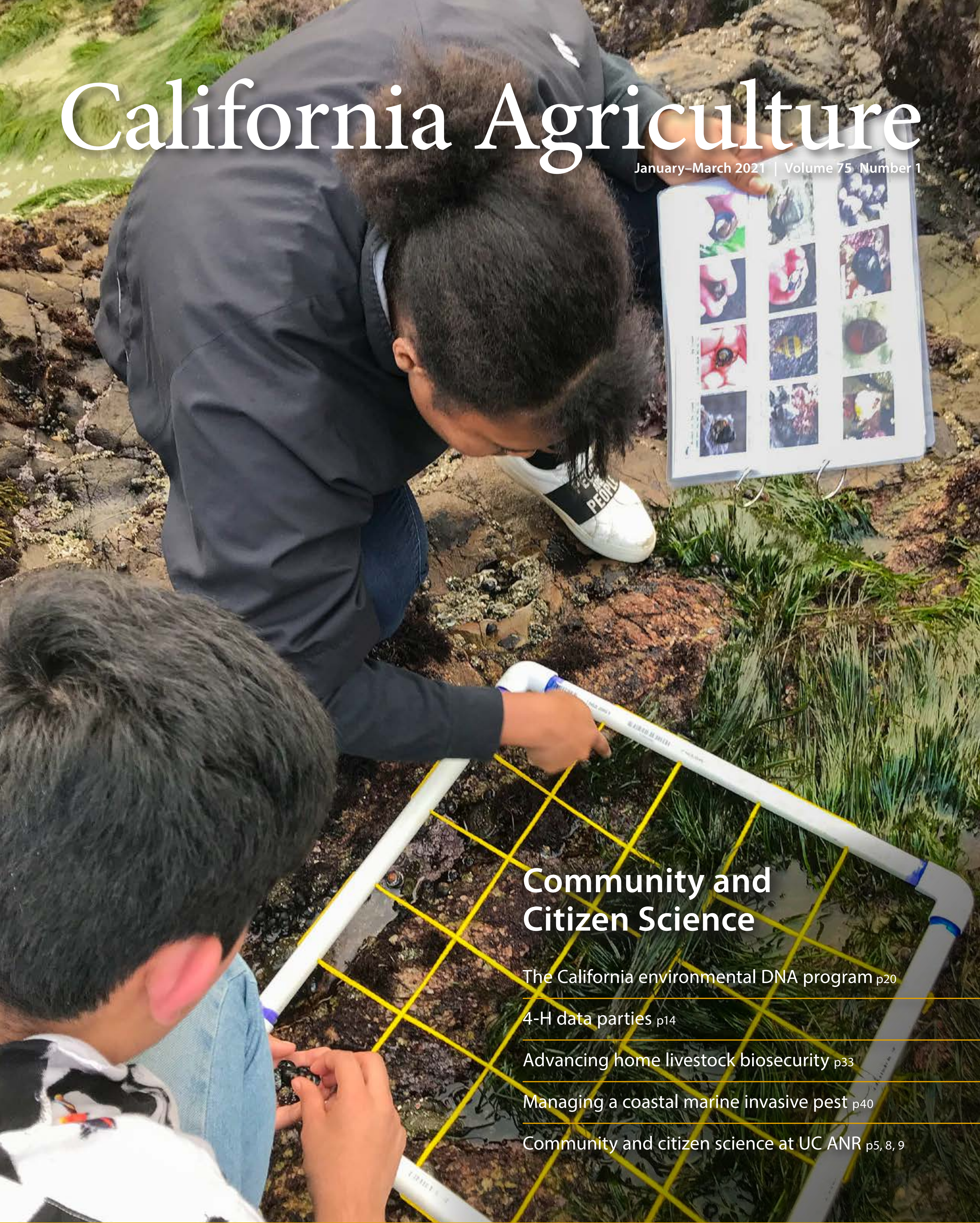

California Agriculture

January–March 2021 | Volume 75 Number 1

Community and Citizen Science

University of California | Peer-reviewed Research and News in Agricultural, Natural and Human Resources

California Agriculture

Peer-reviewed research and news published by University of California Agriculture and Natural Resources

ORDERS AND SUBSCRIPTIONS
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California Agriculture (ISSN 0008-0845, print, linking; ISSN 2160-8091, online) is published quarterly. Postmaster: Send change of address "Form 3579" to *California Agriculture* at the address above.

California Agriculture is a quarterly, open-access, peer-reviewed research journal. It has been published continuously since 1946 by University of California Agriculture and Natural Resources (UC ANR). There are about 10,000 print subscribers.

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Authors. Most authors (75%) are among the roughly 1,000 academics affiliated with UC ANR, including UC Cooperative Extension specialists, advisors and academic coordinators; and faculty in the following UC colleges: UC Berkeley College of Natural Resources, UC Davis College of Agriculture and Environmental Sciences, UC Davis School of Veterinary Medicine, and UC Riverside College of Natural and Agricultural Sciences. Submissions are welcome from researchers based at government agencies and at other campuses and research institutes.

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Agriculture and Natural Resources

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COVER: Students at the Pacific Grove Museum of Natural History (a California Naturalist Partner) participating in a coastal LiMPETS (Long-term Monitoring Program and Experiential Training for Students) survey.
Photo by Pacific Grove Museum of Natural History.

EDITORIAL

Community and citizen science: Inviting the public into UC ANR research

by Glenda Humiston

Online: https://doi.org/10.3733/ca.2021a0008

Community and citizen science (CCS) is an exciting approach to enhance research activities while also expanding community engagement. It advances the work of professional scientists, engages and educates amateur scientists and benefits society by reducing scientific illiteracy — all while creating greater awareness of the crucial work that the University of California and other research institutions perform.

Glenda Humiston, Vice President, UC ANR

This issue of *California Agriculture* reports on a variety of research projects that might never have happened without the involvement of community and citizen scientists. For example, in a project described by Grosholz et al. (page 40, this issue), community scientists working in a Marin County lagoon have helped control populations of the European green crab, an invasive species whose effects on native shellfish are devastating. The community scientists, working on the project for nearly a decade now, have collected data from a large network of crab traps and in some cases have allowed researchers access to private property. Their monitoring work has enabled scientists to develop crab management strategies that have reduced the crabs' population by 70% to 80%. According to researchers, maintaining European green crab populations at this level will, over time, allow for restoration of the lagoon habitat and allow native species to return to abundance. Perhaps most impressively, this ongoing project is now managed almost entirely by community volunteers.

The relationship between professional scientists and community scientists, however, is a two-way street. Because CCS projects allow ordinary people to get their hands dirty in scientific research and begin to understand how science really works, volunteers gain a deeper understanding of the world around them and the specific conditions that exist in their own communities. Often, projects lead to concrete improvements in communities, with longstanding local problems resolved or remediated thanks to knowledge gained from CCS projects — just as in the example above.

But CCS can confer benefits across the whole of society. In the United States, scientific illiteracy is an ever-growing problem with frightening consequences. Take climate change, where public skepticism toward scientific realities can hinder policy responses and individual action to confront perhaps the most pressing problem that humanity will face over the coming decades. Vaccines, which stand among science's greatest achievements, often encounter public resistance — an especially disturbing response during a global pandemic.

Overcoming scientific illiteracy is a wide-ranging challenge that will require an array of responses, but CCS can be an important piece of the solution. For example, children participating in CCS projects can gain respect for the rigorous work that science professionals practice every day. But CCS's potential for overcoming scientific illiteracy isn't limited to kids — adults can also participate in CCS to learn about the world, do science and become better-informed, more-involved community members.

For UC Agriculture and Natural Resources, CCS is a natural fit. UC ANR's mission is to connect the University of California — and the science practiced throughout the UC system — with the people of the state. With UC Cooperative Extension academics and staff working in every California county, UC ANR is well-positioned to broaden the scope and impact of CCS across the state, conferring benefits on scientists, amateur researchers and broader communities. Established and trusted programs, including UC Master Gardener Program, UC California Naturalist and 4-H, provide ideal vehicles for CCS. By helping community members develop research skills and experience, CCS fosters an appreciation for the scientific process, building scientific literacy and public support for research. Come join us in a CCS project in your community! CA

INTRODUCTION

Special issue: Community and citizen science

In this special issue, *California Agriculture* presents research and news on community and citizen science projects across California.

by Ryan Meyer, Sabrina Drill and Christopher Jadallah

Online: https://doi.org/10.3733/ca.2021a0003

In this special issue of *California Agriculture*, we explore diverse examples of science at UC Agriculture and Natural Resources (UC ANR) that have involved participation by people not typically expected to play a role in the research process. They might be school-age youth, clientele of UC ANR advisors, volunteers in programs such as the UC Master Gardener Program or the UC California Naturalist Program, or simply interested or concerned members of the public. We refer to this idea of scientific research conducted, in whole or in part, by amateur or nonprofessional scientists as community and citizen science (CCS). There are many other terms for it (see Eitzel et al. 2017) — such as public participation in scientific research, volunteer monitoring, crowd-sourced science, or participatory action research — emanating from various natural and social science disciplines. CCS projects can take many forms, as demonstrated by the many examples throughout this special issue. They can advance scientific research and monitoring in a variety of ways, build trust among the collaborators and create opportunities for outreach, education, stewardship and mutual understanding.

The traditions of Cooperative Extension overlap significantly with CCS. Cooperative Extension was founded with a mission to "to aid in diffusing among the people of the United States useful and practical information on subjects relating to agriculture and home economics, and to encourage the application of the same" (Conglose 2000). But translating information into a particular context often requires collaboration and a two-way flow of knowledge (Cash 2001). From the very beginning, expertise held by farmers and others in the agricultural system has played an important (if not always explicitly recognized) role in Cooperative Extension research and engagement. In the years since its founding, Cooperative Extension has grown to encompass a much wider variety of stakeholders and communities, accompanied by many new ways of working together through "learning partnerships" (Conglose 2000). This diversity of collaborative forms in Cooperative Extension mirrors what we see in the broader field of CCS, and each can enrich the other.

While the idea is not new (Miller-Rushing et al. 2012), in recent years CCS has become increasingly recognized as a valid scientific methodology, pedagogical strategy and capacity-building approach. The field is evolving as both a subject of research and an area of scientific practice (Tauginienė et al. 2020). It was called out as an interagency priority in recent Congressional legislation (American Innovation and Competitiveness Act 2017), and there is now a federal interagency

Participants in the Friends of the Dunes California Naturalist certification course learn about dune ecosystem stewardship in Humboldt County. Researchers have found that community and citizen science projects can improve research outcomes and benefit participants through deepened learning.

Friends of the Dunes

community of practice. Scholarly publications focused on CCS have increased significantly in recent years with many journals dedicating special issues to the topic, and a new journal for the field — *Citizen Science: Theory and Practice* — recently established. Several new professional associations have been formed, including the Citizen Science Association, which attracts hundreds of scholars and practitioners to its biannual meetings. Many other professional associations — such as the American Geophysical Union, Ecological Society of America, Society for Conservation Biology and the American Association for the Advancement of Science — have begun to focus on CCS in their publications and conferences.

The burgeoning enthusiasm for CCS stems in part from the many different goals and benefits that it can advance. With CCS approaches, public engagement and collaboration are not secondary concerns; they are central to the research. When scientists work with volunteers in collecting data or crowdsourcing data analysis, for example, they are producing scientific knowledge in a traditional sense, while learning from and responding to one another in the collaborative process. A scientist co-creating a project in response to a set of community priorities and questions may still publish novel findings, while at the same time building a research agenda that is responsive to real, urgent, societal needs, and inclusive of the community that motivates that agenda. Researchers are finding that CCS can genuinely improve research outcomes (Cooper et al. 2014; McKinley et al. 2015; Merenlender et al. 2016; Parrish et al. 2018; Theobald et al. 2015), while benefiting individual participants through deepened learning (Ballard et al. 2018; Bonney et al. 2009; NASEM 2018; Phillips et al. 2019), and leading to progress on community and environmental issues (Aceves-Bueno et al. 2015; Dosemagen and Gehrke 2017; McKinley et al. 2015).

California Naturalists in-training learn how to monitor water quality in the Los Angeles River Recreation Zone. Community and citizen science projects can take many forms, from app-based crowd-sourcing projects to community-led monitoring, or co-created projects with private landowners.

Mountains Recreation and Conservation Authority

The CCS projects described in the research papers for this special issue represent a similar range of motivations and outcomes.

Grosholz et al. (this issue, page 40) describe an ongoing project that tightly integrates invasive species science and environmental restoration work and shows how CCS can support environmental education and community-level capacity building through the research process. Volunteers from the local community have played many different roles in this project, from data collection to communication and ongoing management of the restoration program in Seadrift Lagoon in Northern California.

CCS can also serve as a framework for youth education, while linking directly with action at the community level. Smith et al. (page 33) describe a youth participatory action research (YPAR) project, based in the California 4-H Youth Development Program, in which youth designed and led research and risk assessment focused on zoonotic diseases. They used the results of their scientific work to advocate for changes, in some cases leading directly to improvements in biosecurity at county fairs.

Sometimes traditional collaborative activities at UC ANR are enriched and expanded through the introduction of CCS approaches. Bird et al. (page 14) describe their early experiences with participatory evaluation, in which the insights from program evaluation are enriched through collaboration with volunteers.

While CCS is often community-based or highly localized, other cases illustrate how it can be employed to conduct research at broader spatial and temporal scales. The CALeDNA project (Meyer et al., page 20), for example, has garnered contributions from people throughout California. In this example of crowd-sourced data collection, project leaders are also engaging volunteers in dialogue about how to deploy eDNA methods, thus bringing a wider set of perspectives to bear on debates over a new and potentially very powerful form of scientific monitoring.

The contributions from these authors and the other brief examples highlighted in the following pages (Crowder, 9–13) point to a perhaps-unsurprising fact: UC ANR is home to a rich and diverse array of CCS projects and programs, which engage many different audiences in many kinds of activities. The examples show teams leveraging approaches from CCS, such as app-based crowd-sourcing and YPAR. The many different structures can engage many different kinds of audiences across California.

CCS can also help with a variety of problems that pervade our mosaic of public and private lands in California. Helping to build a broader understanding of the conservation of flora and fauna on private lands is one example. In urban areas, small private lots are generally inaccessible to researchers. Inviting residents to collect and share data has revolutionized the study of urban biodiversity (Li et al. 2019). In rural areas, large private property owners have long collaborated with

Cooperative Extension researchers, but the opportunity for landowners to engage directly in data collection can enrich the relationship. The UC Statewide Integrated Pest Management Program has recruited citizens to monitor the distribution of and damage from invasive species that do not recognize property lines. Invasive shothole borer monitoring is a valuable example of work in urban areas (Crowder, page 12).

UC ANR provides a uniquely rich context for conducting research using CCS approaches. Because UC ANR is present in every county in the state, from urban centers to rural communities, it is well-positioned to engage Californians in science. UC ANR programs build human capital that can expand what's possible in CCS. The large corps of trained and dedicated volunteers — in the UC Master Gardener, UC California Naturalist, and California 4-H Youth Development programs in particular — is a ready crew of community members primed to engage in the work of CCS. When urgent data needs emerge, for example in response to pollution concerns related to wildfires (Crowder, page 11), networks of trained UC ANR volunteers have been an invaluable resource. We explore this reciprocal dynamic — CCS approaches as a boon to UC ANR, and UC ANR as a rich context for CCS — to greater depth in a report prepared for UC ANR leadership (Meyer and Drill 2019), and summarized in our article on page 8 of this issue.

We close this introduction with a final note about terminology. We have chosen the broad umbrella term of community and citizen science both here and in the aforementioned report, while recognizing that different forms of CCS stem from a variety of different traditions (Ottinger 2017), and every term has strengths and flaws (Eitzel et al. 2017). For example, some find the word "citizen" problematic for potentially implying that only legal citizens can contribute to science (e.g., Angulo 2020). Others draw clear boundaries around "community science" as an approach driven by community knowledge and priorities, as opposed to the interests of scientists (e.g., Pandya 2019). Rather than dictate a single term, in our editorial process we have encouraged authors in this special issue to use the term that works for them and their collaborators, while being very clear about the reasoning behind that choice.

We hope that you will see in this special issue the many ways that CCS is advancing UC ANR's mission of "serving California through the creation, development and application of knowledge in agricultural, natural and human resources." Collaboration with communities through CCS gives us the potential to co-create useful knowledge, support communities with the power to successfully apply it, and build capacity for stewarding our state's resources. CA

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NEWS

Report: Assessing community and citizen science at UC ANR

The authors uncovered a rich diversity of projects that engage Californians in UC ANR research, and a variety of challenges and opportunities for expanding this work.

by Ryan Meyer and Sabrina Drill

Online: https://doi.org/10.3733/ca.2021a0004

A recent report, prepared for UC Agriculture and Natural Resources (UC ANR) by the UC Davis Center for Community and Citizen Science, explores the many ways that the Cooperative Extension system in California is engaging the public in research, and the opportunities this represents. Community and citizen science (CCS), which refers to science conducted, in whole or in part, by amateur or nonprofessional scientists, is a diverse and growing field of research and practice. CCS projects can take many forms, from app-based crowd-sourcing projects to community-led monitoring, or co-created projects with private landowners (see articles throughout this special issue).

Why examine CCS at UC ANR?

The scale of statewide Cooperative Extension systems, combined with their long history of collaborating with clientele communities, presents a unique opportunity. What can citizen science practitioners and Cooperative Extension programs learn from one another? What unique citizen science opportunities exist in the Cooperative Extension context? How are our notions of citizen and community science challenged by the diverse examples playing out in Cooperative Extension? Over more than a century, the Cooperative Extension programs of land-grant universities have been connecting farmers and a wide variety of other clientele communities with university-based research. Today, Cooperative Extension's public engagement efforts take a variety of forms, many of which fall within contemporary definitions of CCS.

We set out to examine the particular strengths of CCS at UC ANR, while also identifying gaps and challenges. We conducted interviews and a short survey, reviewed program documents, and engaged in a variety of informal interactions with UC ANR personnel, including a symposium at UC ANR's statewide meeting.

A rich diversity of projects and potential

Our results show that there are many different ways in which UC ANR can foster, benefit from and promote innovations in CCS. We identified a wide range of projects underway across the state. Some are community-driven, while others are led by researchers. Some are open to the public, while others target specific groups of collaborators such as high school students or cattle ranchers. In some cases, CCS projects at UC ANR directly serve the interests of a UC researcher, while in other cases the organization is building capacity that others outside the system can leverage for CCS activities. The diversity of motivations, approaches and outcomes of CCS at UC ANR mirrors the evolution of the CCS field, globally. With that diversity and rapid-paced development comes a variety of tensions related to definitions, values, perceived credibility and professional recognition.

We also found some unique advantages for CCS at UC ANR. The organization's ability to form and maintain statewide networks of volunteers (e.g., through the California 4-H Youth Development, UC Master Gardener and UC California Naturalist programs) presents a particularly important and valuable opportunity for UC ANR, and indeed for the state — one that remains relatively underutilized beyond the county scale. We also found that CCS at UC ANR can create feedback loops with other kinds of engagement within research and outreach work, such as education and outreach or traditional clientele input. Finally, we identified a need for more data about participation in CCS projects at UC ANR, which could improve understanding of how these projects address access and equity in UC ANR programs, and how they are helping to expand and deepen engagement throughout California.

A vision for CCS at UC ANR

We believe the results of this work are cause for celebration of the thriving ecosystem of CCS approaches and projects already underway at UC ANR, but more can be done. Recommendations in our report aim to help to build a sense of cohesion around CCS as a concept, without limiting diversity and creativity, through, for example, opportunities for training and exchange, and capacity building for successful projects.

