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Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation

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ABSTRACT

Citizen science by youth is rapidly expanding, but very little research has addressed the ways programs meet the dual goals of rigorous conservation science and environmental science education. We examined case studies of youth-focused community and citizen science (CCS) and analyzed the learning processes and outcomes, and stewardship activities for youth, as well as contributions to site and species management, each as conservation outcomes. Examining two programs (one coastal and one water quality monitoring) across multiple sites in the San Francisco Bay Area, CA, in- and out-of-school settings, we qualitatively analyzed in-depth observations and pre- and post-program interviews with youth and educators. First, we examined evidence from the programs' impacts on conservation in the form of contribution to site and species management. We found that youth work informed regional resource management and local habitat improvement. Second, we examined the youth participants' environmental science agency (ESA). ESA combines not only understanding of environmental science and inquiry practices, but also the youths' identification with those practices and their developing belief that the ecosystem is something on which they act. We found that youth developed different aspects of environmental science agency in each context. We identify three key CCS processes through which many of the youth developed ESA: ensuring rigorous data collection, disseminating scientific findings to authentic external audiences, and investigating complex social-ecological systems. Our findings suggest that when CCS programs for youth support these processes, they can foster youth participation in current conservation actions, and build their capacity for future conservation actions.

1. Introduction

As conservation science and practice increasingly address key challenges in the context of social-ecological systems, we need to better understand how people learn and take actions within those systems. In particular, understanding how environmental and science learning are related to conservation behaviors, now and in the future, is a crucial component of addressing conservation issues from global climate change, degrading water and air quality, biodiversity loss, habitat fragmentation, and fisheries collapse (Monroe, 2003; Schultz, 2011). Positioned as a means to accomplish education and conservation science, citizen science projects have increased in the last decade, (Bonney et al., 2014; Theobald et al., 2015). We refer here to community and citizen science (CCS) as activities or programs in which members of the public collaborate with professional scientists on scientific research and monitoring in either scientist-led or community-led endeavors. CCS, inclusive of citizen science, often includes participants collecting data, but may also include designing the research question and methods, data analysis and interpretation, and/or disseminating conclusions to research and decision-maker audiences (Bonney et al., 2014; Shirk et al., 2012). We specifically include community science, as well as citizen science, in order to include projects that are specifically community-led, often targeting environmental justice issues, that may not identify with the term citizen science (Pandya, 2012). Increasingly, these CCS efforts include youth (up to 18 years old) as well as adult participants.

Educators and conservation organizations have enormous expectations for youth participation in CCS ranging from science learning outcomes, environmental stewardship outcomes and connection to place, and positive youth development through civic engagement (Barton, 2012; Bonney et al., 2015; Krasny et al., 2014). Understanding how youth participation in CCS might contribute to conservation requires a close look at how youth-focused CCS actually happens, and the nature and role of learning and participation. That is, how do youth involved in CCS participate in environmental science and decision-making, what outcomes for conservation occur in the near-term, and in what ways might this participation involve science and environmental learning that will help youth contribute to environmental problem-solving into the future? In this paper we address these questions by examining

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case studies of youth-focused CCS programs, in both in-school and community-based contexts, with the goal of better understanding the role of CCS in enabling members of the public to understand and contribute to environmental problem-solving.

1.1. Conservation impacts of youth CCS

Despite its potential, there is increasing but limited evidence of conservation impact from adult-focused CCS, which we review below, and few have studied whether and how youth-focused community and citizen science contributes to conservation. Conservation impacts are difficult to measure, but Kapos et al. (2008) developed a useful evaluation framework, suggesting six areas of conservation activities that contribute to conservation directly (through site and species management) and indirectly (through education, research, livelihoods related to conservation, and policy). For CCS, which typically targets research, management and education, we consider two main ways youth-focused CCS may contribute to conservation via the data they collect and via impacts on the youth as individuals: 1) *Conservation research and management* - the scientific information generated can inform conservation research and site, species, and land management, and 2) *Conservation learning and action* - the individual participants in the project can learn and be otherwise personally impacted by participating, such that they behave in environmentally responsible ways individually or collectively, immediately, and/or in the future. We cluster both learning and action because these are impacts on the individual, rather than about the impacts of the data collected to inform conservation.

