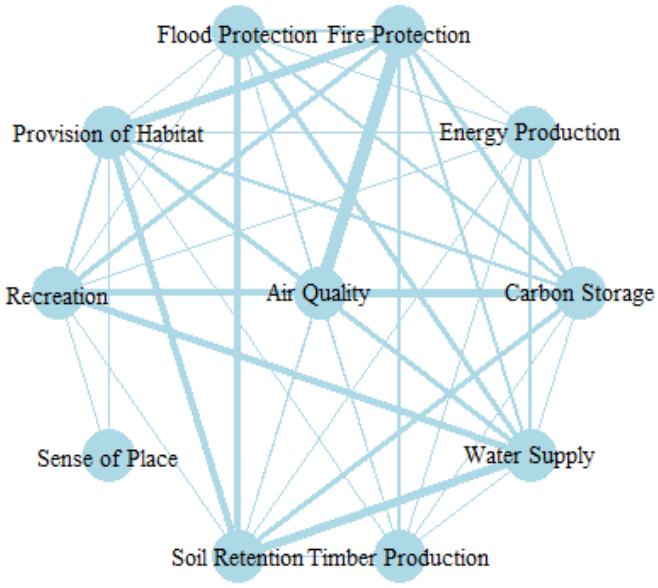

Figure 5- In this graph, line thickness illustrates the absolute strength of the relationship between services, as noted by workshop participants. Notable ties among fire protection, air quality and provision of habitat; water supply and soil retention, and carbon storage and air quality.

Adding to this, our workshop data clearly show the importance of accounting for interaction between ecosystem services when evaluating benefits or costs, as seen in Figure 5. We found 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, are 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 workshops 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 and workshop respondents to ensure the relevance of our final products via feedback sessions focused on the content and functionality of the CECS Ecosystem Solutions Toolbox.

Active Engagement

All of CECS data layers and tools have been created with stakeholders in mind, and groups ranging from regional collaboratives, State and federal agencies, nonprofits, and other research consortia have been involved in their development and refinement. We further outline our engagement with these groups, below.

Outreach to Regional, State, and Federal Agencies

On January 15, 2021 CECS hosted an external project review, engaging 11 individuals representing the CA Forest Management Task Force, CAL FIRE, California Natural Resources Agency (CNRA), the National Parks Service, the 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 this 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 and areas to focus on moving forward. Panelist feedback was very valuable, and we have incorporated this feedback into our research, as well as into the Beta version of the decision support tool.

We have continued to collaborate with all of the above agencies in the last few months, and have found their partnerships beneficial. We learned of several additional historic datasets from CAL FIRE that we were able to incorporate into our analyses, supported the CNRA-led AB 2551 project through a series of calls, and learned more about the ForSys model and USFS's prioritization framework, which has informed our work.

As rapid progress has been made on the CECS Ecosystem Solutions Toolbox, we have begun to hold in-depth discussions about the tool, including demonstrating functionality and gathering feedback on desired improvements. In summer 2020 we engaged with the USDA NRCS California Office, the North Coast Resource Partnership (NCRP), and Siskiyou County in such demonstrations and discussions. We also provided NRCS with a crosswalk table outlining the ways that our data layers align with several of their Resource Concerns.

After UC Davis PI Yufang Jin presented at the North Coast Resources Partnership prioritization meeting in July, we deepened our collaboration with NCRP and Siskiyou County Supervisors and have since shared some of the water and expected effects of management data with them at the HUC level for their watersheds of interest; they are the first group to test out our data, and we will continue to collaborate with them to provide data and analyses and inform planning and policy.

Leveraging Other Projects Funded by Other Sources

When we started to develop the CECS Ecosystem Solutions Toolbox we met with folks from Pyregence, Salo, and EMapR to gain additional insights into user experience and also on hosting and delivering such

large datasets in real-time and sharing best practices. Their experience in creating their own tools and data was invaluable. We also continued to interact with these and other groups during and after the 2nd Annual Statewide Forest Science Research Coordination, hosted by CNRA, SGC, and Governor's Forest Management Task Force in January, 2021. All attendees from CECS benefited in learning from other related efforts across the state, and engaging with colleagues in meaningful discussion during breakout sessions and in follow-up calls.

Of the projects listed above, we have continued to collaborate most closely with Pyregence, and shared our fuels data with them to test out and add to their tool, in return for them sharing their fire spread model with us.

Nonprofit Partnerships

We have also continued our close collaboration with Blue Forest Conservation, as work on the development of ecosystem service and multi-benefit framework has progressed, and a paper was nearly finalized. They have actively participated in beta testing of our tools, and continue to be a strong and reliable partner.