Our vision for CCS at UC ANR looks towards a future where:

1. Opportunities to participate in UC ANR research are more pervasively available, equitable and impactful throughout California.
2. UC researchers who want to engage communities in their work can gain skills and access support structures for doing this effectively.
3. CCS networks at UC ANR are providing a unique statewide resource to researchers, state and federal agencies, and others striving to understand and address large-scale environmental challenges.
4. CCS is expanding awareness of, and appreciation for, the role of UC ANR in California's environment, economy and communities.

We are excited to be able to offer UC ANR leadership a variety of recommended actions to achieve that vision. The full report can be found at https://education.ucdavis.edu/ccs-cooperative-extension. CA

NEWS

Community and citizen science projects around UC ANR

What do coyotes, eggs and leafy greens have in common? They're all subjects of UC ANR research projects to which everyday Californians have contributed.

Online: https://doi.org/10.3733/ca.2021a0002

UC Agriculture and Natural Resources (UC ANR), as an organization that has connected the people of California to UC research for over a century, is very well positioned to take advantage of emerging trends in scientist–community collaborations. The paragraphs below describe innovative projects that UC ANR personnel have developed, just in the last few years, to serve the public good by involving community members in the work that UC ANR does every day.

Caching coyotes

Coyotes eat cats. Humans disapprove of coyotes eating cats. They also react poorly when coyotes attack dogs. They're very, very opposed to coyotes biting humans.

These interactions, along with some milder variants, can be classified as coyote conflicts. In much of Southern California, coyote conflicts — or coyote encounters, in any event — are just a fact of life.

Until recently, however, coyote encounters were mostly a matter of hearsay and Facebook posts. "There was no general effort to collect information about coyote encounters," says Niamh Quinn, a UC Cooperative Extension (UCCE) Human-Wildlife Interactions Advisor at the South Coast Research and Extension Center in Irvine. Because data on coyote encounters was never aggregated, municipal officials struggled to develop coyote management strategies. And this information gap was the impetus for Quinn to develop a community science project known as Coyote Cacher.

Three elements comprise Coyote Cacher. One is an online reporting system that allows residents to report coyote encounters. Another is an alert system that informs residents of coyote encounters within their zip codes. The last is a "back door" that allows municipal managers to view and act on information about coyote encounters. Since the program went live in 2017, the system has logged more than 9,000 coyote sightings or pet encounters — including 936 reports of attacks on pets.

But what actually happens when municipal officials learn of coyote conflicts? Does the Coyote Cacher enable coyote catching?

A young coyote at South Coast Research and Extension Center. A community science project in Southern California called Coyote Cacher allows residents to report coyote encounters and receive alerts of coyote encounters in their zip codes.


Niamh Quinn

Not really. Quinn reports that cities use the Cacher more to manage citizens than to manage coyotes. That is, if coyotes have been particularly active in a specific area, a municipality might send residents an alert along with their utility bills. When people know that coyotes frequent their neighborhoods, they'll more likely take concrete steps to protect their pets. "Coyote Cacher is sort of an Amber alert for pets," Quinn says.

The Coyote Cacher is a fairly easy project to manage — the community scientists who report encounters need no training at all. They just go to a website and fill in fields, providing as much or as little detail as they like. This all-are-welcome approach doesn't necessarily provide Quinn (or municipal managers) with perfect data about coyote hot spots. Instead, it might better reflect reporting hot spots, with volume of reports correlated to community enthusiasm. Still, it serves its purpose as a tool that lets "citizens help cities help citizens."

The technical aspects of the Coyote Cacher tool were developed by a UC ANR statewide program known as the Informatics and GIS Program (IGIS), where GIS stands for geographic information systems. Quinn reports that "I just had the idea. IGIS said 'Let's make this happen.' They did a great job."

Tracking local fire danger

Live fuel moisture is a measure of water content in green vegetation. When live fuel moisture in California becomes critically low, the state's fire season has reached its peak. Natural landscapes — and homes nearby — face a higher risk of fire.

A volunteer samples big-pod ceanothus (*Ceanothus megacarpus*) for a community science project that measures live fuel moisture.

Fire agencies have measured live fuel moisture for decades. They do so by snipping bits of live vegetation, transporting them in airtight containers to laboratories, weighing them, drying them in an oven until they are bone-dry and then weighing them again. The difference between the two weight measurements allows a calculation of live fuel moisture. These calculations help agencies decide where to put the arrow on the Smokey Bear fire danger sign.

But according to Max Moritz — a UCCE Wildfire Specialist, and an adjunct professor at UC Santa Barbara's Bren School of Environmental Science and Management — the information that the agencies produce isn't easy to find unless you already know where to look. And it won't tell you much about fire danger in your immediate vicinity unless you live right where fuels were sampled.

In Moritz's own Santa Barbara County, for example, the U.S. Forest Service regularly measures live fuel moisture — but not in the wildland–urban interface, where most people live. So it occurred to Moritz, at the time teaching a California Naturalist course at the Santa Barbara Botanic Garden, that he could help close this data gap if he recruited students to participate in a community science project. Volunteers were then taken to nearby sites and taught what sort of vegetation to snip (small twigs only, with no fruit or flower). After the samples were dried and weighed, the results began to be published on the Botanic Garden's website. The program Moritz helped establish is, to his knowledge, the first community science program in existence that focuses on live fuel moisture.

The next step he envisions is to disseminate information about live fuel moisture more broadly, perhaps in a local newspaper, and pair the moisture readings with specific, timely information about steps that homeowners should take right away to protect their lives and property. Also, he hopes to help people start their own monitoring programs around the state. "We could really scale it up if we had the right partners," Moritz says.

Eggs and fire

If you asked people to name adjectives that describe chicken eggs, you'd probably hear lots of responses like "fragile," "oval" and "delicious." You'd talk to quite a few people before anyone said "toxic."

But in 2018, when fires raged across much of California, it became reasonable to wonder if urban fires, which can produce smoke laden with fire retardants and heavy metals, could produce toxicity in eggs laid by backyard hens. So Maurice Pitesky — a UCCE Assistant Specialist in Poultry Health and Food Safety Epidemiology at the UC Davis School of Veterinary Medicine — decided, along with colleagues, to conduct a community science project in which owners of backyard chicken flocks would provide egg samples for laboratory analysis. The specific research focus was to better understand the spatial relationship between toxic eggs and fire.

The team recruited flock owners to participate through UC ANR's social media channels and by relying on information they had gathered from an earlier geo-survey of California's backyard poultry flocks (the geo-survey was itself a community science project). They got strong responses from Ventura and Sonoma counties (among other areas) because fires had recently occurred there — and because Sonoma County, in particular, has "a thriving backyard chicken scene." It's a great example of local interest in an important issue driving local participation in relevant community science. It also shows how an existing network of social media and past participants can be crucial to a rapid response investigation. Community scientists sent their batches of eggs to the researchers, who in turn homogenized each batch and sent it off for laboratory analysis.

Encouragingly, they found no relationship between proximity to fire and presence of toxic materials in eggs. They found, however, that 8% of backyard flocks produced eggs with concerning levels of lead. But these higher lead levels were not associated with fire. Instead, they were associated with how long ago homes had been painted and how close they were situated to oil refineries. (The project received $10,000 in UC ANR funding, as well as some funds from the U.S. Department of Agriculture's Center for Food Animal Health.)

Community science projects have kept Pitesky busy in recent years. In addition to the egg study and the geo-survey, he has also conducted a community science project on antimocrobial resistance in California's backyard chickens, aiming to learn whether levels of antimicrobials are different in backyard versus commercial chicken flocks. Results of that study are not yet available, as the coronavirus pandemic has slowed down the testing process.

Fire and leafy greens

Wildfire smoke always poses health risks, especially for children, pregnant women and people with health problems such as diabetes and cardio-respiratory conditions. But when fires blazed across more than 160,000 acres of the wine country in 2017, they burned more than vegetation — they also burned over 6,500 structures. When smoke contains toxic materials that might be found in structures — heavy metals like lead, chemicals like PCBs and various petroleum products — the smoke becomes more dangerous to inhale. But inhalation isn't the only means by which contaminants can enter the body. So in Sonoma County, with its many home gardens and its thriving agricultural sector, many wondered if locally grown produce was safe to eat amid and after the fires.

No body of research existed to answer that question. So Mimi Enright — Program Manager for the UC Master Gardener Program of Sonoma County — quickly organized, along with colleagues, a community science project that involved collecting fresh produce and sending it off to laboratories for contaminant testing. They began training volunteers, many of them Master Gardeners, while the fires were still burning. Once the volunteers had been trained in how to gather and freeze washed and unwashed samples of leafy greens, they collected more than 200 samples from about 30 sites across the county — mostly home and community gardens. In 2018, in an extension of the research, they returned to the same sites to take soil samples. (The founding members of the project, along with Enright, were Julia Van Soelen Kim, a UCCE North Bay Food Systems Advisor; Suzi Grady, Executive Director of Petaluma Bounty; and Vanessa Raditz, who had just completed her Master of Public Health degree at UC Berkeley when the project was initiated and is now pursuing a doctorate at the University of Georgia.)

Their research indicates — good news — that fire-related contaminants in produce are a matter of low concern. The research also indicates that contamination in soil after urban fire seems a matter of low concern, though more research is needed. Nonetheless, the researchers encourage growers in their area to protect their lungs during future fires (for example, by wearing appropriate masks). They recommend that everyone eating fire-affected produce wash it with running water, peel outer leaves from produce if ash if visible and take extra precautions for children, elders or people with respiratory or heart disease.

The community science project was funded by a $10,000 UC ANR Opportunity Grant and later by a grant from the Bay Area Air Quality Management District. The funding allowed the researchers to test

To find whether urban fires could produce toxicity in eggs laid by backyard hens, UCCE Assistant Specialist Maurice Pitesky and his colleagues conducted a community science project in which owners of backyard chicken flocks provided egg samples for laboratory analysis.

When UC Cooperative Extension researchers realized the invasive shot borer was spreading too quickly for a single group of scientists to track, they developed a community science project to train community members in identifying signs of beetle damage.

samples, test hypotheses and generate a report — and also to develop a toolkit that other communities can use to conduct similar research when they are affected by wildfire in the future. In October 2020, the researchers hosted a workshop on post-fire soil safety. Most impressively, the researchers began building a knowledge base around an important, little-studied topic.

Bad beetles

Invasive shot hole borers, small but troublesome beetles, were first observed in Southern California in 2010. Unfortunately for trees (and all who rely on them), these insects carry a fungus that causes Fusarium dieback, a disease that disrupts water movement in trees and eventually kills them. According to Sabrina Drill, a UCCE Natural Resources Advisor in Los Angeles and Ventura counties, the invasive shot hole borer attacks an enormous variety of tree hosts — including native California trees like riparian willows and common street trees like sycamores.

When Drill and UCCE Specialist Akif Eskalen realized that the borer was spreading too quickly and broadly for any single group of scientists to track it, they developed a plan to monitor the insect's spread with the help of volunteers from the UC Master Gardener program and with funding support from the U.S. Forest Service and the Thelma Hansen Trust. Drill and colleagues trained the volunteers to identify signs of the pest. Volunteers then chose areas to monitor, made multiple visits to those locations and uploaded photos to an online survey that Drill had created. Drill reports that, in the first season of observations, just one previously unknown infestation was discovered — good news in itself, though "a little disappointing for a scientist."

Then Drill left for sabbatical. In stepped Beatriz Nobua-Behrmann, the new UCCE Urban Forestry and Natural Resources Advisor in Orange and Los Angeles counties, who decided to introduce some refinements to the project. For one thing, she recruited volunteers from UC ANR's California Naturalist program to supplement the Master Gardener volunteers, and introduced a new online reporting system based on iNaturalist, a platform that California Naturalists are already accustomed to using.

Beyond that, she decided to assess the accuracy of community scientists' identifications of invasive shot hole borers. Identifying the signs and symptoms of invasive shot hole borer infestation isn't easy, she says — even professionals get confused sometimes. So she designed a pilot project, now getting under way, in which participants complete a series of online trainings in identification, and Nobua-Behrmann and her colleagues double-check those identifications themselves. Her plan is to scale up the project once she understands what community scientists are good at identifying and not so good at identifying.

The pilot project, focused for the time being on Orange and Los Angeles counties, will continue at least until the middle of 2021 and, Nobua-Behrmann hopes, beyond. Once Covid-19 is a thing of the past, in-person training will supplant online training, presumably leading to better data quality. And 4-H students might get involved in identification of invasive shot hole borers — not necessarily for purposes of data aggregation, but to provide the young folks experience and education.

Young researchers

Cultivating Youth Scientists with Participatory Action Research is an out-of-school-time program that serves primarily Latino students at two high schools in Sonoma County — the program is delivered in Spanish at one school — as well as at a middle school and a high school in Humboldt County. The foundation of the program is a youth development approach called youth participatory action research (YPAR). In YPAR programs, the idea is that youth can be empowered by conducting research projects. They choose topics on their own, design and conduct their own research and, based on their findings, plan projects to improve their communities or their own lives. Adults provide guidance and facilitation.

Steven Worker is a 4-H Youth Development Advisor in Marin, Sonoma and Napa counties who, along with colleagues, oversees the program. "It's our own spin on YPAR," he says. Worker reports that the program differs from traditional community science projects in that participants don't gather data for scientists. But it qualifies as civic science insofar as it engages young people to perform research themselves (with a twist — they use their research as the basis for concrete action in the world around them). At a Sonoma County high school, participants decided to research the factors that trigger racial bias and then searched for ways to minimize racism's negative impact in their community. At the Humboldt County middle school, participants, dissatisfied with the quality of cafeteria fare, researched why schools serve "fake food" and tried to develop ways for cafeterias to increase the availability of fresh food.

Last spring, the coronavirus pandemic interrupted the program — and the students' research. Worker and his colleagues are preparing to conduct the project virtually this year. Meanwhile, Worker reports that conversations to expand the project to other counties are under way.

UC ANR has provided $194,000 in grant funding for implementation of the program. CA

— Lucien Crowder

Fifth-graders at a food tasting event. Youth Participatory Action Research programs empower youth to choose topics on their own, design and conduct their own research and plan projects to improve their communities.

Jackie Williams, Borrego Springs Elementary School

155,486

4-H youth engage in Healthy Living, STEM & Agriculture, Civic Engagement, and Leadership activities

6,154

UC Master Gardener volunteers gave 539,325 hours to make home and community gardens more sustainable

CALIFORNIA NATURALIST

3,490

Certified California Naturalists provided 46,740 hours of volunteer service in environmental stewardship

9 RECS

Research and Extension Centers discovering new ways to safeguard an abundant and healthy food supply

290

UC Cooperative Extension Advisors and Specialists living and working in local communities

UC CE

In **58** California counties

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RESEARCH ARTICLE

Data parties engage 4-H volunteers in data interpretation, strengthening camp programs and evaluation process

A practice associated with citizen science allows 4-H stakeholders to better engage in program evaluation.

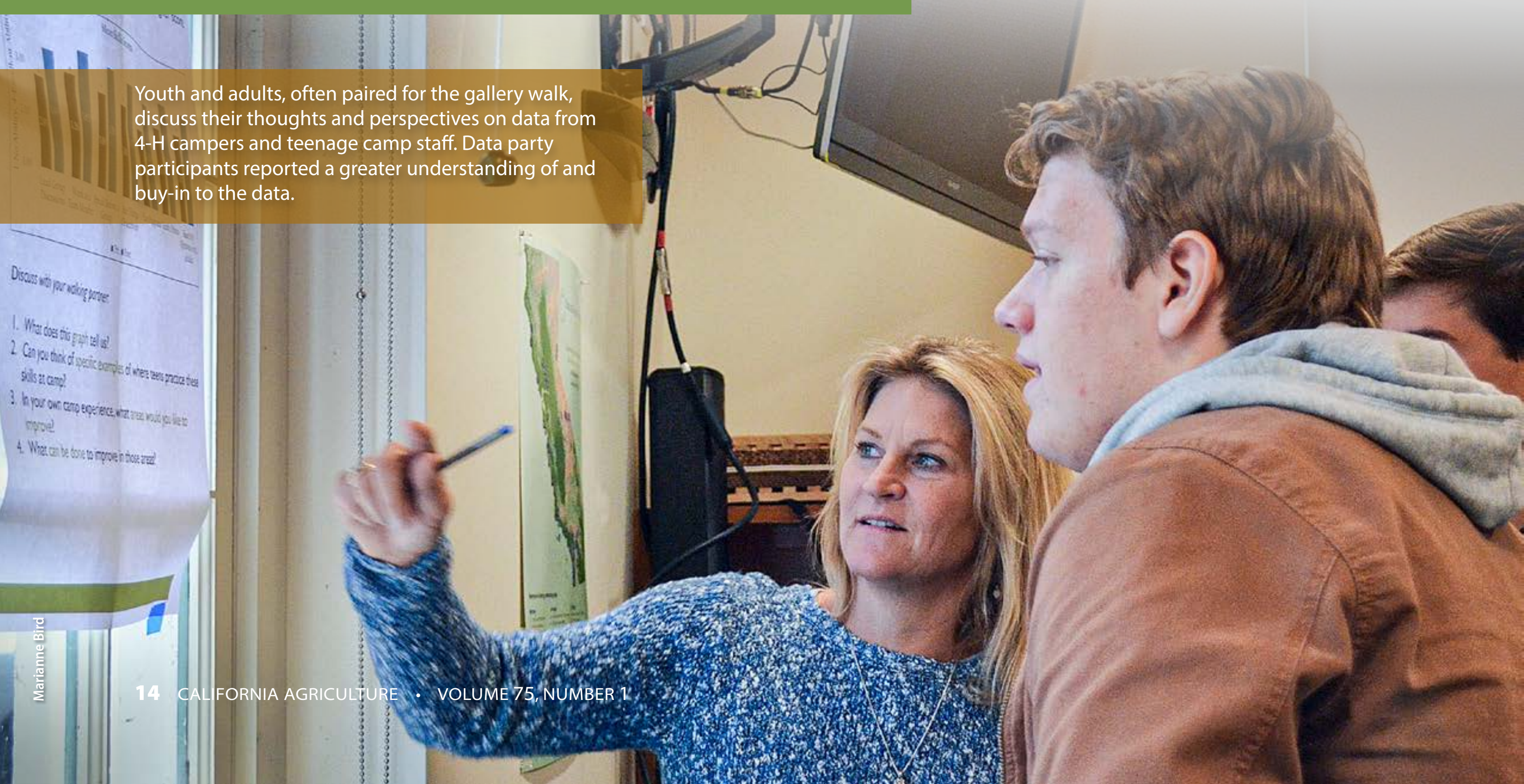
by Marianne Bird and Kendra M. Lewis

Online: https://doi.org/10.3733/ca.2021a0005

Abstract

Participatory evaluation is a form of citizen science that brings program stakeholders into partnership with researchers to increase the understanding and value that evaluation provides. For the last four years, 4-H volunteers and staff have joined academics to assess the impact of the California 4-H camping program on youth and teen leaders in areas such as responsibility, confidence and leadership. Volunteers and nonacademic staff in the field informed the design of this multiyear impact study, collected data and engaged in data interpretation through "data parties." In a follow-up evaluation of the data parties, we found that those who participated reported deeper understanding of and buy-in to the data. Participants also provided the research team insights into findings. By detailing the California 4-H Camp Evaluation case study, this paper describes the mutual benefits that accrue to researchers and volunteers when, through data parties, they investigate findings together.