Recent evidence demonstrates that citizen science-generated data derived from CCS have been used effectively in both conservation research (Theobald et al., 2015), and natural resource management and decision-making (Aceves-Bueno et al., 2015, McKinley et al., this issue). In response to concerns about the quality of CCS data, many argue that it is subject to the same Quality Assurance/Quality Control procedures, study review and scrutiny as any scientific work published in peer-reviewed journals or used for decision-making (Cox et al., 2012; Kremen et al., 2011). In the case of youth, van der Velde et al. (2017-this issue) have shown that youth-collected data can even exceed the quality of that collected by adults, as demonstrated in their study of youth mapping local trash.

Documenting evidence for the impact of CCS participation on conservation learning and resulting behaviors, or conservation actions, is far less straightforward. Several studies have looked at adult learning outcomes of citizen science, which provide evidence of increased understanding of specific ecological or science content (Brossard et al., 2005; Evans et al., 2005), science skills (Evans et al., 2005), or a commitment to carry out future stewardship activities (Crall et al., 2013). However, the relationship between environmental learning and conservation behaviors is impacted by a suite intrinsic and extrinsic variables (Heimlich and Ardoin, 2008; Hungerford and Volk, 1990), and can involve short-term (social-marketing, providing incentives and feedback), long-term behavior change strategies, (cultivating environmental literacy) (Kollmuss and Agyeman, 2002; Monroe, 2003), and the development of environmental identity, which some theorize provides a link between learning and action (Clayton and Opotow, 2003).

Beyond behavior change, CCS can also be a part of efforts to reframe the goals of environmental education to focus on developing individual and community capacity to think critically, learn continually, and act adaptively to promote more resilient socio-ecological systems (Krasny and Tidball, 2010; Stevenson et al., 2014). Because socio-economic and political conditions can undermine the links between learning and resilience (Ballard and Belsky, 2010), we need to examine not only learning outcomes but also processes, and not just variables but the words and actions of people participating in science research that they believe contributes to something meaningful. With respect to youth, for whom we are banking not solely on current behaviors but on the capacity and agency to learn and make decisions into the future, we must understand why and under what circumstances participation in CCS might lead to environmental and science learning, conservation behaviors, and resilient systems.

1.2. Examining youth-focused CCS activities and learning impacts

Questions about what constitutes youth-focused CCS abound. For programs that center around the educational goals of CCS, how is youth-focused CCS distinguishable from doing a classroom science lab or field study in a local park? For our purposes, we define youth-focused CCS as activities by youth that produce data or results disseminated to and useable by professional scientists, agencies and/or managers. Therefore, despite their provision of high quality opportunities science learning, we do not include field-based or lab investigations by students whose data and findings are not disseminated outside the school or not used for research or decision-making.

The expectations for youth-focused CCS are well founded, but under-researched. Science education research in formal classrooms and informal learning settings provides evidence of how engaging in the practice of science affords not only a way to learn experientially (Kolb, 2014), but also provides the opportunity for youth engagement in scientific discourse and reasoning (Chin and Osborne, 2010; National Research Council, 2009). We also know that investigating environmental problems and scientific questions provides students with a meaningful context for learning science as well as a way to engage with their local place and community in transformative ways (Barton and Tan, 2010; Stevenson et al., 2014; Uzzell, 1999). Particularly, evidence from youth participatory action research, in which youth drive the research process, demonstrates how youth can gain capacity, skills and confidence for asking and answering questions collaboratively and enhance their connection to their local place (Ardoin et al., 2013; Cammarota and Fine, 2010). Yet existing literature on the education outcomes of the wider range of youth-focused CCS programs is limited to the potential activities and engagement strategies that may lead to strong science and environmental education outcomes (Kountoupes and Oberhauser, 2008; Morrisseau and Voyer, 2014). Further, while youth citizen science in schools is promoted as a promising context for addressing science education standards (Trautmann et al., 2012), the question remains as to whether school-based citizen science can truly foster the more democratic, social justice outcomes many hope for (Calabrese Barton, 2012). To move the field forward, we must develop a framework that can be used across a spectrum of experiences - in schools and out-of-schools - and can help researchers move beyond conjecture about potential or analogous impacts.