We have continued to collaborate with The Nature Conservancy as well, especially in their work on the TCSI Project. While all benefited from hearing about this project on an all-project call in Fall 2020, CECS researchers who are focused on ecosystem services and valuation were able to take some parts of the TCSI project as a model for which to frame their analyses, and collaboration has been ongoing.

Internship Program

The 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 CECS Ecosystem 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 our project's 2nd Annual Meeting in August 2021 to a virtual audience of over 30 individuals.

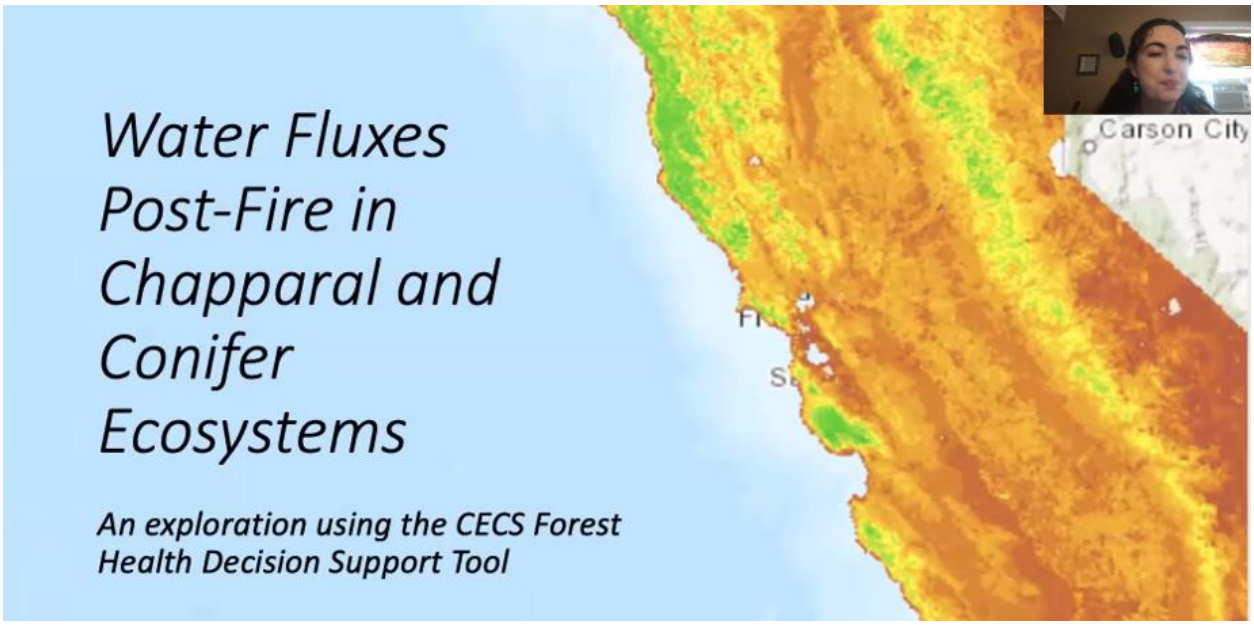

Figure 6- One of our summer interns, Claire Tauber, presenting her findings on the impacts of fire on several data layers in the CECS Ecosystem Solutions Toolbox during our 2nd Annual Meeting.

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.

Communications

Website

The CECS website (https://california-ecosystem-climate.solutions/) was revised in early 2021 to create an easier-to-use interface for site visitors to navigate through. The website highlights our two tools that are publicly available - the CECS Fire Progression Tool and the CECS Carbon Vulnerability Tool, speaks to recent research findings and other project news in our News & Communications page, and houses previous project reports and freely-available CECS peer-reviewed articles for people to explore. The aim of these routine posts on the News and Communications section of the website, which will continue for the duration of the project, is to tell the story of our science in an accessible way and provide continued opportunities for stakeholders to see the impact and applicability of CECS projects.

Videos

In early 2021 we completed and distributed two video clips focused on ecosystem restoration, in partnership with our nonprofit film partner, The Chronicles Group. These clips are part of a larger film, called California's Watershed: Healing, which is being produced by The Chronicles Group and serves as a sequel to California's Watershed: Beyond the Brink, which debuted in early 2020. The goal is for this video to be shared with wider audiences via PBS and similar freely-available public channels, where any interested individuals can learn more about CECS and related projects' work in California.

Newsletter

The CECS team created a quarterly newsletter to update any and all interested stakeholders, with the first edition sent via email, and posted online in October 2020. Anyone interested in receiving project updates can sign up for the newsletter here.

4. Valuing Ecosystem Services

The CECS team is developing tools for valuing ecosystem services to overcome information roadblocks to monetizing the benefits of restoration and apportioning benefits. The focus is on carbon, water, and wildfire risk reduction, further extending to air quality, public health, and local community benefits.