The public can participate to varying degrees and in varying ways in citizen science research. The definition of *citizen science* is multifaceted and in a state of flux (Eitzel et al. 2017), but here in the United States — especially in the field of ecology — we often think of citizen science as a practice in which people contribute observations or efforts to the scientific work of professional scientists, especially as a way to expand data collection (Bonney et al. 2009; Shirk et al. 2012). Shirk et al. (2012) define "public participation in scientific research" as "intentional collaborations in which members of the public engage in the process of research to generate new science-based knowledge." They present models that outline various degrees and types of citizen involvement in the scientific process. As most broadly defined, citizen science includes "projects in which volunteers partner with scientists to answer real-world questions" (Cornell Lab of Ornithology 2019). When we think of citizen science in this context — as



Youth and adults, often paired for the gallery walk, discuss their thoughts and perspectives on data from 4-H campers and teenage camp staff. Data party participants reported a greater understanding of and buy-in to the data.

Marianne Bird

community members and scientists working together to answer questions of mutual interest — we see its application not only in the physical sciences but in the social sciences as well.

Participatory evaluation — the broad focus of this research — is, by definition, a type of citizen science. In participatory evaluation, researchers collaborate with individuals who have a vested interest in the program or project being evaluated (Cousins and Whitmore 1998); such individuals can include staff, participants, organizations and funders. Participatory evaluation is beneficial not only for community members and stakeholders but researchers as well (see Flicker 2008 for an example of benefits to all involved in participatory work). Engaging stakeholders in evaluation data can be difficult, yet we know that understanding and utilizing data are critical to improving program outcomes and practices. Evaluation is useful only insofar as it is understood, embraced and acted upon by those who can affect what happens in a program. This paper describes evaluation of the California 4-H Youth Development Program's (California 4-H) statewide camp evaluation and the use of data parties — a participatory evaluation strategy — as a means of engaging stakeholders (staff members, along with teen and adult volunteers) in data analysis and camp improvement. It explores outcomes and potential impacts when researchers partner with volunteers to better understand the statewide 4-H camp program.

Involving stakeholders in program evaluation entails multiple challenges, potentially including participants' lack of interest or their belief that they are ill-equipped to analyze or interpret data. Participatory evaluation involves stakeholders in a meaningful way, such that they are included in the research and evaluation either from the start or at various points throughout the process (Cousins and Whitmore 1998; Patton 2008). By its nature, Cooperative Extension research lends itself well to participatory research; it is amenable to creating an environment in which stakeholder voices help guide the research process (Ashton et al. 2010; Franz 2013; Havercamp et al. 2003; Tritz 2014).

Data parties are a form of participatory evaluation that focuses on the data analysis and interpretation portion of the research process (Lewis et al. 2019). A data party gathers stakeholders to analyze or interpret collected data, or both (Franz 2013). Though data parties are not a new idea, few articles have reported the benefits and outcomes of such events. Based on our own data parties, participants have found them to be a valuable tool that "breaks down" data into manageable pieces of information and allows stakeholders to process the evaluation findings to generate ideas for program improvement (Lewis et al. 2019). For participants, data parties can create a sense of ownership regarding both the data and the process (Fetterman 2001). Benefits also accrue to the researchers as they engage stakeholders in data interpretation, though these benefits are less documented.

Interpreting data through a data party

California 4-H annually hosts approximately 25 resident camps, each five to seven days long. The camps are locally administered by volunteers and planned and delivered by teenagers. In 2016, California 4-H began the process of evaluating the statewide 4-H camp program to measure youth outcomes and improve camp programs.

Marianne Bird

Camps sent teams of three to six people to the data parties. All were leaders in their camp programs, yet brought differing perspectives as adult volunteer directors, teen leaders or 4-H professional staff. Here, members of a team create their camp improvement plan.

The California 4-H evaluation coordinator (one of this paper's authors) approached the 4-H Camping Advisory Committee — composed of UC academics, staff, 4-H volunteers and teenagers — to design and implement a statewide evaluation of the 4-H camping program. The committee identified outcomes to measure, including outcomes for campers (generally ages 9–13) and teen staff (ages 14–18). The evaluator, working in partnership with the committee, developed two youth surveys to measure the identified outcomes. One survey, which focused on both campers and teen staff, measured confidence, responsibility, friendship skills and affinity for nature. A second survey, focusing on teen staff, assessed leadership skills and youth-adult partnership. See Lewis et al. (2018) for details on the development of these tools. The 4-H Camping Advisory Committee and the evaluation coordinator realized that it would be important to share the evaluation results with the camps involved in the study and therefore decided to conduct data parties. The UC Davis Institutional Review Board approved the evaluation.

Participants

Nine 4-H camps participated in the statewide evaluation during the summer of 2016 and 12 camps did so in 2017. Two daylong data parties were held, one in each study year, after the conclusion of the camp season. We invited all camps included in the study to the sessions, emphasizing that individuals in key leadership roles (for example, adult camp administrators, youth directors and 4-H professional staff) should attend. Seven of the nine camps participated in the first data party and five of 12 participated in the second (table 1). Though the individuals who attended were engaged in participatory evaluation, we use the term *participants* to refer to stakeholders with leadership roles at camps and *evaluator* to refer to the person or persons who took the lead on data analysis and developing the tools for the data party.

TABLE 1. Participation in California 4-H camping evaluation data parties by study year

Study year	No. of camps in study	No. of camps represented at data party	No. of participants at data party	Role at camp		
				Staff	Volunteer	Youth
Summer 2016	9	7	24	8	10	6
Summer 2017	12	5	19	5	9	5

Format of data parties

A data party can consist of multiple activities and tools — such as a gallery walk, data place mats and data dashboards (see Lewis et al. 2019 for examples). At the data parties described in this research, we presented data derived from surveys in an accessible format, creating a series of posters and place mats that each contained a digestible amount of information on a particular topic, such as mean difference between campers and teen leaders on target outcomes; gender differences; or before-and-after differences in teen leadership skills. Each data-party day included the following activities:

- A Gallery Walk in which pairs of participants from different camps viewed eight to 10 posters that featured statewide data. Participants then discussed their observations about the data and the patterns they recognized in it. Figures 1 and 2 show example posters.

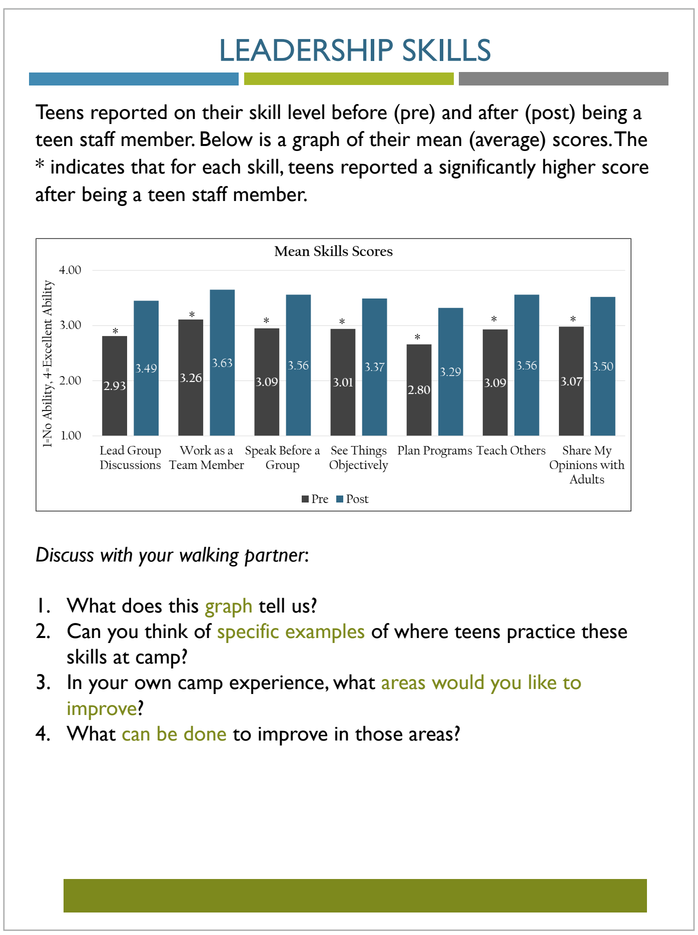


FIG. 1. Example data party poster

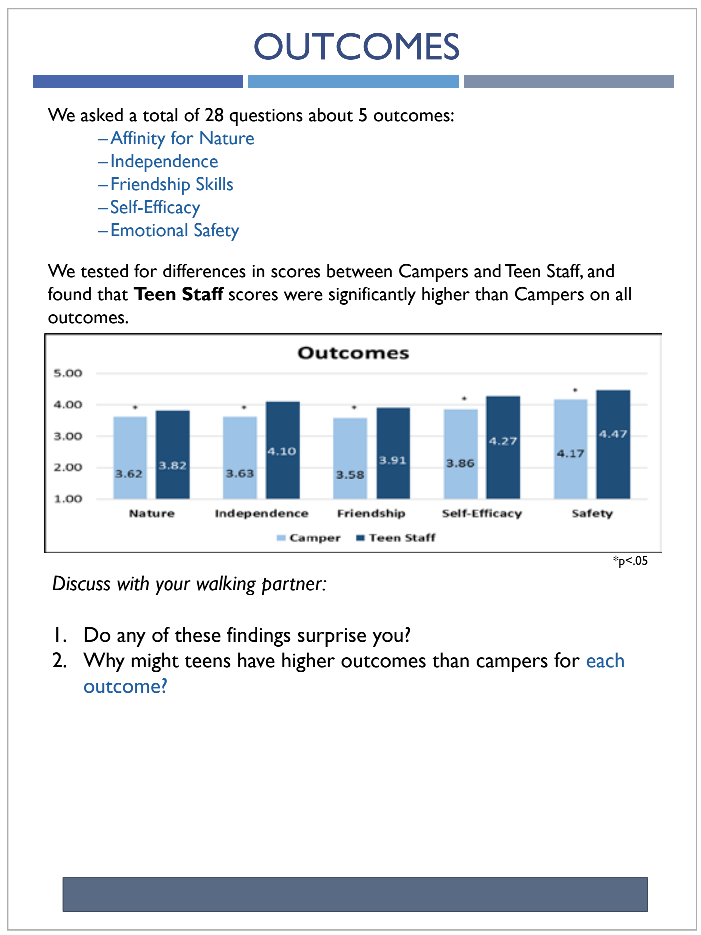


FIG. 2. Example data party poster.

- Review of data place mats, which contained graphs and qualitative word clouds that represented survey responses for individual camps in the study; afterward, participants shared reflections on the place mats with participants from their own camps and other camps. Figure 3 shows an example of a data place mat.
- Introduction of tools to share survey findings. These tools helped participants clarify how they intended to share findings, and with whom.

Participant assessment

We administered online follow-up surveys of all data-party participants nine months after the 2017 data session and 18 months after the 2016 session. Through open-ended questions, we asked participants what insights they had gained from the analysis session and how they had utilized data and learnings. Nine data-party participants completed the survey; three had attended the 2016 session only, two had attended the 2017 session only and four had attended both. Three were adult volunteers and six were professional staff. Using a five-point Likert scale, participants rated the usefulness of various data-sharing strategies, and also rated their understanding and ownership of findings and their ability to communicate findings. A copy of the assessment is in the online technical appendix.

The participant experience

Participants provided positive reports on the data party, with 100 percent of respondents saying they had gained new insights through the sessions. The majority agreed that the process led to greater understanding of the camp data and, ultimately, improvements in their camp programs (see fig. 4).

Researchers noted high levels of engagement among participants as they explored data within and across different camps. Participants asked questions, readily contributed to the facilitated discussions and were curious to know why their camps may have scored higher or lower than other camps on specific measures. Investigating the data brought to light issues in their programs that they hadn't considered and produced ideas about how to strengthen the programs. Survey responses verify these observations:

> *"It was interesting to see the remarks by the teens and campers. I think those remarks gave a lot of insight into how they see camp, and that in turn sparked ideas."*

> *"The affinity-for-nature scale helped me to think about how to better support our 4-H camps with environmental education."*

Participants cited various ways in which they utilized the findings presented at the data parties. These included modifying staff training, sharing findings with camp staff or 4-H management boards and making specific programmatic improvements, as cited below:

> *"Comments in regards to nature were especially helpful when planning our camp program this year. In training, it was helpful to see where teen staff needed support as well as putting a name to some of the skills we taught."*

> *"We discussed [our camp's data] with our county management board and with our camp staff. It gave our camp greater importance to board members who don't value camp. We looked at things we needed to focus on when planning our camp."*

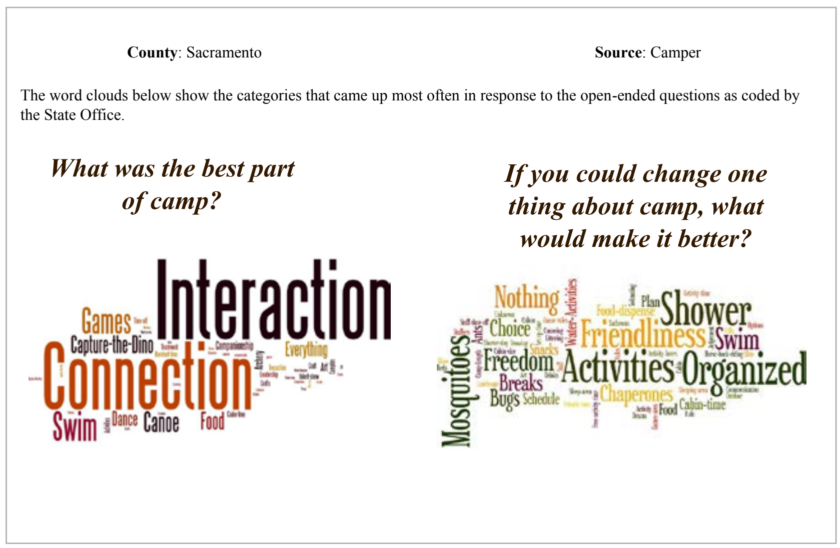


FIG. 3. Example data party place mat.

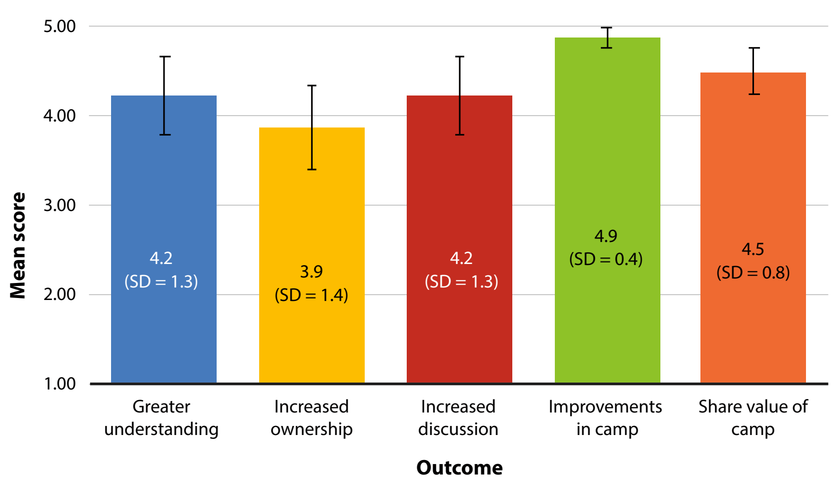


FIG. 4. Outcomes of the data-party experience as reported by participants. Scale is: (1) strongly disagree, (2) somewhat disagree, (3) neither agree nor disagree, (4) somewhat agree and (5) strongly agree. A copy of the assessment is in the online technical appendix. SD = standard deviation, bars represent standard errors.

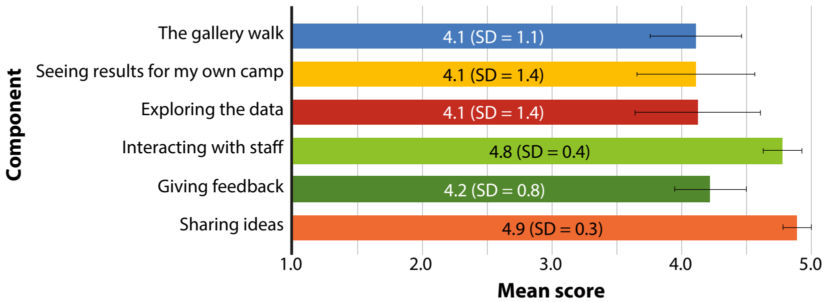


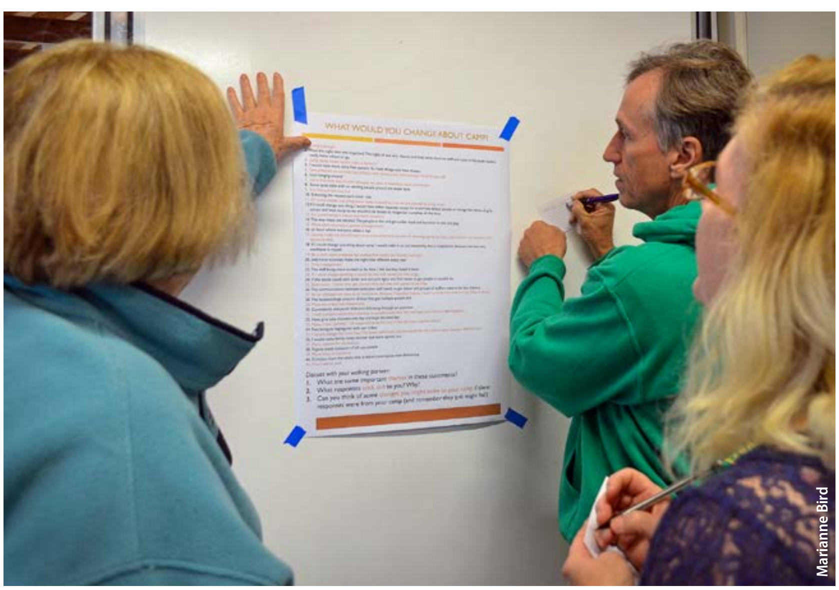
FIG. 5. Usefulness ratings of data-party components as reported by participants (n = 9). Scale is: (1) not at all useful (2), slightly useful, (3) moderately useful, (4) very useful and (5) extremely useful. A copy of the assessment is in the appendix. SD = standard deviation, bars represent standard errors.

Participants valued interactions with 4-H academics knowledgeable about the data, as well as interactions with peers (see fig. 5). As the comments below demonstrate, they derived considerable benefit from interactions with others whose camps were part of the study.

"We received valuable feedback from not just the data, but from dialogue with other 4-H camp program leaders. It helps to keep us focused on what will make our camp program the best it can be."

"It was helpful to see that other camps struggle in some of the same areas as our camp. Some examples are: working with diversity and inclusion of all, and outdoor education."

Two-thirds of respondents indicated that their camps had created plans for improvement based on the data. Almost all strongly agreed that the data had led to improvements in their programs.



Participants explore a series of posters that present statewide camp evaluation findings on a Gallery Walk. Group work is central to the data party, and participants value investigating and discussing data and generating ideas with peers and 4-H staff.

Benefits for camps and researchers

A main focus of participatory evaluation is that, when stakeholders become involved in the evaluation process, they perceive greater relevance in and take greater ownership of evaluations, making them more useful to those involved with the program (Cousins and Whitmore 1998; Patton 2008). Findings from the statewide camp evaluation support this idea. Further, inviting stakeholders — the volunteers, staff and youth involved in 4-H camps — to interpret the findings also benefitted the researchers conducting the evaluation. We summarize benefits for both groups below.