Further, we need a framework for conservation learning and action that addresses issues of power and positionality, rather than being resigned to only typical environmental behaviors such as recycling, minimizing home energy or water use, or picking up trash. Inside and outside of school, youth, especially those from marginalized communities or populations, often don't feel empowered to act, or don't have access to the means through which to take meaningful action in science and conservation, (Basu and Calabrese Barton, 2009). We argue that tightly bounded definitions of environmental learning and conservation action do not take in account young people's histories, ambitions, resources, and networks that are unique and particular to the places and communities they live, nor do they reflect the nature of learning that we see happening when young people engaged with authentic environmental CCS.

1.3. Environmental science agency (ESA)

To begin building a framework to help us understand both current and future environmental actions and behaviors of youth in CCS, we draw on Basu and Calabrese Barton's (2009, 2010) concept of critical science agency. In developing critical science agency, youth rely on science subject-matter knowledge to make change, and to leverage their own science expertise "to reflect and act on injustice in their lives" (Basu and Barton, 2010).

To apply this framework to a conservation and environmental science context, we refer here to *environmental science agency* (ESA). To examine learning as environmental science agency, we focus on ways that young people use science learning and participation as a foundation for action related to environmental sustainability. Becoming a legitimate participant in a community that engages in environmental sciences and conservation requires that a young person not only gain an awareness of conservation issues and proficiency with tools to research and act on these issues, but also that she or he aligns, at least in part, with the values, goals, and norms of these communities (Lave and Wenger, 1991). Further, by drawing on critical science agency, we reframe the goals of conservation education around practices that support young people in acting (individually and collectively) with the tools of science in ways that are purposeful, personally consequential, and in service of more sustainable social-ecological systems. An ESA framework helps draw a line between the current actions of young people, and the ways their science learning can lay the groundwork for future actions (Barton et al., 2012). Programs oriented toward development of ESA support young people in becoming agents of change (Freire, 2000), and ask educators and researchers to look for small, incremental changes young people make in their lives and local communities, alongside larger changes made through participation in collective actions and activities.

Basu and Barton (2009) explain three key components of critical science agency around which we focus an examination of environmental science agency; our proposed version of critical science agency implies that youth (see Fig. 1):

(a) *Understand environmental science content* and the "processes, skills and modes of inquiry associated with this content" (Basu and Barton, 2009). This includes engagement with environmental sciences and conservation particular to ecosystem health. We look at what concepts, practices and epistemologies they take up, when they make use of these concepts, and how these vary across projects and participants.

(b) *Identify areas of their own expertise* associated with environmental science. We draw on this aspect of critical science agency to look at the ways that young people develop particular roles within their project groups and environmental science more generally. We look at how young people come to specialize (or not) in parts of the scientific work being done in their CCS projects, taking into account ways that individuals position themselves through project work and narratives of participation, as well as ways in which they are positioned by others.

(c) *Use environmental science expertise and CCS practices as a foundation for change*. Making use of participation and increased proficiency in environmental science and conservation may include shifts in position or identity that extend beyond project work, drawing on perspectives and tools of science to understand the everyday world in new ways, formulating personal ambitions and goals in new ways, and/or taking actions to envision and direct the world in personally consequential and environmentally sustainable ways.

If looking to future environmental behavior as an outcome of environmental science education and participation and means to conservation impacts, we need to better understand how young people become more purposeful and powerful in their lives. In this article we work to understand what gaining agency with and in science and the environment means, by asking, *What is the evidence of contributions to conservation of youth CCS activities, with respect to current site and species management, and to learning processes that contribute to conservation into the future*? We use the lens of environmental science agency to

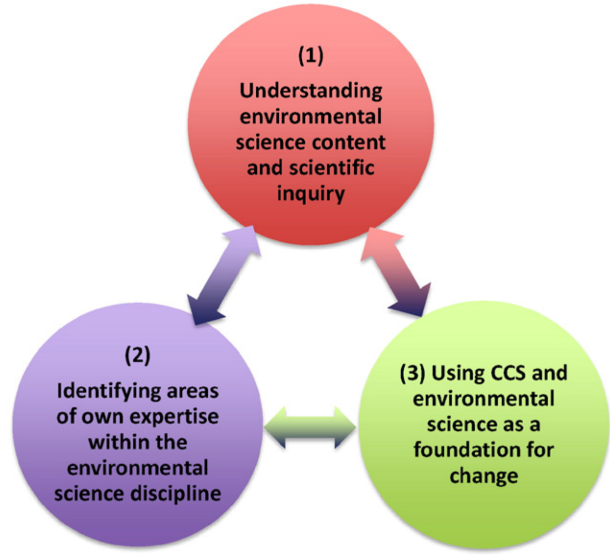

Fig. 1. The three components of environmental science agency and their interdependent relationship.