These valuation tools can be leveraged to support partnerships and agreements on a project-by-project basis; to motivate project investments from the different beneficiaries; and to accelerate the pace and scale of much needed restoration.

The ecosystem services and valuation portion of the project has received increased focus in the past year, with substantial progress on a valuation framework. A perspective paper was nearly completed, in collaboration with CECS partner, Blue Forest Conservation. 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.

UC Merced postdoc, Min Gon Chung, started to perform analyses to examine changes in forest biomass, evapotranspiration (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 code relies on the CECS 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. He has also begun to integrate his biophysical analyses with valuations tools for changes in values of carbon stocks and water diversion with forest restoration activities.

Meanwhile, UC Irvine postdoc Charity Nyelele focused on recreation to develop methods of quantifying visitation, a proxy of recreational amenity, using crowdsourced Flickr data, machine learning techniques and publicly available geospatial datasets. Additionally, she applied the travel cost method using the Flickr visitation data to estimate the monetary value of recreational visits to the TCSI, our case study site. Charity also considered benefit transfer methods that can be applied to explore the range of values associated with recreation in the area and started looking at the management layers developed by Clarke to tease out the impact of different management approaches on recreational visits. She has begun to draft manuscripts on this work.

These analyses will continue to evolve as more data becomes available from the CECS Ecosystem Integration Model output. As valuation methods are refined, they will also be integrated into a new sub-tool of the CECS Ecosystem Solutions Toolbox.

Challenges & Solutions

Overall, the project is on track and doing well. While the COVID-19 pandemic did slow progress on the hiring of new team members in the last year, we did eventually fill the positions, and work has gotten back on track. We did have two key researchers move on to other roles in the last year as well, but our team has come together to pick up the extra work and analyses. Our team is strong, and our resolve to get the work done and make a positive impact is even stronger.

Work is now progressing rapidly, but at the same time, we are planning strategically for the last year of the project to ensure that we wrap up our data and tools on time and on budget.

Summary of Work Toward Priorities & Goals

Our project emphasizes the following SGC Priority Research Areas: 1.) Supporting and protecting vulnerable communities from the impacts of climate change.; 3.) Integrating land use, conservation, and management into California's climate change programs.; and 4.) Increasing data accessibility and planning support for local and regional climate change planning. Our work meets several of the SGC's threshold requirements, including clear ties to state climate mitigation goals, filling gaps across current State research programs by working in close conjunction with current agency initiatives, meaningfully engaging stakeholders throughout the entire project lifecycle, and leveraging and complementing existing research funding to accelerate climate change research, innovation, and policy and technology development and Adoption. In collaborating with State and federal agencies as well as nonprofit institutions, we are addressing the critical science bottlenecks, and adapting our work to better suit the needs of people who will utilize it to further climate policy and innovation.

Over the past 12 months, we have engaged our partners in every phase of our work, from ecosystem network mapping workshops, to focused group discussions of what would be most helpful in the decision support tools, to feedback calls and countless messages to share our beta version of the CECS Ecosystem Solutions Toolbox and accompanying underlying CECS-created datasets. These formal workshops and informal calls and messages ensure stakeholder input and feedback will be made a priority in our analyses and the further refinement of the beta version of CECS Ecosystem Solutions Toolbox interface and functionality. Ultimately, our research and tool, when combined and synchronized with other efforts currently underway, will increase data accessibility, helping decision makers to create policies and programs to protect California's ecosystems and people from the detrimental effects of climate change, including communities that are particularly vulnerable.

Next Steps

The next few months of the project will focus on the completion of version 1 of the few remaining data layers we hope to add to the CECS Ecosystem Solutions Toolbox, as well as the further refinement (and version 2) of layers created to date. This refinement will be informed by stakeholders starting to use our tools and data products. The Beta version of both data layers and tool interface will continue to be shared with agencies and other partner organizations for feedback so we can do just that. Analyses will continue, and the ecosystem services and valuation portion of the project will be further built out.

We will deepen our outreach efforts with stakeholders, focusing on interactive workshops and in-depth interviews regarding the tool and its underlying layers. Integrated with the results from the survey and previous workshops, the outcomes of these continued engagement activities will inform the design and content of the final CECS Ecosystem Solutions Toolbox, which should be released in Spring 2022. We will also continue our email newsletter and social media presence to provide stakeholders updates about the project, more opportunities to connect with our team and test our suite of tools, and reports on project findings.

We are strategically planning for the project closeout in the next year, and to deliver practical and useful tools to stakeholders. Progress will continue to be shared with SGC and other partners and stakeholders for continued feedback and evaluation, which will help to improve the quality of our final suite of tools, and extend the potential for their adoption and impact.