Insights into the data

Asking stakeholders to analyze and interpret their own data increased the evaluator's understanding of the meaning of some responses. For example, many qualitative responses to survey questions referred to camp traditions that were unfamiliar to the evaluator. It was difficult for the evaluator to effectively code the qualitative data without gaining insight from stakeholders about what these references meant. Additionally, stakeholders demonstrated robust understanding when they were asked not simply to embrace findings but to look for patterns, explore what surprised them, ask their own questions and come to their own conclusions. Stakeholders created their own knowledge, leading to deeper learning (Piaget 1971).

Sense of partnership between UC academics and key program stakeholders

Evaluation can be seen as a measuring stick and therefore people being assessed may approach it guardedly. As Franz reported (2013), the methodology of including stakeholders in analysis may contribute to community-building between stakeholders and evaluators. The 4-H camp assessment built a bridge between UC and volunteers, increasing communication and trust.

Refinement of data collection instruments

Through the data parties, evaluators received feedback on the survey instruments. Though the California 4-H Camp Advisory Committee had provided input on development of the surveys, several staff and volunteers felt — after the first year of data collection, and reflecting on responses that youth gave — that one of the measures did not capture the targeted outcome. At a data party, the evaluator was able to discuss ideas with staff and volunteers, which allowed refinements in the survey to better fit the 4-H camp context.

Greater ownership of the findings

Sometimes in amassed data, individuals may not see findings as representative of their experience. But data-party participants, when empowered to make meaning from their own data, not only gained greater understanding of the findings but also took greater ownership of them. Participants' sense of control and destiny shifted. The external evaluator was no longer in sole control of the findings and camps became more likely to embrace program improvement.

Limitations

The data-party assessment described here is not without limitations. Our sample size is small. The sample could be biased because we may have received responses only from individuals whose experience at the data party had been positive. We were unsure how effective this method of sharing data would be, and we did not formally evaluate the data parties when they occurred. We also did not collect any information from stakeholders who did not attend a data party. We do not know why those stakeholders did not attend — whether because they did not understand the purpose of the data party, lacked interest in the evaluation or found the date or location of the data party inconvenient. Finally, no teen staff members responded to the survey. Teens play a distinct role as members of camp staff, and no doubt their experience of data parties is distinct as well. The perspective of teens would be useful for improving the researcher-practitioner relationship that is central to citizen science. Despite these limitations, the participants and evaluators who engaged in the data parties did report several benefits, as outlined above. Continued interest in holding data parties for the camp evaluation, and in increasing use of data parties for other California 4-H research projects, supports our conclusion that this form of participatory evaluation is an excellent tool for involving stakeholders in the research process.

Future directions

The success of the data party in the 4-H Camp Evaluation Study has led to continued use of this tool as a vehicle to promote understanding and engagement. We have successfully replicated the data-party model with other stakeholder groups, including as a means to share 4-H Youth Retention Study data with 4-H volunteers. Since the data-party format is sometimes discussed as a way to share information with stakeholders, we developed a tool kit to assist others in constructing their own data parties. (The tool kit and templates for posters and place mats are available at bit.ly/data_party.)

Conclusion

Most researchers are not trained or encouraged to share authority with individuals inexperienced in the research process — especially in the realm of evaluation, where distance is equated with objectivity. Yet engaging those closest to data in analysis and interpretation allows practitioners and researchers alike to gain more nuanced insight. Involving stakeholders in understanding data fosters stronger, data-driven decisions about program improvement. Furthermore, it may increase stakeholder interest in the evaluation process. Since 2016, participation in the camp study has steadily grown (from nine to 22 sites) — and camps, once involved in the study, have been likely to continue the yearly evaluation. While we have no empirical evidence that data parties lead to an increase in study sites, the growth in participation may indicate that participants see value in the evaluation process (Patton 2008) when it includes a data party. For these reasons, the partnership between volunteers and researchers — a partnership enhanced by the use of data parties — has led to deeper understanding of the California 4-H camping program and greater commitment to program improvement. CA

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RESEARCH ARTICLE

The CALeDNA program: Citizen scientists and researchers inventory California's biodiversity

By connecting different grassroots eDNA projects, and making data open to explore, we are finding patterns that may help guide eDNA-based biomonitoring.

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Online: https://doi.org/10.3733/ca.2021a0001

Abstract

Climate change is leading to habitat shifts that threaten species persistence throughout California's unique ecosystems. Baseline biodiversity data would provide opportunities for habitats to be managed under short-term and long-term environmental change. Aiming to provide biodiversity data, the UC Conservation Genomics Consortium launched the California Environmental DNA (CALeDNA) program to be a citizen and community science biomonitoring initiative that uses environmental DNA (eDNA, DNA shed from organisms such as from fur, feces, spores, pollen or leaves). Now with results from 1,000 samples shared online, California biodiversity patterns are discoverable. Soil, sediment and water collected by researchers, undergraduates and the public reveal a new catalog of thousands of organisms that only slightly overlap with traditional survey bioinventories. The CALeDNA website lets users explore the taxonomic diversity in different ways, and researchers have created tools to help people new to eDNA to analyze community ecology patterns. Although eDNA results are not always precise, the program team is making progress to fit it into California's biodiversity management toolbox, such as for monitoring ecosystem recovery after invasive species removal or wildfire.

The Earth is facing unprecedented threats to its ecosystems due to climate change, habitat destruction, pollution and other anthropogenic factors. With the sixth mass extinction of life upon us (see Ceballos and Ehrlich 2018), policymakers and the public need more information to address the grand challenges of how to protect, conserve and restore the health of vital ecosystems that provide food, medicines, raw materials, energy and cultural attributes essential to human survival and well-being.

In California, one of three North American biodiversity hot spots (Myers et al. 2000), 40 million people must find a way to thrive while protecting biodiversity. The economy of California, now ranked fifth in the world, relies heavily on natural resources industries; the state ranks first in recreation tourism out of the 50

Paired burn eDNA samples from the Whittier Fire area, in the Santa Ynez Mountains, help CALeDNA researchers to track biodiversity change after wildfire.

CALeDNA volunteers

NHMLA program coordinator Dean Pentcheff, *left*, moves algae during low tide at Point Fermin Park in San Pedro, Los Angeles County, to uncover sediment for eDNA sampling by a Snapshot Cal Coast volunteer, *right*.

states, second in seafood production, third in lumber production and has 39 mined minerals that occur in commercial quantities only in California (California Department of Conservation 2019). Inventories of California's biodiversity are needed to maintain the myriad ecosystem services residents rely on, but collecting detailed biodiversity data is costly and time consuming.

Fortunately, in the past decade there has been a rise in community-driven biodiversity monitoring integrated into public data archives (Pearce-Higgins et al. 2018) and data verification platforms (e.g., wildbook.org; Bird et al. 2014) that make data sets readily available for rigorous analysis (Hochachka et al. 2012). The motives for data collection are diverse, including self-education, which is one popular use of iNaturalist, a phone app for photographing, geotagging and identifying organisms maintained by the California Academy of Sciences (it contains nearly 318,000 species, recorded in 57,000,000 observations by 1.4 million people).

Another motive for data collection is to help professional researchers with community-relevant research. Many of these programs build natural history museum collections and research (Ballard et al. 2017), monitor invasive species (e.g., mussels: Miralles et al. 2016; butterflies: the Pieris Project, Pierisproject.org; Ryan et al. 2019) or improve resiliency of local biodiversity resources of economic value, like fish stocks (Fairclough et al. 2014). Still, there are gaps, where closer interactions between the public and professional researchers could benefit from community-collected data (Theobald et al. 2015) and where closer interactions could bolster co-created or bottom-up participatory action research that has greater potential to address social justice challenges (Ryan et al. 2018).

Biodiversity research in California can increase the feedback loop between the public and researchers as both groups engage in data analysis and interpretation. The state has numerous world-class research institutions as well as curated living and *ex situ* natural history collections and 13% of the United States' colleges, with hundreds of thousands of residents already engaging with environmental sciences and research (Bureau of Labor Statistics 2019). In addition, the state has a strong naturalist certification program, California Naturalist (calnat.ucanr.edu), created by the UC Division of Agriculture and Natural Resources. Its curriculum includes participation in citizen and

Glossary

Beta diversity: Measure of diversity between areas; accounts for the number of taxa common to both areas and the number of unique taxa in each area.

Bioblitz: Hands-on, educational and fun community science activity such as a bird or wildflower survey; usually occurs in a day and often contributes to biological research, monitoring projects or research resources (e.g., iNaturalist).

DNA barcodes: Short DNA sequences of a region that vary in sequence among species and therefore can be used to match DNA to a species or strain.

DNA metabarcodes: Sequencing a specific DNA barcode region of a genome from multiple organisms within a single sample. The many resulting sequences are matched to known DNA barcodes, allowing variants to be assigned to identify species present.

eDNA (environmental DNA): DNA of organisms collected from environmental samples such as soil, air, plant surfaces or water.

Polymerase chain reaction (PCR): A technique used in molecular biology to make many copies of a region of DNA to allow for sequencing.

Voucher specimen: An organism or part of an organism, such as a plant cutting, that is preserved for scientific use and used as a reference to confirm identity. DNA barcodes are usually sequenced from voucher specimens.

community science (CCS) (Merenlender et al. 2016). In 2016, the UC Conservation Genomics Consortium was launched to catalyze genomics tools and studies in California, funded by the UC President's Research Catalyst Award. As one of its activities, the Consortium aimed to capitalize on this public naturalist renaissance and available biodiversity expertise to create a program for community science and researcher-guided citizen science meant to equip people with a new biodiversity research toolkit.

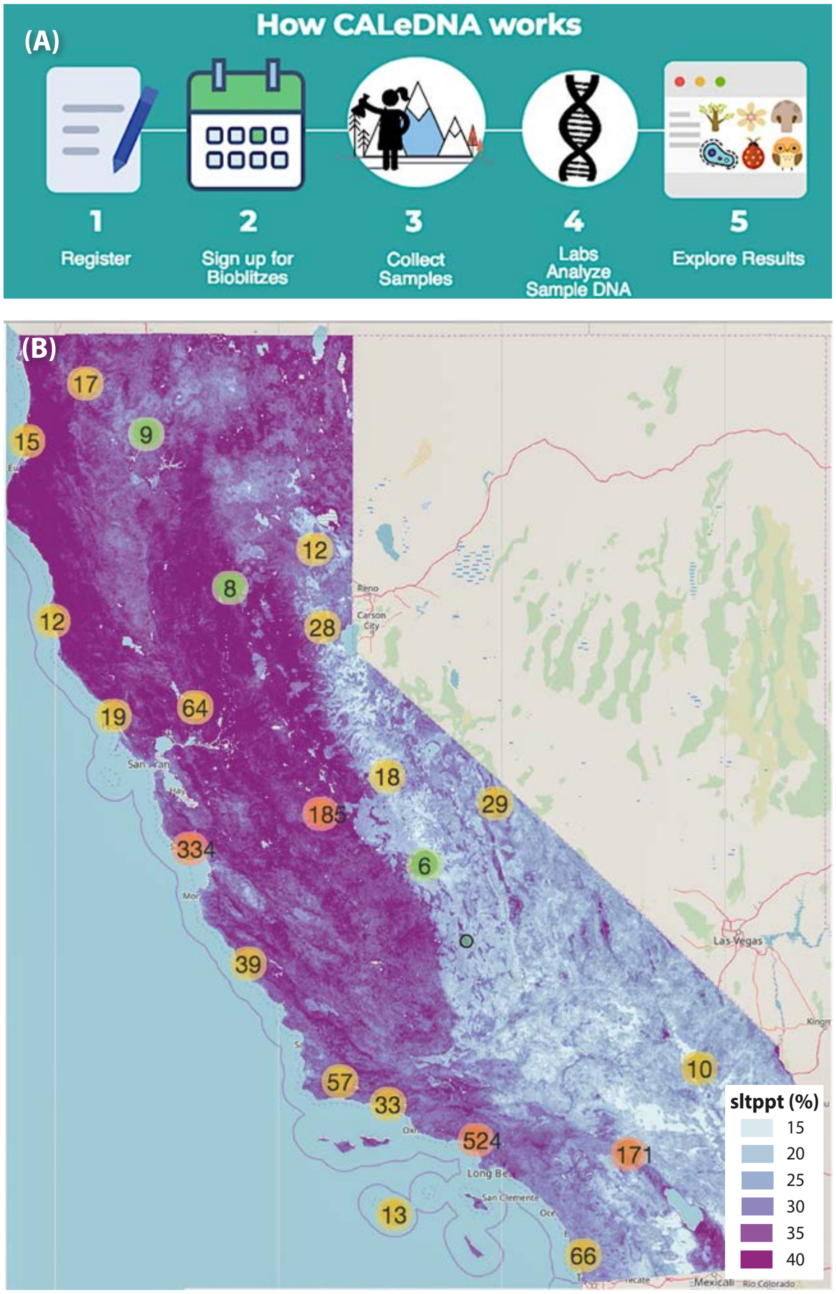

FIG. 1. Volunteers can participate in the CALeDNA process (A) by attending organized bioblitzes or by emailing a request for a kit and then collecting samples on their own. Volunteers have sampled sites in many regions of the state; eDNA results are made public as they become available so that anyone can explore them on the CALeDNA website, www.ucedna.com, and plot them (B) against different maps (such as this one, showing proportion of silt in soils, "sltppt %") to generate hypotheses based on spatial patterns.

CALeDNA (*Cal 'ee' D-N-A*) is a statewide community science program that the Consortium launched in 2017 to facilitate the collection and analysis of California environmental DNA (eDNA) for broad biodiversity inventory and assessment. Dozens of researchers, including students, staff and professors across California, connected online to develop a high-throughput pipeline for community science–driven habitat monitoring and characterization using molecular, DNA-based detection methods. They worked together to decide on how to collect and store environmental samples from eDNA, how to generate eDNA data, how to analyze it and how to share results with the public, in a way that would also enable comparative exploration results from different eDNA samples and grassroots projects.

The workflow of the CALeDNA program enables biodiversity data collection and analysis using DNA-based technologies through a series of steps (fig. 1A). CALeDNA recruits and trains community scientists online and in-person, advertising field work events through different networks on the CALeDNA website, ucedna.com. Partnerships with groups such as California Naturalist and conservation/revitalization networks are key to recruitment. These community scientists partake in soil and sediment collection using sampling kits and a phone app, and they continue to connect with the researchers and students who process and study the samples in the lab by tracking project progress online. All participants are asked to explore eDNA results and think about how biodiversity connects to grand management questions (fig. 1B). Often, the availability of existing collections in an area inspires plans for future collections, particularly in the UC Natural Reserve System. Community scientists often propose other natural areas to sample to fill sampling or data gaps.

Diverse communities of researchers and the public have helped develop both the research questions and the functionality of CALeDNA by implementing the workflow for their own bioblitzes and eDNA research projects. From grassroots initiatives to projects funded by the state of California, DNA-based monitoring is being used in biosafety (e.g., by the California Water Quality Monitoring Council, mywaterquality.ca.gov/monitoring_council/mmw.html), in informing restoration (e.g., by the Protecting Our River project, protectingourriver.org, and the California Conservation Genomics Project) and in trials to complement or replace wildlife trawls (e.g., at the Port of Los Angeles and Port of Long Beach; Gold et al. 2019, unpublished). With eDNA and biodiversity genomics at the center, the CALeDNA community is growing collaborative partnerships with land managers, policy informers, naturalists, museums and government agencies to help realize the value of environmental samples, shared protocols and eDNA data itself to address the grand challenges of how to steward ecosystems.

eDNA metabarcoding: A different form of biodiversity monitoring

Probing eDNA for many kinds of organisms at once can help address the challenge of monitoring marine, terrestrial, freshwater and even airborne ecosystems on an ecological community level (Banchi et al. 2018; Bohmann et al. 2014; Thomsen and Willerslev 2015). All organisms shed DNA as they live and decay, and these DNA molecules can be isolated, sequenced and identified (Taberlet et al. 2012). DNA persists in surface soils and shallow sediments for variable lengths of time: mere days in the ocean (Lafferty et al. 2018), and usually for weeks or months in terrestrial environments (Barnes and Turner 2016). In all ecosystems, temperature, ultraviolet light, microbial metabolic activity and eDNA shedding rates play complex roles in the production, movement and degradation rates of eDNA (Barnes and Turner 2016; Deiner et al. 2017). Under certain conditions, like the bottom of a lake, eDNA may be protected from these physical and chemical threats and may also be sheltered from consumption by active microorganisms (Palchevskiy and Finkel 2006), leading to its persistence for thousands of years (e.g., Graham et al. 2016). CALeDNA researchers are striving to estimate what slice in space and time each local community they find in eDNA represents.

There are many ways to track species' eDNA. Some eDNA surveys are targeted, tracking a single species usually by means of quantitative PCR (polymerase chain reaction) (Biggs et al. 2015; Sutter and Kinziger 2018). However, a holistic eDNA-based inventory of a location's biodiversity is also possible and is akin to a kind of forensic reconstruction of the local organismal community (Thomsen and Willerslev 2015). This inventory involves next-generation high-throughput sequencing technologies such as with Illumina systems, or third-generation sequencing technologies such as PacBio and Oxford Nanopore Technologies, which all substantially reduce the cost of DNA sequence data and allow thousands to billions of different sequences to be retrieved in little time from hundreds of samples at a time.

Simply sequencing the DNA extracted from an environmental sample will overwhelmingly have microbial sequences. To capture more biodiversity without needing to sequence as deeply, eDNA is inventoried by "DNA metabarcoding". Here, specific DNA regions, usually DNA barcodes, are targeted and copied from organisms in an environmental sample of mixed DNA. The copies are sequenced and matched to reference DNA barcodes that communities around the globe have generated from voucher specimens for over three decades.

Different barcoding regions of nuclear and organellar genomes are diagnostic for species in different lineages of organisms, so to broaden taxonomic biodiversity included in DNA metabarcoding surveys, multiple regions are often used simultaneously with multiplexed metabarcoding. This allows a simultaneous inventory of biodiversity across organismal kingdoms, for costs currently under $100 a sample, and likely less in the future as we optimize third-generation sequencing technologies (Hebert et al. 2018) and as sequencing prices continue to drop. For CALeDNA, typically six DNA regions are used to obtain metabarcodes from each environmental sample, yielding lists of well over 1,000 unique taxa per sample that span all kingdoms of life.

The promise of eDNA monitoring has led to its widespread development and application. It's in use in large-scale biodiversity monitoring networks, including the Group on Earth Observations Biodiversity Observation Network (GEO BON)/Marine Biodiversity Observation Network (MBON), in federal monitoring agencies, including the U.S. Geological Survey and National Oceanic and Atmospheric Administration, in

In 2017 and 2018, CALeDNA coordinated a weekend bioblitz to sample along a 1,200-kilometer span of coast from Arcata to San Diego. *Inset*: A volunteer collects samples at the beach.

local agencies such as the Southern California Coastal Water Research Project, and in research institutions, including the Natural History Museum in Los Angeles (NHMLA).

California's research communities have pioneered DNA-based environmental assessments, such as the teams at Southern Sierra Nevada Critical Zone Observatory and the Aronson Lab (see Aciego et al. 2017) and Stanford's Center for Ocean Solutions (see Andruszkiewicz et al. 2017). Diverse researchers and resource managers have been using eDNA approaches to detect and monitor endangered species, track the emergence and spread of invasive species, and inventory biodiversity in a wide range of habitats from submarine canyons to alpine forests, demonstrating the breadth of applications of this emerging technique. Work thus far has still largely focused on water sampling or on limited groups of taxa, such as bacteria or fish.