ask whether and how youth can contribute to conservation through CCS. We investigate these questions by tracing participation across two CCS programs in in-school and out-of-school cases.

2. Methods

We used a case study design (Yin, 2013) to examine youth-focused CCS programs in which youth-generated data was used by scientists or decision-makers. We selected two programs with three implementation sites in the San Francisco Bay Area, California. We treated each of the three sites as case studies because conditions of implementation were different: two sites of the Long-term Monitoring Program and Experiential Training for Students (LiMPETS) program, one in a school context and one in an out-of-school internship program at a natural history museum, and one site of the East Bay Academy for Young Scientists (EBAYS) program in a summer out-of-school program. We intentionally selected three case study sites in which youth participated in many aspects of the scientific process, including dissemination of findings to an external audience. This is not necessarily representative of typical youth-focused CCS programs across the US or globally; however, from preliminary research we posited it is a unique and crucial component of youth CCS for learning. Most participation by youth in CCS occurs during the field data collection process (Sadler et al., 2010), with classroom/indoor introductions and debriefs, over a short time period (one to three one-hour class sessions). Instead, we chose to focus on extended, intensive cases of youth-focused CCS in order to understand the learning by youth given the opportunity to deeply engage in a variety of ways with science, the place they work, other adults in the community, and each other. We also wanted to examine a wide variety of conditions and mechanisms that might affect youth learning.

2.1. Program descriptions and study sites – case study background

Long-term Monitoring Program and Experiential Training for Students (LiMPETS) began in 2002 when the National Marine Sanctuaries (NMS) of the West Coast partnered with non-governmental organizations and universities to streamline their intertidal student monitoring programs, with the goal of providing useful data to the NMS while also involving teachers and youth in real science and increasing their awareness of and interest in the marine environment (limpets.org) (Table 1). In the San Francisco Bay Area, over 40 classrooms and out-of-school groups (totaling approximately 2500 youth and teachers)

Table 1
Overview of conservation research focus, organizational structure, youth audiences, site characteristics.

	LiMPETS program	EBAYS program
Conservation research or monitoring focus	Establish baseline data for monitoring overall health and environmental disturbances on California coastline - specifically Sandy Beach and Rocky Intertidal monitoring programs	Investigate water and air pollution, and/or energy consumption, at sites around Oakland, CA
Organizational structure	Sites in-school (Sept.–June), and out-of-school (summer and/or after school) Project coordinators train educators and youth, educators or project coordinator supervises students during one or more data collection field trips, students or educators upload data to online project database, educators debrief with youth analyze data. (Note in some sites youth also develop a research question to investigate in the LiMPETS database, conduct extensive analysis, and disseminate findings)	Sites in-school (Sept.–June), and out-of-school (summer and/or after school) Project coordinator works directly with youth during summer program to develop research question, conduct data collection, analysis, and dissemination of findings to local officials & community members and at scientific conference
Youth audience	Middle school to College-aged students, out-of-school sites are high school-aged youth in summer or year-round internship program	Middle and high school students, out-of-school sites are middle and high school-aged youth in summer program
Locations of activities	Middle and high school classrooms in the San Francisco Bay Area, out-of-school in natural history museum classroom and lab settings, both at beaches along CA coast, (Note in some sites also professional science conferences)	Meeting rooms at schools, community centers and parks; lake and creek shores in Oakland, CA, professional science conference in SF

participate each year at separate sites spanning 150 miles (240 km) of California coastline. All interested teachers participate in an introductory training, after which they train their students with the support of LiMPETS materials, with close oversight by program coordinators. Students then follow LiMPETS protocols to monitor one area of the Rocky Intertidal or Sandy Beach supervised by their teacher. Our two case studies focus on the Sandy Beach monitoring as that is the most frequently used protocol by K-12 youth.

East Bay Academy for Young Scientists (EBAYS) is a program of the Lawrence Hall of Science at University of California, Berkeley (Table 1). It began in 2002, with the goal of giving underserved and marginalized communities in the region access to innovative, hands-on science research activities to develop STEM skills and become young community leaders (www.lawrencehallofscience.org/ays/). EBAYS works with several high schools in the East San Francisco Bay Area each year, as well as several out-of-school sites during the summer and school year, totaling approximately 200 youth each year. Their sites are selected based on collaborative partnerships with city and school organizations. Youth projects within the EBAYS programs, ranging in duration from 3 weeks to 6 months or more, focus on air quality in local neighborhoods, water quality in local water bodies, and energy and air quality in schools. The longer-term research project on which our case study focused was conducted by a small out-of-school group (3–10 youth) at a local creek, and involved not only water quality monitoring but also habitat restoration work that had been underway for two years. A majority of EBAYS projects also engage youth participants in presentation of data and/or findings to local agencies, city governments, and environmental advocacy groups working actively on the issues being studied.

2.2. Data collection

To gather data about the three case study sites, we collected observational field notes, reviewed program and student-produced artifacts (Bowen, 2009) and conducted semi-structured interviews (Patton, 2002) with 25 youth participants, and LiMPETS and EBAYS program coordinators. We rely most heavily upon a set of nine purposefully selected youth (Merriam, 2014) whose interviews, fieldwork and presentation at a scientific conference or in the form of blogs reflect the culmination of the youths' work in the program.

2.2.1. Interviews

We conducted semi-structured pre- and post-program interviews with 25 youth at the program sites, lasting 30–90 min each. These took place anywhere from 2 weeks to 6 months apart, depending on the length of the program. Pre-program interviews focused on youth perceptions and experiences with science and scientists, environmental issues and actions, civic engagement, and the activities and roles they anticipated playing during the program. Post-program interviews focused on their experiences during the program as well as follow-up on pre-program questions. Examples of interview questions were,

- "Tell me about the project you worked on during the program?"
- "What parts of the project were most important to you and why?"
- "Did you get a chance to think of your own questions to research, tell me about that?",
- "What kinds of tools or technology did you use in the project?"
- "Did you get a chance to present your work or ideas to anyone outside the program? What was that like?"
- "How would you describe your role in the group, or contribution to the group, overall?"

We also interviewed program coordinators to find out about both program structure and for evidence of how the program data or findings, and youth activities, contribute to site and species management.

2.2.2. Observations

To understand the ways in which youth actually participated in the science and conservation activities of the program, as well as the roles and practices youth took up over the course of the program, we conducted intensive participant observations of 70–100% of the program activities, depending on the site, in which youth participated. This included introduction and training sessions indoors, field data collection trips, analysis discussions, interactions with local residents, city officials, program scientists and coordinators, and presentations at scientific conferences and city meetings.

2.3. Data analysis

Data analysis involved multiple stages and levels of coding (Corbin and Strauss, 2014). We open coded the field notes to determine in what parts of scientific process as well as other program activities in which youth actually participated. We then selected three focal youth within each case study site (total of nine), based on their representing demographics of participating youth and the range of types of participation and overall experiences with the project. We compiled profiles of all focal youth, drawing from observation data to describe their activities within the project, and including their own reflections, recollections and expectations drawn from the pre- and post-interviews. The profiles allowed us to consider youth experiences holistically during analysis, but also to focus on actions and reflections most relevant to science learning and environmental stewardship. Treating each youth as a focal case, we then used qualitative coding across profiles and pre- and post-program interviews to identify instances in which focal youth described or enacted aspects of ESA, specifically using codes for when youth expressed understanding of environmental science content, identified areas of their own expertise, or used their own environmental science expertise or CCS practices to take action within or outside the project activities. All profiles were coded by at least two researchers to ensure that coding was done accurately and reliably. After comparing, checking and clarifying coded instances, we looked across youth cases to seek patterns in the activities and conditions to help us understand how CCS participation might support, or undermine, development of ESA. All coding was verified by at least two researchers. Because agency is both a generative and an iterative process and product, and not a static characteristic of an individual (Barton and Tan, 2010), we examine and report the processes through which youth seem to be developing ESA, rather than state that they have achieved or acquired it.