The CALeDNA approach to inventorying biodiversity across kingdoms poses its own set of challenges. Although eDNA approaches appear to be ideally suited for intensive and taxonomically broad biodiversity monitoring programs, we've found little overlap in the taxa identified in eDNA surveys and those identified in traditional field surveys (direct observations, usually by a trained taxonomist or with tools like iNaturalist), which suggests eDNA-broad biodiversity monitoring captures other angles of biodiversity that may complement but not necessarily replace targeted surveys. The reasons for the limited overlap are many, but a lack of published reference DNA of all species certainly limits DNA metabarcoding. CALeDNA researchers are expanding collaborations to test whether the patterns of biodiversity variation over space and time that were established with traditional data are reinforced with eDNA data. The improvement of eDNA metabarcoding assays, the availability of more reference sequences, and an optimization of eDNA sampling to have the best chances of including species' DNA, will help explain how molecular methods can complement traditional field surveys (Bohmann et al. 2014; Thomsen and Willerslev 2015).

eDNA is being studied at five vernal pools on the UC Merced Vernal Pools and Grassland Reserve. Dr. Andy Aguilar (left), professor at California State University Los Angeles, talks to volunteers about fairy shrimp.

CALeDNA study sites

Study sites are chosen in three ways: by researchers with projects under way who need eDNA collection in certain areas or habitat, by natural areas managers who request eDNA data and can offer some funding to process samples, and by community science volunteers who email CALeDNA and offer to collect at sites. Volunteers can collect for CALeDNA anywhere they please, as long as they have proper permission, such as collection permits or written permission from a landowner. Obtaining permission to collect eDNA may take time, but it has not discouraged volunteers interested in adding an area of their interest to the CALeDNA map (fig. 1B). CALeDNA, at present, reimburses all permitting fees incurred. This can also benefit groups; for example, one volunteer, a teacher, independently obtained a permit for collecting at a local park in summer 2018 and brought the Youth Science Institute summer camp students to collect. In 2020, when stay at home orders restricted public participation in some collections, CALeDNA researchers used Go-Pros and Zoom to aid virtual participation, allowing students and public volunteers to still choose sites to sample.

At the time of writing, one-third of CALeDNA samples are from UC natural reserves. UC boasts the largest university reserve system in the world: 41 reserves totaling over 756,000 acres of land and 50 miles of coastal shoreland (UC Natural Reserve System 2020). Most of these reserves aren't open to the public, but UC researchers may visit, accompany volunteers or send volunteers to hike through and sample eDNA. The reserves are ideal for providing a biodiversity baseline for the state because they include coastal to montane biomes.

All reserves have hosted numerous traditional biodiversity surveys, and we use these to assess the extent of overlap between eDNA metabarcoding and traditional sampling, which can illuminate the bias as well as complementarity in eDNA and visual/observational surveys. The reserves offer additional abiotic data that may strengthen statistical analyses and models to describe eDNA patterns. Weather station and flux tower data are often available from reserves; such data have been used by the Institute for the Study of Ecological and Evolutionary Climate Impacts (iseeci.ucnrs.org). Since 2012, NASA has flown planes with sensors over parts of California, with priority over UC natural reserves, to collect high-resolution hyperspectral and

LiDAR data that describe the abiotic and biotic features of the local environment. These data inform the design of their large Surface Biology and Geology study that includes new biodiversity observation capacity from space.

Volunteers' samples

Volunteers may join a bioblitz or sample a site on their own. In either case, they receive a sampling kit of gloves and prelabeled cryovials in bags of three, and an optional meter for collecting abiotic data (fig. 2A). Each sampling kit is used with an electronic web form for smartphones and tablets or with a paper form, where the volunteer provides critical collection metadata (fig. 2B). The metadata fields were designed to collect more information than required for current sample description standards (e.g., in NCBI's BioProject); the additional data make samples more likely to be used as a research resource (e.g., Darwin Core, dwc.tdwg.org; Global Genome Biodiversity Network, ggbn.org).

We use the KoBoToolbox (kobotoolbox.org) platform to create the web form and curate the information. Results are backed up in real time. CALeDNA metadata needs are dynamic because of different research projects needs and because data standards continue to change. KoBoToolbox allows multiple forms to be created with the same minimum essential questions.

The eDNA archives

Each eDNA sample tube is treated as a valuable biological research collection and is archived in a –80°C freezer in the permanent Donald R. Dickey Bird and Mammal Collection at UC Los Angeles (UCLA) or in a freezer at another UC campus as part of a satellite collection. We intend for the CALeDNA samples to be used to track environmental change over the next 100 years. When samples are processed and results are published online, the physical locations of the archived samples are reported and archived as part of the sample metadata. CALeDNA became a member of the Global Genome Biodiversity Network in 2019, which means we will be sharing our collections with researchers worldwide as a public research resource.

The research collections that CALeDNA volunteers make are usually shipped with FedEx, which allows us to email shipping labels to volunteers. If the samples have not yet been frozen, we ask volunteers to keep the samples refrigerated until they are ready to ship, or to keep the samples at room temperature if they are going to be shipped within 1 week of collection. Tests have shown that freezing and thawing samples causes DNA profiles to vary, but maintaining a stable temperature helps to preserve the balance of DNA profiles (Earth Microbiome Project 2019; Thompson et al. 2017). We chose to avoid adding stabilizing buffers to the environmental samples, which may pose unknown effects to the sample integrity and limit their downstream use as research resources. Once archived in the freezer, the sample is available to be subsampled and shipped for a plethora of research purposes.

Sample collection and processing

CALeDNA staff and interns continuously generate DNA data as sample collections increase. Under current funding, we are sequencing 10% of the samples received and make these results immediately open to the public.

Sample collection involves collecting three vials from a site; these are treated as biological replicates.

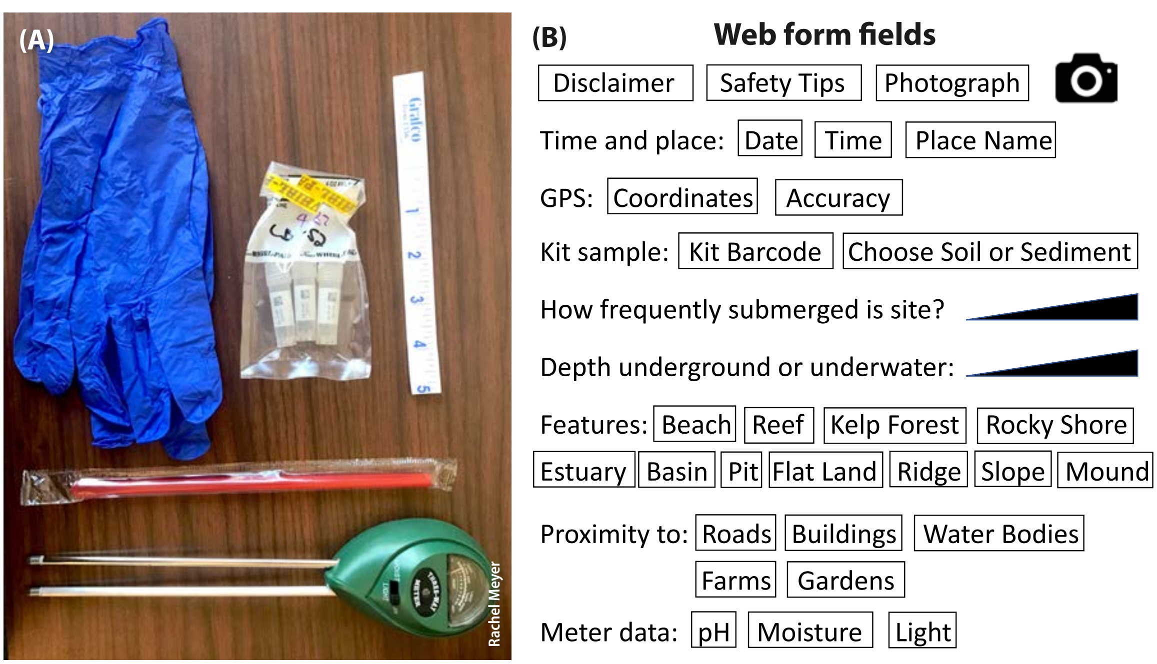

FIG. 2. (A) The CALeDNA kit includes gloves, three vials for biological replicates inside a protective Whirl-Pak bag, a straw to sample sediment or to move debris to expose topsoil, and a ruler. The three-way pH/moisture/light meter is optional and mainly used for classroom-based research and education. Collectors complete a web form (B) on their smartphone or tablet, or use a paper form, to provide important metadata for the site they are sampling.

The replicates are thawed on ice, and a subsample of soil or sediment from each is pooled into a single tube, mixed and used for DNA extraction. Since CALeDNA is a dynamic program, our collection methods are already diversifying. For example, the Aronson Lab at UC Riverside is engineering rollers as eDNA surface collectors, along with wearable passive eDNA samplers. UCLA undergraduate interns are testing whether swabs from flowers provide enough eDNA to inventory invertebrate pollinators and the flower microbiome, with seed funding provided by the Golden Gate National Parks Conservancy. UCSC researchers are partnering with Cornell University and NASA to swab grapevine stems and leaves for biodiversity that may indicate plant health.

UCSC graduate student and expert entomologist Jon Detka hikes at UC Fort Ord Natural Reserve to collect for CALeDNA.

Wai-Yin Kwan, who developed many CALeDNA web tools, at her first eDNA bioblitz in the Mojave Desert.

DNA is processed through a series of steps to generate metabarcoding libraries. Because contamination from the collector or from the lab is a common problem in eDNA research, sometimes field blanks are collected, which allow researchers to parse from the sample DNA most contaminants from the collector, equipment and supplies, and air. When extracting DNA, an additional lab blank sample is also extracted as every batch of samples are processed. Researchers use a variety of methods to informatically remove the contaminants observed as blank sequences or taxa from the study so they don't bias the analyses. The details of the DNA preparation pipeline and CALeDNA protocols can be found on our website, ucedna.com, in the "methods for researchers" space.

In brief, each barcode region we target requires three separate PCR reactions as technical replicates, which helps reduce reaction bias in the results, meaning for six barcoding regions, there will be minimally 18 reactions per sample if all are successful. Metabarcode libraries are sequenced on a MiSeq machine that generates paired reads each 300 nucleotides long, allowing us to sequence through a 600-nucleotide-long piece of DNA, which exceeds the length of most DNA barcodes. For a lengthier barcode, such as the *CO1* locus, we typically sequence only a portion of it, which is usually sufficient to inventory animals (Leray et al. 2013). Each barcode region we use to probe DNA diversity in a soil, sediment or water sample is sequenced to between 25,000 and 100,000 reads.

These DNA data are processed through software in the Anacapa Toolkit (Curd et al. 2019), which was developed for multilocus metabarcoding. It combines state-of-the-art methods and is flexible enough to handle many kinds of eDNA data. The raw, unprocessed DNA data are eventually deposited in the National Center for Biotechnology Information's (NCBI's) Sequence Read Archive, while processed results and detailed metadata are shared on our website and in other long-term archiving platforms such as Dryad, datadryad.org.

Results from each barcode region are a list of taxa and the number of sequences that matched each one in each sample. The taxa may be identified to the level of species or limited to a higher rank, such as genus or family, depending on the completeness of DNA barcode reference databases and the number of diagnostic DNA bases for that particular organism. An analysis of California coastal taxa, for example, shows 20% of organismal families still have no published DNA sequences at all. CALeDNA scientists in the Nielsen Lab at UC Berkeley are working to minimize the effects of missing data, but while matches aren't perfect, researchers manually check the results to identify errors and consider these in planning downstream research.

Despite the data gaps and limitations, plenty of biodiversity patterns can be gleaned from using the taxon lists of the best assignments we can currently obtain, or from summarizing taxa to higher levels, like family. A disclaimer on our website educates participants about the state of eDNA technology, to help prepare them to interpret that a species found is a "best hypothesis" of the true species there, given limited reference data. Many of the taxa we report, for example, are not ever found in California, and this is probably because the California species has not been sequenced, but a related species somewhere else has been. To help the public scrutinize results, we include the Global Biodiversity Observation Facility (GBIF) occurrences map on our website for each taxon under the eDNA result. GBIF is a database of all species observations and collections. Taken together, we hope online eDNA data exploration will encourage enthusiasm for biodiversity genomics, and ideas about what we may expect in the future if much more biodiversity sequencing across the tree of life is accomplished (e.g., Lewin et al. 2018).

Open data

To allow community scientists to track our progress once samples are received, we put the field data online shortly after we receive them and strive to put the sequencing results online within a month of their generation. Our impetus for committing to open data is other scientists' around the world increasingly committing to the 2014 FAIR (FORCE11.org) guiding principles for managing research data to benefit data providers and data consumers: findability, accessibility, interoperability and reusability.

There is, however, one area where we obfuscate results: endangered and threatened species. Because endangered species may more easily be poached with eDNA leads, the CALeDNA website omits the specific sites where species on the IUCN (International Union for Conservation of Nature) Red List of Threatened Species and other endangered species lists have been found.

Processed eDNA results can be shared and explored with an interactive results analysis platform called ranacapa (Kandlikar et al. 2018), which allows users to execute the same first-pass biodiversity data analyses of research projects as professional community ecologists typically do, without needing to code or learn to use advanced statistical software. Plots and statistics are produced with explanations aimed at the undergraduate level. This enables community science users to reproduce results reported by CALeDNA on the website or in scientific journals. Because data and tools are shared early in the analysis stage, community and citizen scientists may make some discoveries first, report them to CALeDNA, and through this feedback loop earn coauthorship on research publications while bringing attention to the biodiversity in areas they care about.

CALeDNA research projects

Pillar Point: eDNA, DNA, human observation

Our first bioblitz, in early 2017, was in collaboration with the California Academy of Sciences (CAS) and the NHMLA to explore a potential complementary trifecta for biodiversity monitoring: human visual observation (CAS), DNA barcode sequences from local species (NHMLA) and eDNA (CALeDNA). We chose Pillar Point, in San Mateo County, because CAS has been running monthly bioblitzes since 2012 at the Pillar Point Harbor tidepools and adjacent areas within Half

Dr. Tiara Moore, *left*, samples eDNA along a lagoon to inventory community species and track their responses to environmental stress. A volunteer, *right*, helps count organisms using traditional ecology methods.

Moon Bay (inaturalist.org/projects/intertidal-biodiversity-survey-at-pillar-point). Their and other observation data, along with voucher specimen records, are shared in GBIF, where we accessed it for this study.

We found considerable overlap in the monitoring results, with 127 families observed visually and by eDNA. However, this number declines at genus and species levels, suggesting both visual observation and eDNA have limitations in making correct assignments. Working closely with NHMLA, we were able to identify errors and then focus on total-biodiversity patterns (fig. 3). We created a web interface for this project to help people compare eDNA and observation data from the area (data.ucedna.com/research_projects/pillar-point).

Point Fermin: eDNA, local DNA barcoding

NHMLA runs semiannual bioblitzes as part of Snapshot Cal Coast (calacademy.org/calcoast) during low tide at Point Fermin Park in San Pedro, Los Angeles County. They take photographs and make voucher collections, which later are DNA barcoded for the *CO1* region as part of the DISCO (Diversity Initiative for the Southern California Ocean) project, research.nhm.org/disco/disco.html. CALeDNA runs annual bioblitzes at Point Fermin to build eDNA collections concurrent with NHMLA specimen collections to help us assess how much eDNA results improve with very local DNA barcoding.

California macroecological patterns

From April to July 2017, a series of bioblitzes and independent community science activities in parks and reserves brought in thousands of soil or sediment samples to the CALeDNA collection. CALeDNA scientists selected 278 sites that represented latitudinal transects along forest, shrub/scrub and coastal areas. Sequencing results revealed more than 25,000 unique taxonomic entries. UCLA doctoral student Meixi Lin led the team in performing different kinds of biodiversity analyses, including zeta diversity (Simons et al. 2019), and gradient forest (Ellis et al. 2012) statistical modeling that incorporated NASA satellite data, to study which environmental factors shape local communities (Lin et al. 2020).

Coast biodiversity patterns

In 2017 and 2018, with over two dozen colleagues from UC, California State University and coastal reserves, CALeDNA coordinated a weekend bioblitz to sample along a 1,200-kilometer span of coast from Arcata to San Diego. The sample collectors iteratively collected from dune or bluff, swash, and estuary zones. The research questions, led by Drs. Dannise Ruiz and Michael Dawson at UC Merced, are testing whether classic theories of terrestrial and marine biodiversity patterns, which were developed with macrobiota such as animals, stand with eDNA-based microbial unicellular and macrobiotic multicellular inventories. Results thus far show that eDNA biodiversity follows expected patterns along the California coast.

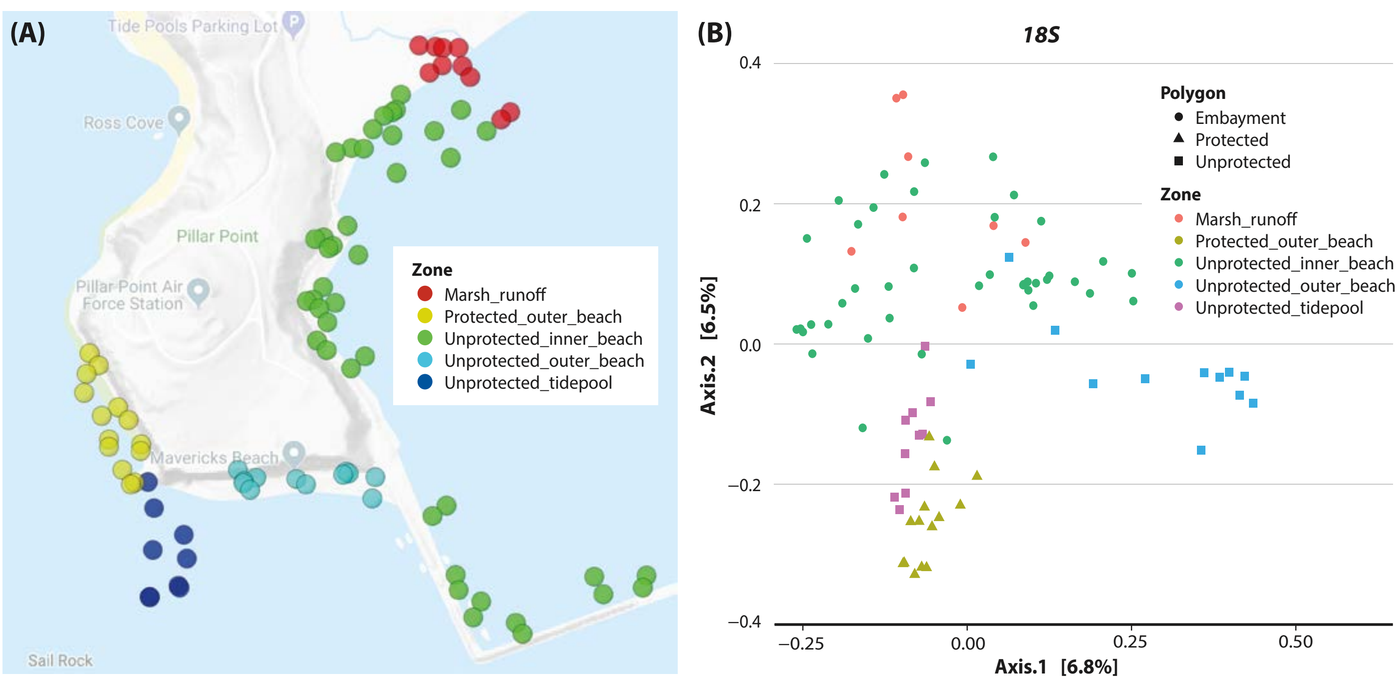

FIG. 3. (A) Pillar Point project map of sampling areas. (B) Site compositional ordination with a Jaccard principal coordinate analysis shows more similar sites plotted closer together. This analysis is a standard way to explore beta diversity across multiple samples. The metabarcoding results used were from the *18S* locus that captures eukaryotic diversity. The protected outer beach and the unprotected tidepools look similar through the lens of eDNA. This suggests the tidepools, which are easily accessible, may be useful as surrogate monitoring sites to understand the outer beach biodiversity health and change.

eDNA in vernal pools

Vernal pools are temporary wetlands, filled by substantial rainy seasons, snowmelt or groundwater. The pools host many California endemic species with special adaptations to pool depth, morphology and geochemistry. CALeDNA researchers from the UC Merced lab of Dr. Jason Sexton are studying eDNA of five vernal pools on the UC Merced Vernal Pools and Grassland Reserve to build a more comprehensive taxon inventory. Hundreds of volunteers from California Naturalist programs and the UC Merced Carson House supported the bioblitzes. Preliminary results suggest that when we see an eDNA signal of endemic endangered plants that only sporadically emerge, such as Colusa grass (*Neostapfia colusana*), it forecasts their emergence in the pools that year.