3. Results

We found a variety of ways that youth-focused CCS contributes to conservation, both through science that informs site and species management, and through learning processes and outcomes. We particularly focused on describing the scientific work youth did, and identifying the learning processes and outcomes that contribute to youth capacity to tackle conservation challenges into the future. Here we report our findings regarding, 1) how youth participated in the scientific process in each study site, 2) evidence of contributions to conservation through site and species management of youth CCS activities, and 3) evidence of contributions to conservation through youth learning processes and outcomes, which include a) examples of when youth exhibited the three components of environmental science agency, and b) the processes within community and citizen science practices that emerged as the key ways environmental science agency was fostered and developed in youth.

3.1. Youth participation in the scientific process

While participation by youth was similar across sites in many ways, we also found several differences across the three cases (Table 2). Unlike many youth-focused CCS programs, we found that, in addition to more common activities like data collection, youth in all three cases studies presented their findings to a public and/or scientific audience beyond their school or program. Some of the youth in the EBAYS case and in the out-of-school LiMPETS case had been participating for 2 or 3 years. Also, whereas the youth in EBAYS worked in a small group to investigate a question developed by their program coordinator and youth from prior years, youth at both LiMPETS sites formed groups to investigate their own research questions, heavily scaffolded by LiMPETS staff and teachers and drawing from the larger program's overall baseline monitoring work. Finally, the audiences and media youth employed to present their findings differed: the in-school LiMPETS case youth wrote science blogs that were disseminated to a public audience via the LiMPETS network, whereas the out-of-school LiMPETS and the EBAYS youth created scientific posters they presented at a national professional science conference. The in-school LiMPETS youth spent less time doing field data collection (one field day), whereas the out-of-school LiMPETS and EBAYS youth had repeated fieldwork over a longer period (several weeks or months).

3.2. Contributions to conservation through site and species management

3.2.1. LiMPETS

Data contributed by youth in LiMPETS contributed to site and species management of the Greater Farallones National Marine Sanctuary (GFNMS) in two main ways: 1) ongoing monitoring of prey species, *Emerita analoga*, as it relates to population trends of marine mammals and seabirds, and 2) uses of the data for monitoring impacts of unanticipated human and environmental events. 1) Population increases and decreases of certain megafauna, in some cases, are tied to sand crab population trends or the presence of an Acanthocephalan parasite carried by the sand crab. The GFNMS Science Coordinator meets with the LiMPETS program coordinators to decipher relationships of these trends. 2) For explicitly human-caused severe events, LiMPETS sand crab data served as baseline data and for ongoing monitoring of the effects of the Cosco Busan oil spill in 2007, a container ship that crashed into the base of the San Francisco Bay Bridge.

3.2.2. EBAYS

The research conducted by the out-of-school EBAYS group has contributed to the site management of the riparian area they studied in two main ways: 1) The data informs monitoring and enforcement actions by the city Public Works and Environmental Services Division. As a result of the group's initial study, the creek was tested by the city for a possible sewage break and then flagged for ongoing fecal coliform testing when no point source was identified. Therefore, EBAYS conducts ongoing water quality monitoring there and reports results directly to the city's Environmental Services department, which serve as preliminary detection of contamination spikes. This has led to increased materials support from the city for volunteer clean-up efforts, park development, and creation of public outreach materials on the issue. 2) The youth-generated research findings and restoration work motivated and informed ongoing collaborative restoration work that involves support from the City and local community, led by EBAYS youth and project leaders. As their findings showed lack of biodiversity and high levels of toxins in the creek, the group decided to take actions by removing trash and invasive species at one section of the research site. This was followed by planting native species and became the focal point for community and city support, which have contributed plants, tools and labor. After three years at the site, EBAYS youth found lower chemicals of concern in the most recent monitoring data. In addition to continually expanding restoration of the site, the EBAYS youth have begun to impact community perceptions of and use of the creek site, transforming it from an overgrown corridor that encouraged dumping and defecation into a more park-like space frequented and protected by neighbors.

3.3. Contributions to conservation through youth learning processes and outcomes

We found several ways in which development of ESA was evidenced by youth involved in the three sites studied, though some youth in each case did not demonstrate learning processes for all three components. Specifically, we identified the moments, activities, and contexts in which youth in each case study site showed evidence of developing all three areas of ESA, from 1) understanding the environmental science, to 2) taking on roles of expertise within the science, to 3) using the environmental science to take action (Table 3). This allowed us to identify that environmental science agency was fostered through participation in three processes at the core of community and citizen science: a) the process of ensuring rigorous data collection and quality, b) the process of disseminating research findings and communicating project work, and c) the process of engaging with complex socio-ecological systems as something to act upon. We provide more detailed explanations for confirming and disconfirming evidence below.

3.3.1. Examples of environmental science agency (ESA)

3.3.1.1. Understanding environmental science content and scientific inquiry. We found evidence in the youth interviews and observations that all nine focal youth used skills and knowledge in the environmental science disciplines (Table 3), though did so in different areas and to differing degrees. All focal youth used or described new ecological knowledge specific to their research question, which varied across sites: for the in- and out-of-school LiMPETS participants, most often this meant youth

Table 2
Aspects of conservation science research or monitoring that youth engaged in as part of case study programs.

	In-school LiMPETS case study site	Out-of-school LiMPETS case study site	EBAYS out-of-school case study site
Duration	Youth spent 15+ hours over 11 class periods from September–November	Youth spent 30+ hours over 18 sessions from June–December	Youth spent 30+ hours over 30+ days from June–December
Developing research question or monitoring goal	*For Program*[a] – youth learned about the LiMPETS focus on monitoring sand crab distribution and abundance *For Site*[b] – youth developed their own research questions (RQ) to ask of the statewide LiMPETS dataset with support from program coordinators and the classroom teacher. Ex: How did the recent oil spill affect sand crabs? How do mole crab populations vary from urban beaches to remote beaches?	*For Program* – youth learned about the LiMPETS focus on monitoring sand crab distribution and abundance *For Site* – youth developed their own RQ to ask of the state-wide LiMPETS dataset with support from program coordinators, the museum educator, and past youth participants. Ex: Is there a relationship between sea-surface temperature and the prevalence of *Profilicollis* spp. (a parasite) in *E. analoga* (the pacific mole crab)?	Youth continued investigation of water quality in the creek that had been developed by program educator and youth over the previous 3 years work at the site. During analysis, educator and youth clarified their question to examine relationship between site characteristics, site usage, and water quality. Ex: How do levels of ammonia, phosphate, and nitrate in the creek change from year to year? How do restoration efforts of our group affect health of the creek?
Designing the study and methods	*For Program* – youth learned field data collection methods from program coordinator and classroom teacher	*For Program* – youth learned field data collection methods from program coordinator, museum educator, and past youth participants.	Youth learned and implemented study protocols developed by program educator and youth over the course of previous 3 years work at the site.
Collecting data	*For Program* – youth laid out transects, collected population data on sand crabs and abiotic factors, at one beach during one field day. (Some non-focal youth did not do field day). *For Site* – some groups gathered additional data across CA coast to add to analysis of LiMPETS dataset with assistance from the program coordinator, such as dates for El Nino years, dates of oil spills, and sea temperature data.	*For Program* – youth laid out transects, collected population data on sand crabs and abiotic factors, at the same beach site weekly for 8 weeks, also collected sand crabs and dissected for parasite analysis in the lab *For Site* – gathered additional data on sea surface temperature at their local beach to add to analysis of LiMPETS dataset, supported by a local oceanographer.	Youth collected water samples and made observations of site conditions at six sites along two neighborhood creeks and analyzed levels of ammonia, nitrate and phosphate using aquarium test kits.
Entering data	Youth recorded data on paper datasheets. Due to time constraints, the classroom teacher entered the data into the LiMPETS website.	Youth recorded data on paper datasheets. One youth participant in a “field coordinator” role entered all of the sand crab and parasite data to the LiMPETS website weekly.	Youth entered data in field notebooks and then transferred data into Excel spreadsheets on program computers
Selecting and analyzing data	With guidance from the LiMPETS program coordinator and classroom teacher, youth selected appropriate data from the larger network database. They graphed the data to find patterns and worked with program coordinator to draw scientifically accurate conclusions, which they wrote in their blogs.	With guidance from two out-of-school educators and a local oceanographer, youth selected data from the larger network database. They then used excel to create a graph and run statistical analyses. As a group, with guidance from museum educators and the oceanographer, youth drew conclusions and wrote the text of their posters.	With guidance from lead educator and college-age mentor, youth graphed data to understand patterns across the two creeks and over time, then discussed these patterns together with educators and refined analysis in the process of writing for posters and presentations.
Disseminating findings to scientific or public audience	*For Site* – youth worked in groups to write-up their investigation and findings of RQ of statewide dataset and findings for online blogs, on LiMPETS website, with feedback from program coordinators. Blogs were shared with the LiMPETS network as well as the school e-newsletter. Youth informally shared their work with passersby on the beach.	*For Site* – youth worked in a group to develop and present a scientific poster at two professional scientific conferences on their analysis of the state-wide dataset, receiving feedback from scientists. Youth informally shared their work with passersby on the beach during monitoring. Youth also presented findings to their peers, museum staff, and program funders in a showcase.	Youth worked with program educator and volunteer mentor to develop and present a poster at professional scientific conference, and worked with educator to prepare slides and for presentation to representatives from Oakland City Hall, local environ. advocates, and community leaders; Youth also informally discussed research and restoration work with community members near the research site.
Other activities		*For Site* – one participant incorporated the research into his senior project at school, collecting additional data and writing a final report and presentation.	Following-up on research findings, youth helped plan, implement and monitor restoration work at the research site, including invasive species removal, planting and coordinating volunteers