Invasive grasses, species patterns

Invasive plants alter the community composition of fungi (Hawkes et al. 2006), plants (Gaertner et al. 2014) and microbiota (van der Putten et al. 2007) in the systems that they invade. The Fort Ord Natural Reserve has supported multiday bioblitzes that have added nearly 200 samples to the CALeDNA collection with associated metadata of which sites have invasive grasses. UC Santa Cruz (UCSC) graduate student Sabrina Shirazi is identifying associations between invasive grasses and the rest of the community by examining microbiota detected with eDNA. Dense sampling at reserves like Fort Ord, which has a mosaic habitat of forb, shrub, native or invasive grass–dominated, and tree-dominated land, provides the critical data for developing hypotheses about species patterns that we can test more generally with statewide CALeDNA data.

Lagoon biodiversity and stress

Dr. Tiara Moore, while pursuing her Ph.D. in the Fong Lab at UCLA, worked with CALeDNA to bring community scientists to Carpinteria (Santa Barbara County) and Upper Newport Bay (Orange County) to sample sediment from different areas of lagoons. She used eDNA to inventory community species and track their responses to environmental stress related to formation of macroalgal blooms dominated by sea lettuce (*Ulva* spp.). To accomplish this, she combined eDNA metabarcoding with the GeoChip 5.0 (Glomics, Norman, Okla.), which quantifies the presence of more than 22,000 genes involved in stress response and ecosystem functioning. Her findings, in preparation for publication, detail the metabolic processes in the eutrophication of lagoons.

Burn sites, plant resilience

California has experienced an increase in wildfires and wildfire burn intensity, which have devastated areas that are normally spared as climate refugia, such as wetlands. CALeDNA community science volunteers and UC undergraduate classes began sampling paired burned and unburned sites in late 2018, and continue to resample sites that were affected by fire. In 2019 and 2020, we have increasingly received samples from many UC students and UCNRS staff to archive the soil in burned areas, like items in a time capsule, so they may be used for future wildfire ecological research.

The many samples have enabled CALeDNA researchers to track biodiversity change after fire and to identify plant–microbe networks (fig. 4) that may help explain the resilience of some California native plant species to fire disturbance. Data sets are being used by CALeDNA staff in undergraduate education modules, and by students for their own research. UCLA undergraduate Eric Beraut (now alumnus) used Klamath Mountains postfire eDNA samples, collected by volunteer initiative, to quantify how much the time since the last wildfire predicts soil fungal diversity.

Desert eDNA

UC's Burns Piñon Ridge Reserve and Anza Borrego Reserve, as well as the Wildland Conservancy's Pioneertown Mountain Preserve, and Center for Natural Lands Management's Thousand Palms Oasis, have hosted eDNA bioblitzes to describe and compare biodiversity in desert ecosystems. Community scientists, including John Frazier from Friends of the Desert Mountains, have contributed substantial collections to CALeDNA. Results have revealed first observations in the United States of exciting single-celled eukaryotic extremophiles and desert-adapted bacteria and provide rich

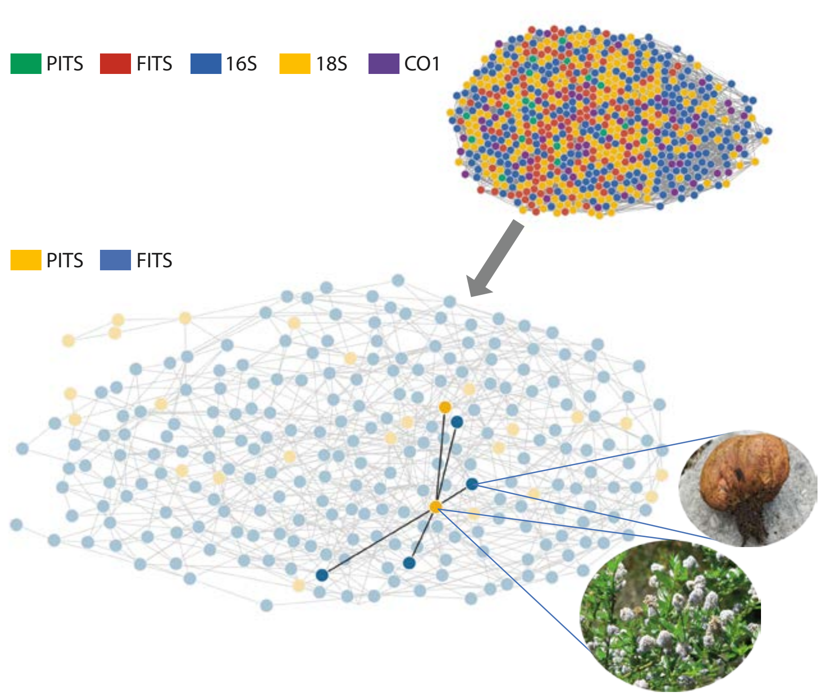

FIG. 4. Ecological co-occurrence networks can be made using multilocus metabarcoding data. Habitats that experienced wildfire up to 12 years ago are co-analyzed using all markers (*16S*, *18S*, fungus *ITS1 "FITS"*, plant *ITS2 "PITS"* and *CO1*). Focusing on plant-fungal interactions (the PITS and FITS only plot), we found that *Ceanothus thyrsiflorus*, a fire-responsive plant (Davis et al. 2010), was associated with *Rhizopogon*, a fungus also known to be fire responsive (Glassman et al. 2015). Source: Eric Beraut.

records of invertebrate occurrences, including hard-to-observe taxa such as tardigrades. We are developing deeper collaborations with desert nature reserves to monitor invasive species and track habitat restoration processes.

eDNA methodology study

The Shapiro Lab at UCSC has tested how different approaches in preparing eDNA libraries influence results, which will help us improve methods to make CALeDNA research more efficient and reduce costs and technical bias. The lab's results have identified enzymes that amplify DNA with less bias (Nichols et al. 2018). Graduate student Sabrina Shirazi has recently completed a study to determine how few PCR replicates and how little sequencing depth are needed to assign an unknown sample to a site in California (Shirazi et al. 2020). This work will be instrumental in helping researchers do high-throughput processing of CALeDNA collections to detect habitat change over time.

eDNA undergraduate studies

In microbiology classrooms

In winter 2017, CALeDNA began a partnership with the UCLA Microbiology, Immunology, and Molecular Genetics (MIMG) department on its Course-based Undergraduate Research Experience (CURE) curriculum. CUREs have been demonstrated to provide a more inclusive avenue for students who might not otherwise have the opportunity to participate in research (Auchincloss et al. 2014). The MIMG CURE is a two-quarter research immersion curriculum in which upper-division undergraduates work in teams to formulate and test their hypotheses regarding soil microbial ecology, using eDNA and traditional bacterial cultivation methods (Shapiro et al. 2015). Graduate students doing related eDNA research visit the classrooms, which we hope encourages undergraduate students to consider scientific careers.

With the CALeDNA sample collection kits and eDNA analysis tools, CURE undergraduates have compared the soil microbiomes of California native and invasive plant species, natural and managed ecosystems, and studied the effects of human impact and burning on microbiomes. The partnership between CALeDNA and MIMG has also inspired graduate students and instructors to spearhead the development of eDNA and microbiology analysis tools, such as ranacapa (Kandlikar et al. 2018) and PUMA (Program for Unifying Microbiome Analysis; Mitchell et al. 2018). Several MIMG students have joined the CALeDNA labs as research interns.

Group photograph of volunteers in Merced after sampling grasslands.

eSIE project

In 2018, the Howard Hughes Medical Institute (HHMI) funded a novel project, eSIE (Environmental DNA for Science Investigation and Education), led by professors Bob Wayne (UCLA) and Beth Shapiro (UCSC). This program aims to educate and encourage undergraduates to enter STEM fields through field-based and flipped learning courses, workshops and research, with eDNA providing entrée into the diversity of natural and social sciences. California's DNA: A Field Course, an introductory course for first-year students and transfer students, debuted in fall 2018. Biodiversity in the Age of Humans, a five-credit course, debuted on both campuses in spring 2019. Four postdocs, Kim Ballare, Chloé Orland, Ana Garcia-Vedrenne and Maura Palacios Mejia, are improving the course content and publishing it for others to implement (Garcia-Vedrenne et al. 2020).

In summer 2018, we launched annual short-term CALeDNA Summer Research Institute sessions, in the Santa Monica Mountains and in Santa Cruz, on the UCSC campus. They were open to UCLA and UCSC undergraduates and students at two California State University campuses: Los Angeles and Dominguez Hills. Activities were designed to prepare participants for beginning research projects in molecular labs. UCLA and UCSC are offering 10-week paid summer research internships for students to work on eDNA with many different faculty (through 2022 with HHMI support).

Building a stronger eDNA community

We hope to make breakthroughs in what community and citizen scientists can do by inviting them to participate in all parts of the research process. We are continuing to build resources for diverse groups to use CALeDNA results and connect with university researchers through our web interface and bioblitzes.

Several of our team members participate in working groups, facilitated by the Southern California Coastal Water Research Project, to build an eDNA projects map of California, which will grow out from the CALeDNA web tools. Seed funding from the Metabolic Studio foundation is helping CALeDNA work across nonprofit organizations and government agencies to plan bioblitzes and data analysis strategies that more directly integrate with social community values. Through these grassroots projects, we're developing ideas for what an eDNA science and technology center should look like: a place where the public has a physical and virtual space to engage in eDNA research and innovation. We are currently soliciting feedback on how CALeDNA may serve the community and how eDNA science may inform policy.

In the next phase of the program, we will tie CALeDNA into the Earth BioGenome Project (EBP) (Lewin et al. 2018). EBP is a "moonshot" to sequence the genomes of all eukaryotic species on Earth. There are approximately 9,000 eukaryotic taxonomic families on Earth and at least 35,000 species in California. By partnering with DNA barcoding and genome sequencing initiatives, CALeDNA can overcome weaknesses in diagnosing taxa with DNA metabarcoding, and, in turn, will provide information on where unsampled species occur so that they may be sampled for EBP collections. We are also using our experience organizing public bioblitzes to design genome collection events for EBP, including partnership work with NHMLA's Urban Ocean Expedition. In this next phase, we will work with EBP to advance ethical policies around eDNA and genomic collections as well as data management.

The future will require a tremendous task force of community scientists, naturalists, observers, local scientific societies, biological collections and information curators to help eDNA work lead to concrete findings and translate to new solutions. We echo the messages of Biggs et al. (2015) and Buxton et al. (2018) that eDNA for community and citizen science projects needs investment in research coordination and volunteer support. An engaged public will be able to translate big biodiversity data into innovation if it is sufficiently detailed, systematically collected, relatable and accurate. Research scientists also need to have more opportunities to step out of insular communities and the grind of rapid research to listen to different communities who share a connection to their research sites.

CALeDNA's projects in the first year were not easy, and often frustrated volunteers, because protocols were not yet optimized around participants' experience. For instance, initially participants were tasked to collect too many samples with too many conditions and too little of the preplanning needed to be successful while having fun (after all, bioblitzes are usually on the weekend). We reduced the number of samples needed to fulfill a collection kit from six to one, and substituted some of the preplanning needs by collecting more metadata during sampling through our KoBoTools app. This has helped us retain volunteers because they have an enjoyable outdoor experience. Further, having learned from our shift to more virtual engagement because of the COVID pandemic, we are investing more effort in developing online participation that meaningfully connects volunteers and research scientists after sampling completes, rather than emphasizing the bioblitz experience.

As researchers who are committed to attributing work appropriately, while working with the public on a level that is new for many of us, we recognize there is a huge need for new ways of showing contribution to a research publication that are more considerate of community and citizen scientists. New progressive journals, such as *Advanced Genetics* (Wiley), are paving the way, crediting contributors who play more diverse roles than traditional authors. Giving credit is critical, especially when we use community-collected data in research publications (Theobald et al. 2015; Ward-Fear et al. 2020). CA

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We thank the UC Office of the President Catalyst Program (CA-16-376437) and the Howard Hughes Medical Institute Grant (GT10483), NSF-DEB 1644641 (to NK), NSF-DGE 1650604 (to GK), NSF-GRFP 2015204395 (to ZG). We thank UCLA UPLIFT (award #K12 GM106996). We thank Michael Dawson (UC Merced) for contributing to the CALeDNA program design, for coordinating the coastal bioblitzes and for constructive comments on the manuscript. We thank the following people who have guided the CALeDNA program: Eric Crandall (CSUMB), Alison Young and Rebecca Johnson (California Academy of Sciences), Greg Suba (CNPS) and Joseph Miller (UCSC). We thank former interns Amber DeVries, Laura Rabichow, Larysa Bulbenko, Aoife Galvin and Audrey Mahinan. We thank the UCLA UX Team for guiding the web development. We thank all UC Natural Reserve managers who made CALeDNA collection possible and inspired research questions, and especially acknowledge the contribution of the late Don Canestro (UCSB).

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RESEARCH ARTICLE

4-H youth advance biosecurity at home and in their communities

Yuba-Sutter youth successfully completed the 4-H Bio-Security Proficiencies Program and effected change as community science experts.

by Martin H. Smith, Woutrina A. Smith and Cheryl L. Meehan

Online: https://doi.org/10.3733/ca.2021a0007

Abstract

Youth participants in 4-H animal science projects are involved extensively with raising and exhibiting agricultural animals, often on backyard farms (Smith and Meehan 2012). Since backyard farms can serve as sources and vectors of pathogens (FAO 1999; WHO 2011), it is critical that 4-H youth take an active role in preventing the introduction and spread of economically important animal diseases. Fifteen 4-H youth from two counties in California participated in the 4-H Bio-Security Proficiencies Program, a long-term community and citizen science project focused on animal and zoonotic disease risk education and mitigation. Then, in the role of community science experts, they acted upon the risk assessments and mitigation plans they had developed to improve biosecurity practices and reduce the likelihood of disease spread on their home premises and at their local county fair. They also extended their knowledge to the broader livestock exhibition community through outreach videos.

A key feature of citizen science is building upon knowledge acquisition through the application of scientific information to relevant issues of community significance (Mueller et al. 2012). In this manner, communities become the laboratories within which individuals can learn to understand problems and their causes, think critically about solutions and work collaboratively to achieve positive change (Cooper et al. 2007). For that reason, Barton (2012, 1) maintains that citizen science is "about participation within and for communities."

Youth-focused community and citizen science refers to the engagement by youth in projects or activities "that produce data or results disseminated to and useable by professional scientists, agencies, and/or managers" (Ballard et al. 2017, 66). According to Kozol (2005), young people can be trusted with input to scientific processes because they may approach issues without the biases of adults, particularly when scientists and

Members of Browns Valley 4-H in Yuba County and Franklin 4-H in Sutter County became citizen scientists and stepped into the role of biosecurity experts, sharing their experiences and recommendations with members of the Yuba-Sutter Fair board of directors.

teachers play an active role guiding inquiry. When youth are knowledgeable about the systems or contexts within which issues exist, as well as the associated science, they are less likely to be excluded from the process of developing and implementing solutions and can be powerful stakeholders in the process of community-based citizen science (Mueller et al. 2012).

Proficiency level 1

1. Complete "Bio-Security: Assessing and Preventing the Spread of Disease" activity.
2. Review Endemic and Foreign Animal Disease Matrix.
3. Complete "Animal Health Assessment" activity.
4. Complete 2 weeks of health journaling on own animal.
5. Submit completed Health Assessment Activity and health journal to 4-H project leader.

Proficiency level 2

1. Complete "Assessing Critical Control Points Associated with Disease Transmission" activity.
2. Review the on-farm Bio-Security Risk Assessment Tool.
3. Complete "Risk Assessment: A Picture Says a Thousand Words" activity.
4. Complete a Bio-Security Risk Assessment and document with photos or video.
5. Present completed activity and Bio-Security Risk Assessment to 4-H project leader.

Proficiency level 3

1. Complete the activities "Risky Business" and "Bio-Security and Financial Risk".
2. Complete the activity "Developing a Plan for Change in Bio-Security Practice".
3. Implement and document (photos or video) Plan for Change in Bio-Security Practice.
4. Present completed Plan for Change in Bio-Security Practice to 4-H project leader.

Proficiency level 4

1. Discuss options and create plan for public presentation on biosecurity.
2. Develop public presentation.
3. Deliver public presentation.

Proficiency level 5

1. Work collaboratively with county fair representatives to develop a plan to improve education outreach and biosecurity practices at fair.
2. Work collaboratively with fair representatives to implement plan to improve education outreach and biosecurity practices at county fair.

All materials are available at ucanr.edu/sites/youthscientificliteracy/.

FIG. 1. 4-H Bio-Security Proficiencies Program sequence.

Implementing science-based biosecurity practices in the care of 4-H animals is necessary to reduce risks associated with animal and zoonotic disease-causing agents. This is true both for home farms and public venues such as fairs and shows, to which youth travel with their animals as many as seven times during a single project year (Thunes and Carpenter 2007). The presence and persistence of fecal-borne pathogens (e.g., *E. coli, Giardia, Cryptosporidium, Salmonella* and *Campylobacter*) has been documented at California exhibitions (Daniels et al., unpublished; Keen et al. 2006; Roug et al. 2012), as have a number of practices associated with disease transmission risk such as fecal contamination of animal bedding and barn tools and infrequent use of hand-washing stations by visitors and exhibitors (Ibarra et al., unpublished; Smith and Meehan 2012).

Recent UC Agriculture and Natural Resources (UC ANR) outreach efforts have focused on biosecurity education using the 4-H Bio-Security Proficiencies Program (Smith et al. 2011; Smith and Meehan 2013; see figure 1). The program includes five proficiency levels: the first, second and third focus on the development of scientific literacy related to disease transmission, as well as skills development via the assessment and mitigation of biosecurity risks on their home premises. The fourth and fifth levels include community science actions, including assessing biosecurity risks at a local fair, and developing proposed solutions and collaborating with community stakeholders to implement changes in fair policies and procedures to support biosecurity risk reduction strategies.

The program has been shown to improve youth's conceptual understanding of biosecurity, advance their skills associated with best practices and support related risk mitigation strategies on home premises and at public venues (Smith and Meehan 2013). These findings are consistent with literature emphasizing the importance of authentic engagement in advancing understanding of scientific concepts (e.g., Bybee and McCrae 2011; Falk et al. 2007); however, little research exists regarding the application of scientific understanding by youth to influence biosecurity policies and practices within their communities.

4-H biosecurity risk management project

4-H youth from two counties in California participated in a long-term, science-based biosecurity and risk management project that included completion of the five levels of the 4-H Bio-Security Proficiencies Program. As an extension of the program, youth in this project also had the opportunity to continue their community science actions over several years through collaboration with university academics to develop biosecurity educational videos and additional outreach efforts designed to engage their communities.

Youth participants were recruited by collaborating county 4-H program representatives and youth development advisors. Recruitment efforts included presentations at 4-H project meetings, county council meetings, informational brochures and phone and email contacts. Participation was voluntary and required that youth attend 10 to 12 project meetings over several months. Fifteen youth, ranging in age from 9 to 14, from Yuba-Sutter 4-H enrolled in the project. All youth were enrolled in animal science projects involving the rearing and care of one or more animals. Annual 4-H enrollment fees were covered for all project participants.

Biosecurity education

In the first phase of the project, the 4-H youth participated in the 4-H Bio-Security Proficiencies Program (Smith and Meehan 2013), a multiweek education intervention facilitated by adult 4-H volunteers. The volunteers received professional development on science content and effective teaching strategies, following a modified version of the Step-Up Incremental Training Model (Smith and Enfield 2002), whereby educators' capacity is built systematically through a series of workshops that include face-to-face seminars and synchronous (real-time) distance learning technologies (e.g., Adobe Connect and teleconference calls). This approach to professional development integrates multiple strategies (e.g., extended duration, emphasis on pedagogical knowledge and reflective practice, use of online strategies) recommended for 4-H volunteers (e.g., Kaslon at al. 2005; Smith and Schmitt-McQuitty 2013). The workshops were facilitated by Dr. M. Smith and Dr. C. Meehan.

The 4-H Bio-Security Proficiencies Program follows the five-module sequence outlined in figure 1. Youth were required to complete each component of a proficiency prior to proceeding to the subsequent proficiency level. They submitted a proficiency checklist to document the completion of those requirements. All youth who completed the stated requirements were awarded a pin and certificate at each level as recognition and evidence of their achievements.

Youth surveys

After finishing each proficiency level, youth completed surveys that measured changes in knowledge and skills relating to the themes for levels 1 through 4. The themes were understanding disease transmission and monitoring animal health (level 1); critical control points and risk assessment (level 2); financial risk assessment and mitigation planning (level 3); and risk mitigation action, communication and advocacy (level 4).

The surveys were designed using a retrospective format to reduce response shift bias, a threat to internal validity that can arise when using a pre/post format (Raidl et al. 2004). Surveys included five sets of paired questions: question A asked about the youth's current level of knowledge or skills relative to a specific topic after the educational intervention (post); question B asked about the youth's level of knowledge or skills relative to the same topic prior to the educational intervention (pre). Each question had four response categories ranging from poor to excellent. Four response categories were used to help ensure discriminating answers by participants and eliminate the potential misinterpretation of a midpoint (Croasmun and Ostrom 2011).

The survey response data were ordinal and not normally distributed; thus, the Wilcoxon's signed-ranks test was used to determine change between post and pre responses. Item-level analyses were conducted to allow for identification of differences within each survey. To demonstrate changes in both domains (knowledge and skills) across the four proficiency levels, we analyzed responses to all nine knowledge questions and all 11 skills questions combined.

Biosecurity recommendations made by 4-H youth were implemented by the Yuba-Sutter Fair leadership, including adding additional hand-washing stations.

Members of Browns Valley 4-H in Yuba County and Franklin 4-H in Sutter County participated in the Bio-Security Proficiencies Program offered by UC Davis. The members were very excited to see how choices they make actually affect their livestock. They saw firsthand why they can't be sloppy and pour grain into the pen. There are reasons for feed troughs. Members learned how pathogens are transferred. They realize how pathogens transfer from shoes to mouth if biosecurity standards aren't kept. The teens are more energized to share their videos with peers and community members about biosecurity. They want other 4-H members to know how to reduce the spread of diseases. They worked hard on their research and are doing things in the community to share the experience and the results of what they learned.

—Tracy Bishop, 4-H program representative, UCCE Yuba-Sutter

TABLE 1. Results of Wilcoxon's signed-ranks test comparisons for each proficiency level (P1, P2, P3, P4) by survey question (1 to 5)

P1: Understanding disease transmission, monitoring animal health					
Q	P1-1	P1-2	P1-3	P1-4	P1-5
n	13	13	13	13	13
W	−38	−37	−55	−55	−66
$N_{s/r}$	9	9	10	10	11
p	0.05	0.05	0.002	0.002	0.001
P2: Critical control points, risk assessment					
Q	P2-1	P2-2	P2-3	P2-4	P2-5
n	15	15	15	15	15
W	−78	−78	−91	−68	−105
$N_{s/r}$	12	13	13	12	14
p	0.001	0.003	0.000	0.004	0.000
P3: Financial risk assessment, mitigation planning					
Q	P3-1	P3-2	P3-3	P3-4	P3-5
n	15	15	15	15	15
W	−80	−80	−66	−45	−105
$N_{s/r}$	13	13	11	9	14
p	0.002	0.002	0.001	0.01	0.001
P4: Risk mitigation action, communication and advocacy					
Q	P4-1	P4-2	P4-3	P4-4	P4-5
n	14	14	14	14	14
W	−45	−36	−36	−105	−45
$N_{s/r}$	9	8	8	14	9
p	0.01	0.01	0.01	0.001	0.01

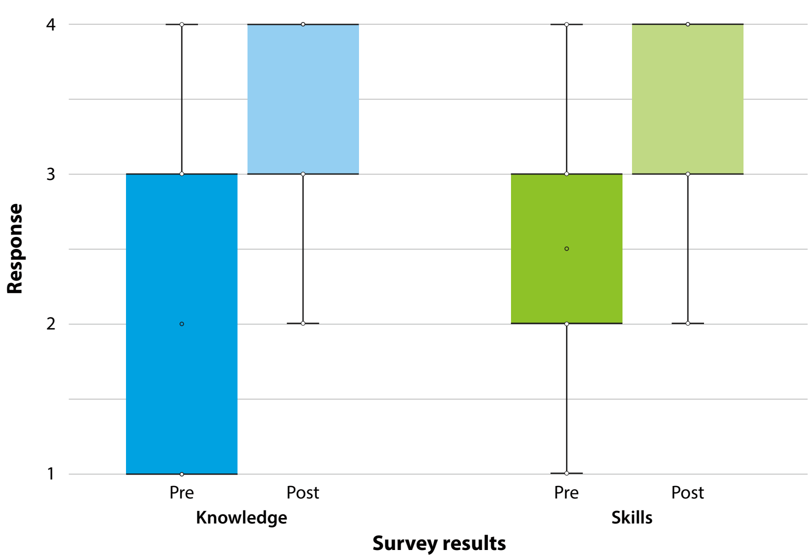


FIG. 2. Box and whisker plot of pre and post survey responses for knowledge- and skills-based questions.

Survey results

Significant ($p < 0.05$) improvements in survey response were found for all 20 questions across all four proficiency levels (table 1, fig. 2). Looking at the responses by domain, we found that the interquartile range of pre knowledge was broader than for pre skills, indicating a wider range in reported knowledge than skill abilities at the outset of the program. Increases from pre to post were significant for both knowledge and skills (knowledge: $W = -3{,}913$, $z = -7.38$, $p < 0.0001$; skills: $W = -4{,}900$; $z = -8.42$, $p < 0.0001$).

Community science at the county fair

Levels 4 and 5 of the Bio-Security Proficiencies Program focus on the communication and extension of knowledge and skills gained through the previous three levels (see figure 1). These proficiencies are the heart of the community and citizen science component of the program, as they ask youth to step into the role of biosecurity experts and share their experiences and recommendations with others in their community. To meet this requirement, youth participants developed and presented biosecurity improvement plans to leaders and officials of the Yuba-Sutter Fair.

Recommendations made by youth were taken under consideration by fair leadership, and changes in practice were implemented. Youth described examples of the improvements, including adding additional hand-washing stations and signage in and around barns and replacing the long-standing practice of mixing species in "champions row" with individual champion pens in species-specific barns to reduce the risks of pathogen transmission associated with interspecies contact.

Community outreach videos

In the year following their completion of the Bio-Security Proficiencies Program, 4-H youth participants had an additional opportunity to share their experiences and knowledge with the broader fair and exhibition community. They helped a team from UC Davis Veterinary Medicine Extension develop three educational videos on science-based biosecurity best practices. In the videos, funded by the California Department of Food and Agriculture, youth made on-camera appearances and summarized their understanding of biosecurity risks, related their experience in risk assessment and mitigation and made recommendations to improve practices. The videos targeted three audiences: fair administrators, youth livestock exhibitors and the general public. The videos were posted on the Yuba-Sutter 4-H Facebook page, where they were viewed over 3,000 times in the first 24 hours. Videos can be accessed at ucanr.edu/sites/bio-securityeducation/.

Youth reflections

After participating youth had completed the Bio-Security Proficiencies Program and the videos project, we conducted a focus group interview with them and their project leader to gain more insights into their experiences. Focus groups are carefully planned discussions that collect information from a specific group of individuals (Kreuger and Casey 2015).

In response to a focus group question on why they became interested in the Bio-Security Proficiencies Program, youth responded as follows:

Our initial interest in the project was to learn more about safety and cleanliness for animals, not only for the animals but for people, too. We wanted to learn better ways to take care of our farm animals to make sure they're less susceptible to diseases. Additionally, by learning about biosecurity, we could help make sure our livestock and other animals were safe around us and other people; it was just safer for everyone. Lastly, by learning to make improvements in biosecurity we can help create a clean and safe product for consumers.

Youth described understanding the connection between biosecurity practices relating to hygiene and disease prevention.

We learned new ways to keep a clean environment for our animals, and that it's easier to clean your stalls every day so waste doesn't build up and make it worse for the animal. By doing this, it helps keep our animals from being exposed to some of the diseases we encounter in everyday life.

The project leader also described the incorporation of new practices into animal care routines as a result of youth learning about the importance of biosecurity to the health of their project animals.

For example, since participating in the project, [a 4-H youth] now disinfects his animals' pens before the animals arrive, and [a 4-H youth who had prior experience with a sick animal] started cleaning the water nipples and other tools regularly. [A 4-H youth] also began keeping her animals separated at home to reduce the likelihood of disease spreading between the different species in her care.

Over and above making changes to their practices at home, participating youth applied their knowledge about biosecurity to the care and housing of their animals at the Yuba-Sutter County Fair. The fair, as a public venue, presents different biosecurity risks and mitigation challenges given that youth exhibitors must contend with visitor behavior and may have limited control over how and where their animals are housed. Youth described individual decisions they made to improve biosecurity practices with their animals; additionally, they explained how they collaborated to make some larger-scale changes to support better biosecurity for the broader community of fair exhibitors and visitors.

The fair is the "big thing" for our 4-H program, and there are many people around the animals and touching them. So last year at our local fair we put up a rope at the back end of the beef barns to make sure people don't go over to our cattle and touch them. We also worked to keep their water cleaner. We put filtered water in their big water trough and put fish in their water to make it cleaner and more like home so the cows would drink. We've added hand-washing stations at the fair, so when you go from one barn to the next you can wash your hands so that you don't spread diseases to the other animals. There are also signs at the fair that remind people to wash their hands after they touch animals.

Although the Bio-Security Proficiencies Program had concluded over 2 years before, the 4-H youth described having sustained their engagement through a variety of outreach education efforts, some of which were recounted by their project leader:

[4-H youth] advised visitors at this year's fair to wash their hands before they pet other animals so they wouldn't transfer germs. These fair visitors responded in a positive manner and washed their hands. [A 4-H youth's] swine group presented on biosecurity best practices at their club meetings, informing 4-H members from other species

Yuba-Sutter 4-H

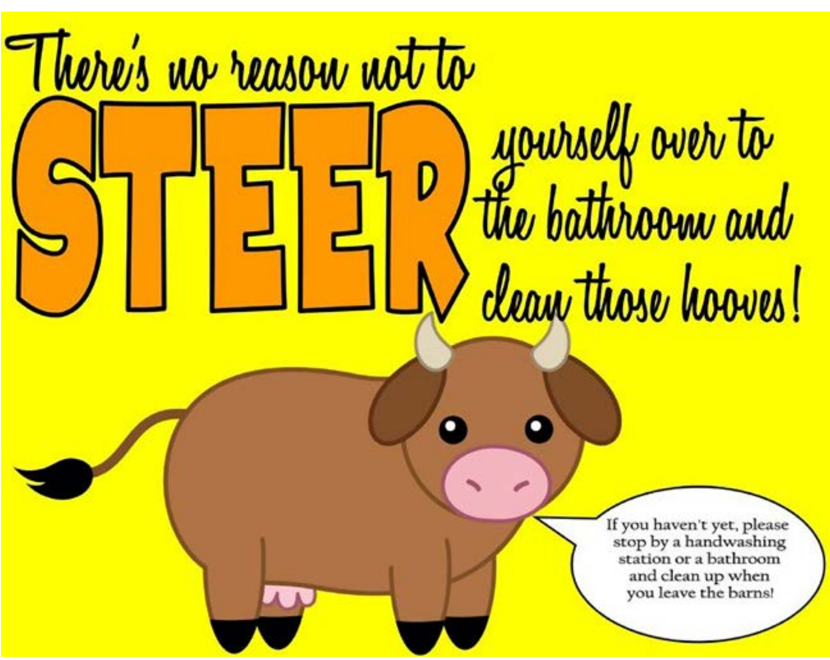
To reduce the risks of pathogen transmission associated with interspecies contact, a significant change was made in the long-standing practice of mixing animal species in the "champions row." After presentations by 4-H youth, champions were housed in individual champion pens in species-specific barns.

groups and encouraging them to participate in good biosecurity practices. We were also involved in developing educational videos on biosecurity that demonstrated good practices at home and the fair. [A 4-H youth] spoke to FFA [Future Farmers of America] members at his high school. He said it opened their eyes to biosecurity and that his talk gave them a different perspective on the importance of keeping animals and their environments clean and the consequences if they are not.

Youth also shared their ideas regarding future opportunities to further develop their involvement with biosecurity education and outreach. They indicated their interest in expanding their roles as educators, mentors and resources to their broader 4-H community.

Biosecurity recommendations made by youth were taken under consideration by county fair leadership and changes in practice were implemented.

In the future, we as teen leaders should start doing lessons on biosecurity with new 4-H members early in the season before they get their animals. That way, they can have a little bit of background knowledge on biosecurity and we can keep the trend going further. So if we kept it going for the next couple of years it could keep carrying on down the line. [A 4-H youth] suggested that the group of 4-H members that did the Bio-Security Proficiencies Program could go around to different clubs in the area and give presentations and spread their knowledge with everybody in the area. It could help create lots of differences at the fair. Additionally, the group could do a field day presentation and demonstrate to other 4-Hers how to keep project areas and pens clean, both at home and at the fair. This could even be a 4-H Emerald Star project.



Signage to encourage hand-washing was one of the improvements at the Yuba-Sutter Fair that emerged from local 4-H youth completing the 4-H Bio-Security Proficiencies Program.

Youth became community science experts

Youth participants in this project developed expertise in science-based concepts regarding disease transmission and risk assessment. In addition, they built skill sets around risk mitigation and the application of best practices to home and fair settings. These experiences provided important, real-world contexts for youth to engage in and extend science. Through this experience, youth became community science experts and combined their scientific knowledge and skills with their experience in their communities to inform actions that pertained to relevant issues (Barton et al. 2013).

When youth are in this role, they are situated as experts in their communities and can help make a difference through the application of science in authentic ways. Additionally, with the scientific expertise youth bring to bear on relevant issues, the power dynamics within a community can be reorganized such that authority is shared and youth are recognized as having the capacity to lead (Barton et al. 2013). We saw evidence of this in the interactions between youth and the fair leadership, where a sustained relationship was developed that resulted in tangible, positive actions being taken to improve biosecurity practices.

According to Wandersman (2003), one important aim of community science is to help enhance the quality of life in a community through strategies such as prevention, health promotion and education. 4-H youth involved in this project became community science experts through their participation in the Bio-Security Proficiencies Program. Specifically, they advanced their knowledge and skills related to concepts such as modes of disease transmission, animal health assessments, biosecurity risk assessment and risk mitigation.

Subsequently, in the role of community science experts, the 4-H youth helped to improve the well-being of their community by identifying biosecurity risks at their local fair and presenting their findings and making recommendations (education) to fair authorities (Zaff et al. 2010). Youth worked with county fair representatives to implement many of their recommendations that focused on reducing pathogen transmission (disease prevention) to lessen the incidence of animal and zoonotic diseases (health promotion).

Not only did 4-H youth in this project follow the design principles outlined by Barton et al. (2013) to develop scientific expertise around a relevant issue and educate others within their community during the project, they sustained their engagement in community and citizen science efforts. Youth continued to work with their local fair to make additional site improvements to promote biosecurity; they engaged in the development of educational videos designed to educate the general public, fair exhibitors and fair administrators about good biosecurity practices at fairs and shows, they made presentations to various 4-H and Future Farmers of America (FFA) audiences and they made plans for future education outreach endeavors.

Relevant and meaningful engagement

When science is positioned from the perspective of the individual and is situated within authentic science-related situations that may be encountered in everyday life, science understanding and abilities become relevant and meaningful to the learners (Falk et al. 2007; Roberts 2007). This approach to advancing youth scientific literacy — referred to as a citizen's perspective — is emphasized in California 4-H (Roberts 2007; Smith et al. 2015). Specific to this project, it was important to the participating 4-H members to apply good biosecurity practices to the environments where they raised and showed their livestock; additionally, they saw the importance of sharing their knowledge and skills with other youth exhibitors, fair management and community members.

This project provided insights into how content and skills learned by youth through their participation in a 4-H curriculum can inform a meaningful service-learning project that is extended to members of their community. All of the curriculum materials needed to implement the Bio-Security Proficiencies Program are available free of charge at ucanr.edu/sites/youthscientificliteracy/.

We envision the Bio-Security Proficiencies Program as an important component of 4-H Animal Science projects where livestock, poultry or small mammals are raised for exhibition and recommend that it be incorporated into traditional 4-H Animal Science programs. Using it, 4-H staff and volunteers can support improvements in knowledge, skills and community science practices among youth members, and, potentially, reduce the risk of a disease event within their membership or community. CA

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RESEARCH ARTICLE

Engaging the importance of community scientists in the management of an invasive marine pest

Sustainable management of a nonnative predatory crab in a coastal lagoon in Northern California succeeded due to the involvement of community scientists.

by Edwin Grosholz, Sabrina Drill, Linda McCann and Kate Bimrose

Online: https://doi.org/10.3733/ca.2021a0006

Abstract

The introduction of nonnative invasive pests is among the many threats facing coastal ecosystems worldwide. Managing these pests often requires considerable effort and resources, and community scientists can be essential for providing the capacity needed for management and monitoring activities. In response to the invasion of a Northern California estuary by the predatory European green crab, a collaborative team of academic researchers and community scientists initiated a local eradication program. The green crab is listed among the world's 100 worst invaders, and threatened both native species and commercial shellfisheries. The program dramatically reduced the green crab population over a 5-year period, but it rebounded, which necessitated a switch in project goals from eradication to population suppression. Community scientists were essential for facilitating this switch by providing the necessary capacity to quantify population characteristics and maintain reduced crab populations. The result was a sustainable program that successfully maintained low green crab densities, which will likely improve habitat for native species.

Among the many threats to coastal ecosystems around the world is the ongoing introduction of nonnative species — the problem shows no sign of abating, and, for most invasive taxa, introduction rates are increasing (Seebens et al. 2017). The numbers of nonnative species in coastal areas of California, like many similar areas in the United States, continue to grow as the result of human-mediated movements of species from other regions, often by ballast water and hull fouling associated with commercial shipping. Effectively managing invasive species requires consistent monitoring over time and throughout the area of infestation.

Involving community members in monitoring can be a first step toward building capacity for under- or unfunded programs to undertake the kind of large-scale monitoring required to manage the most

The invasive European green crab (*Carcinus maenas*). The involvement of community members was key to the success of the sustainable management program that significantly reduced the abundance of this crab in a Northern California estuary.

significant invasions (Johnson et al. 2020). In addition, involvement of community scientists in identifying the arrival of new invasive species or managing ongoing invasions can allow for rapid response, effective monitoring and increased public support for management actions. The application of community science to address invasive species has been shown to be successful for management of plants and pests (e.g., Gallo and Waitt 2011; Meentemeyer et al. 2015).

We use the term *community* science to describe the process of involving members of the public in scientific research. We eschew the common term *citizen* science because of the association of citizen with immigration status; we are not interested in the legal immigration status of those individuals we seek to work with. We believe this choice of terminology appropriate for the community science field as a whole, and particularly important for invasive species projects. Invasiveness, like immigration status, is only meaningful in specific geographic contexts. Managing the movement of species outside of their native range, into environments where they may detrimentally impact local ecosystems and thereby become "invasive", can require global cooperation among peoples in multiple countries. Emphasizing national boundaries through use of the term citizen can deter that kind of cooperation.

Here we document the successes of, and challenges to, a community science program that was able to address the need for intensive monitoring, public education and engagement, and capacity building for the management of a recent introduction of a nonnative predatory crab. Involvement of community scientists was essential for the success of this program, which has significantly reduced the abundance of this invasive species in a local habitat.

Community scientists participated in a full range of activities from primary data gathering and recording to ongoing project management. This allowed community members to take a more deliberate role in decisions about future actions. The project ran initially as a collaboration among scientific researchers and volunteer community scientists. Over time, it shifted to a program that is now run almost entirely by volunteer community scientists. The efforts of the community scientists have resulted in a sustainable management program, which has reduced the abundance of the invasive crab and will lead to improved habitat for native species.

European green crab on West Coast

The European green crab (*Carcinus maenas*) has been introduced to several continents around the world (fig. 1). The species was first detected on the west coast of North America in San Francisco Bay in 1989 (Cohen and Carlton 1995). Management concerns began as the crab continued to spread along the coast, north and south from San Francisco (fig. 1). The European green crab has substantially impacted native species in nearby estuaries and threatened to have significant negative impacts on local shellfisheries (Grosholz et al. 2000; Grosholz 2005; Grosholz et al. 2011). A population of green crabs was observed in 1996 (E. Grosholz, personal observation) in the small, semi-enclosed Seadrift Lagoon in Stinson Beach (fig. 2).

The Pacific States Marine Fisheries Commission, a federal agency with authority over fisheries from California to Alaska, was concerned about the potential impacts of the crab's arrival on shellfish populations in the Pacific Northwest and Alaska. With initial funding from this agency, a consortium of three institutions, UC Davis, the Smithsonian Environmental Research Center and Portland State University, undertook a proof-of-concept approach to determine

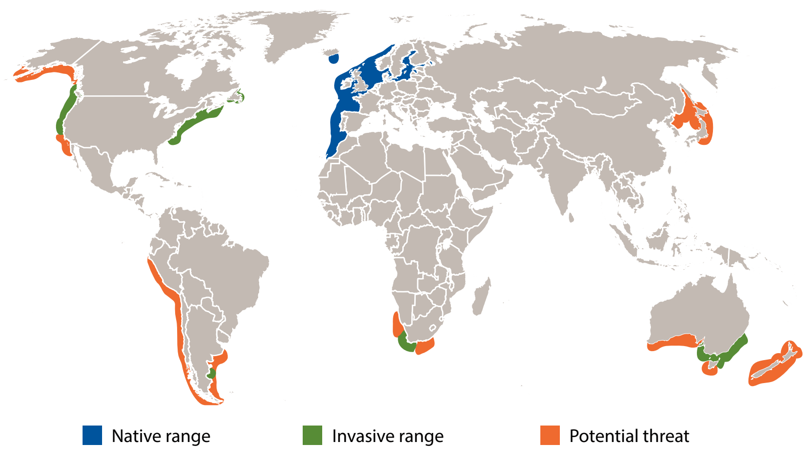

FIG. 1. European green crab distribution extends far beyond the native range and is a potential threat to several coastal areas around the globe.

FIG. 2. Map of Seadrift Lagoon, adjacent to Bolinas Lagoon and north of San Francisco, where green crabs were first found in 1996.

the effectiveness of a small-scale trapping program to remove crabs. The initial goal, from 2009 to 2014, included working with community scientists and was primarily science oriented: to understand the effort needed to reduce or eradicate this isolated population of European green crab.

Engaging community scientists

In the process of planning for the intensive trapping, we realized that we would need additional capacity to manage a network of up to 120 baited traps per day. We were able to engage local volunteers initially recruited from the list of homeowners provided by the Seadrift Homeowners Association. Local homeowners also donated the long-term use of their property, dock and water access to support the necessary field activities. Within a year of the project start, we had engaged a local resource management agency, the Gulf of Farallones National Marine Sanctuary, now called the Greater Farallones National Marine Sanctuary (GFNMS), which had been supporting other nearby restoration programs. GFNMS maintained a substantial list of people from the region who would routinely volunteer their time with local restoration projects supported by GFNMS, including local residents and students from summer camps and schools.

Community scientists shown collecting data from the crabs trapped in Seadrift Lagoon (background).

Small female European green crab captured as part of a population wide mark-recapture survey in which crabs are marked by clipping the two right most anteriolateral spines.

As the program progressed, its goals evolved. In 2014, after 5 years of sustained trapping efforts that had successfully reduced the green crab population to 10% of its 2009 size, there was an explosion of juvenile European green crabs, resulting in a 300% increase in catch per unit effort (see Grosholz et al. 2021). It became clear that eradication was likely not possible, so after 2014 the project focused on suppression of the green crab population. The goal changed to maintaining a small population using a sustainable management program relying on public engagement.

In alignment with the new focus, we increased our efforts to educate community members about the impacts of invasive species such as the European green crab and the possibilities for restoring native fishes and invertebrates. There was also an increased focus on encouraging community members to take a larger role in the green crab removal program. Community scientists were asked to participate in many aspects of the monitoring.

The primary activities of the program involved trapping, which served both a monitoring and a management function. It allowed us to collect data about population dynamics and demography, and served as a method of invasive species management as trapped crabs were removed from the system. In introductory discussions with trapping volunteers, we explained the larger goals of the program as well as recounting past successes and missteps. We described the impacts that European green crab had on local shellfisheries and native species along the California coast as well as the specific impacts in Seadrift Lagoon, so that community members would understand the importance of their participation.

At the start of trapping periods, new program members were shown how the traps were collected, rebaited and redeployed. We trained them in processes involved in data collection by showing them how to (1) distinguish green crabs from native crabs, (2) safely handle crabs that were retrieved, (3) determine sex and reproductive status (females with eggs), (4) distinguish different types of injuries, such as lost claws and legs, (5) measure the size of crabs, (6) identify previously captured crabs, by their clipped spines, and (7) accurately record and check data.

Our use of mark-recapture surveys as a method of estimating the size of the crab population was explained. During the weeks when we were conducting those surveys, we instructed community scientists how to mark a captured green crab by clipping pairs of its anterio-lateral spines and how to log its location (trapping station).

All data were collected daily on waterproof data sheets during crab trapping periods, collated, and checked by volunteer coordinators. These data were subsequently transmitted to researchers and underwent a check for quality and accuracy by a seasonal assistant. Data were archived on the UC Davis server and are publicly available.

Eradication failure, 2009 to 2014

Despite a considerable trapping effort, we were unable to eradicate the European green crab from Seadrift Lagoon. However, many of the control and management goals of the project were met. Initially, there was a dramatic reduction of the green crab population in Seadrift Lagoon, from 125,000 crabs in 2009 to < 10,000 crabs by 2013 (Grosholz et al. 2021). That 90% reduction in the population was followed in the spring and summer of 2014 by a dramatic population explosion of the green crab (Grosholz et al. 2021). Using an extensive mark-recapture effort, we estimated the population in August 2014 was > 350,000 crabs, which was more than a 30-fold increase over the numbers in 2013 and nearly triple the population size in 2009 (~ 100,000), when the removal efforts began (fig. 3).

Subsequent studies and population genetic evidence strongly support the idea that this dramatic recruitment of the invasive crab was the result of local population dynamics (Grosholz et al. 2021). Theoretical models of both fisheries and nonnative species management show similar effects of intensive harvest of predatory species. In such harvested populations, there is evidence of unusual reproductive success, more formally known as overcompensation (de Roos et al. 2007). There are, in fact, a few striking examples of introduced species control programs going wrong, like ours. One is the 7-year effort to remove smallmouth bass from lakes in upstate New York, which resulted in greater bass abundance, primarily due to increased juvenile survival (Weidel et al. 2007).

We had inadvertently reduced the population of green crabs to the point where the population control of recruitment by adult green crabs was gone. Normally, adult green crabs would cannibalize most of the newly recruiting juvenile crabs, but now, with most of the adult crabs removed, the newly recruiting juveniles survived to enter the population in record numbers. Documenting this rebound in the crab population derived from the participation of numerous community scientists and local observers. It drew a considerable amount of media attention due to the counter-intuitive outcome.

Sustainable management, 2015 to present

As described earlier, after 2014, we refocused our efforts with the community toward developing a sustainable green crab management program in the Seadrift Lagoon. Many volunteers had heard of the population explosion or witnessed it firsthand and were eager to participate in removal efforts. These efforts have included dozens of volunteers since 2015, with an average of 60 person-hours per week dedicated to trapping, data collection, mark-recapture studies and related activities.

With this much effort, we have been able to reduce the abundance of invasive green crabs. From 2015 until the time of this writing, we have reduced the crab population to 20% to 30% of the 2014 population and maintained it at that level. This level seems a sustainable population size, given the available effort by volunteers; and not reducing the adult crab population below 10% reduces the possibility of repeating the population explosion of 2014. The current sustainable green crab density will likely permit increased colonization by native species and recovery of ecosystem function over time. Maintaining it is only possible through the continued participation of community volunteers in the now annual summer trapping program.

Our program was successful from several perspectives. Many dozens of local homeowners and their families participated in this project over several years. It was also very successful in regard to the quality of the work provided by the community scientists. While retention of volunteers across years remained challenging, we were successful in continuing to engage new participants each year. There are trade-offs between retaining experienced volunteers and engaging support from a larger proportion of the community — in our case, we believe the program benefitted from the latter.

We have data on the volunteer hours for the 2018 and 2019 removal seasons; they show 57 volunteers worked a total of 460 hours removing and recording

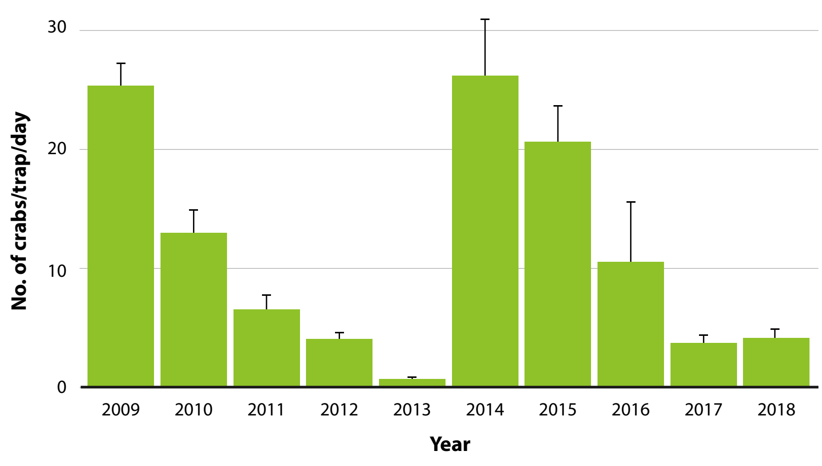

FIG. 3. Number of crabs captured per trap per day, or CPUE (catch per unit effort), over a standardized trapping period (typically 3 months) at Seadrift Lagoon from 2009 to 2018.

data on green crabs. The volunteers included 12 children from a nearby summer camp. Several of the 2018 volunteers returned in 2019 to continue to help with the project. The program manager currently has a list of over 40 volunteer community scientists who wish to receive annual announcements on the dates and times of upcoming removal seasons.

The program, and our informal conversations with participants, helped contribute to a better community understanding about European green crab population processes and how to manage the local green crab population long-term. We communicated with participants on a wide range of subjects regarding the ecology of Seadrift Lagoon and the surrounding ecosystem. The project team was engaged in learning as well, as some of our volunteers were knowledgeable and had useful information to share with us about the lagoon and its invertebrate inhabitants.

Education goals

As stated above, over the course of the project, the goal shifted from eradication to suppression of the crab population over the long term. As the goal evolved, we realized how important it was for the community to understand the underlying issues as well as the more immediate goal of project. In other words, our green crab management efforts could benefit from work on two interrelated educational goals: (1) awareness and understanding of our particular project and (2) overall understanding of green crab population dynamics, and more generally the threats posed by marine invasive species.

Our trapping program was visible to homeowners and particularly to seasonal renters, who were among the most numerous community members, and who observed groups of volunteers handling crabs and recording data on docks along the perimeter of the lagoon. Initially, we asked the Seadrift Homeowners Association to distribute information to homeowners and renters by posting signs at entrance and exit gates, and in informational packets dispersed to homes prior to each rental stay. The information alerted people of our activities around the lagoon and emphasized the need to not disturb deployed traps.

The information distribution was not particularly effective in recruiting volunteers, partly because many of the people who received it were there only for a short rental stay. We realized that involving the local homeowners in the process of population control would be a much more effective education tool than just posting a flyer. Despite the considerable time that local homeowners and renters spend on coastal recreation (swimming, surfing, sailing, kayaking, paddle boarding, etc.), multiple informal conversations with homeowners suggested a lack of knowledge regarding the issue of invasive green crabs. Consequently, we expanded our efforts with the assistance of the Seadrift Homeowners Association to increase outreach to community members by participating in Homeowners Association board meetings and public events.

Ultimately, the trapping and population management project proved to be an effective teaching opportunity to show homeowners and renters the impacts of European green crabs and to make them aware of how their own activities could contribute to crab population management. We have not formally quantified this result with before/after survey methods, but informal conversations with homeowners, and other anecdotal evidence, have indicated a significant shift in both their awareness of the problems caused by green crabs as well as their understanding and acceptance of our management activities.

When we began the green crab management program, there were complaints from homeowners to the Homeowners Association regarding our activities. Some homeowners were put off by our presence, and their children enjoyed capturing the very numerous green crabs in one shallow area. However, as the program progressed and we involved more people in the community science activities, they learned and found the idea appealing that their kids would have a greater variety of crabs and other species to capture if we could reduce the number of green crabs. As a result, some households began their own informal management activities, capturing green crabs with makeshift traps and bait.

A significant education opportunity occurred following the media coverage on the crab population explosion. We explained the failed eradication program to the broader community and the need to maintain a low but sustainable population level of green crabs, in hopes of facilitating the repopulation of native species.

Changing role of community scientists

As the goals of the project changed, the role of community members changed as well. The community scientists started to participate not only in the trapping but also in collecting demographic data, including the mark-recapture survey data described above. A few community scientists also took an active role in the data collation and data organization. As of 2019, the project has been managed entirely outside of the academic realm except for the ultimate use of the data. All of the management activities, the trapping, counting and mark-recapture assessments, are now organized by community scientists working in partnership with the program coordinator, Kate Bimrose, and the Greater Farallones Association.

Challenges and lessons learned

Along the way, we learned several important lessons from this project. The first is the difficulty in maintaining a long-term community science program, which became necessary once eradication was not a likely outcome. We learned the importance of being able to recruit new volunteers into the program, and that the recruitment of volunteers was often a function of the effort put into it. As in similar projects (e.g., Gallo and Waitt 2011), we experienced a volunteer fatigue factor; it is often difficult to encourage participation across multiple years. This challenge was addressed by the willingness of the local resource management agencies to devote staff resources toward recruiting new community scientists, and our cooperation with the Seadrift Homeowners Association. In casual conversations with some homeowners, we heard they were participating in restoring or maintaining habitat quality based on their sense of ownership of the area.

The second lesson we learned was the essential role of a volunteer coordinator for projects like ours. Maintaining the trapping surveys requires considerable skill and energy to reach out to volunteers, schedule numerous volunteers throughout the trapping season, coordinate with larger groups like schools and summer camps, maintain trapping equipment and supplies, and so on. A very organized and dedicated person is needed to undertake the responsibilities of organizing these efforts. The current coordinator, Kate Bimrose, participated as a volunteer early in the project and thus had all the necessary project skills and was proficient in data collation and management.

The third lesson we learned was that involving younger community scientists, with school and camp groups, requires preparing more active learning opportunities. We occasionally facilitate these activities by training teachers or camp counselors in the day-to-day work of the trapping surveys.

Although we were not able to eradicate the invasive European green crab from Seadrift Lagoon, we have met the challenge of reducing green crab numbers since 2009. Each trapping season since 2014, the number of green crabs has declined; and we have been able to measure the relationship between trapping effort and population reduction (table 1), a central goal of the project. But with the decline in green crab numbers, the effort needed to remove the remaining crabs increases exponentially. With limited staff and resources, this highlights the necessity of involving local communities in research projects to limit invasive pests.

Community volunteers can expand scientific efforts both in time and space, and increase public knowledge about important environmental issues such as invasive species. Our project demonstrated both the benefits of engaging community scientists as well as the challenges involved in recruiting and maintaining volunteer groups and educating and training the participants. It is our hope that community volunteers will sustain the crab management effort in Seadrift for years to come. CA

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TABLE 1. Relative trapping effort for reducing European green crabs at Seadrift Lagoon, 2009–2018

Year	Trap days*	CPUE†	Relative effort‡
2009	1,260	27.2	46
2010	1,380	10.4	133
2011	1,530	6.3	242
2012	840	3.5	239
2013	600	0.6	952
2014	2,070	22.4	92
2015	1,680	13.4	125
2016	1,260	8.9	142
2017	1,620	4.1	399
2018	1,440	3.8	381

* Trap days = no. of traps per site × no. of sites × no. of trapping days from May to October of each year.
† Catch per unit effort (CPUE) = mean no. of crabs captured per trap day.
‡ Relative effort = trap days divided by CPUE.

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Online UC ANR webinars and classes

UCCE Statewide Prune Day

Date: Feb 24, 2021
Time: 8:30 a.m. to 12:30 p.m.
Location: Online
Contact: Luke Milliron, lkmilliron@ucanr.edu or 530-828-9666

Irrigation Management Tools and Technologies

https://ucanr.edu/sites/Test1/files/343456.pdf

Date: March 3, 2021
Time: 9:00 a.m. to 11:00 a.m.
Location: Online
Contact: Registration: Andrea Ramirez aiestrada@ucanr.edu; content: Ali Montazar, UCCE Imperial County amontazar@ucanr.edu or 442-265-7700

Agritourism Intensive for Mendocino, Lake and Sonoma counties

https://ucanr.edu/AgtourMendo

Date: March 3, 2021 to April 7, 2021, every Wednesday morning
Time: 10:00 a.m. to 12:00 p.m.
Location: Online
Contact: Penny Leff, UC SAREP paleff@ucanr.edu or 530-902-9763 (cell)

Turning Dirt into Gold – UC Master Gardener Program El Dorado County

http://mgeldorado.ucanr.edu/Calendar/

Date: March 20, 2021
Time: 9:00 a.m. to 10:30 a.m.
Location: Online
Registration: https://ucanr.edu/survey/survey.cfm?surveynumber=32834