[a] *For Program* refers to activities related to addressing the LiMPETS program monitoring goals.
[b] *For Site* refers to activities related to the specific research questions youth asked at the site level.

Table 3
Evidence of environmental science agency (ESA) for youth during CCS participation, and the key processes that fostered all three components of ESA.

Evidence of three components of environmental science agency		
1. Understanding environmental science content and scientific inquiry	**2. Identifying own areas of expertise within the environmental science discipline**	**3. Using CCS and environmental science as a foundation for action and change**
a. Key process of CCS: ensuring rigorous data collection and analysis		
● **Learned skills for and value of calibrating measurements with peers**[a] ● Became conscious of and skilled at careful collection of ecological data[a] ● Learned subtleties and ways of attending to sample size (L) ● Learned that selecting datasets involves choices & tradeoffs[a]	● **Became specialist in specific data collection or analysis methods**[a] ● Adapted and personalized methods to ensure data quality (E) ● **Took leadership role in data collection (teaching new participants, overseeing high quality data collection) (O)** ● Saw themselves and were recognized as part of the scientific community because own data or analysis was usable by other scientists (O)	● **Leadership role in data collection led to leadership role in project from year to year (O)** ● Learned that high quality data/research can drive changes in management and policy, and provides a personal entry point to effect change (E)
b. Key process of CCS: disseminating research findings and communicating science and project work		
● **Developed knowledge and skills with tools of presentation/collaboration (Google docs, Powerpoint, Excel for graphs)**[a] ● **Learned skills in science writing - norms of language and organization**[a] ● **Learned norms of science conferences, public speaking, answering questions and getting feedback from scientists during poster presentations (O)**	• **Took on more responsibility for communications to outside audience (for writing, analysis, editing, inviting poster visitors at conference)**[a] • Saw self and was recognized as part of scientific community when treated as colleagues at conferences (O) • Identified self as a competent public speaker (O)	• **Shared research (and accomplishments) with family, teachers, friends, community leaders**[a] • Became excited that sharing research prompted other community members' action[a] • Learned perseverance[a] • Transferred public speaking practices/skills to other settings • Overcame shyness and reluctance to speak • Took actions to establish self in scientific community at conferences and in writing
c. Key process of CCS: investigating complex social-ecological systems (SES)		
● **Learned new ecological knowledge, relevant ecosystem structures and functions**[a] ● **Learned complexity of social-ecological system (SES), relevant feedbacks loops among social systems and ecosystems**[a] ● Learned connections between ecosystem health and human health, that nature-human relationship holds more than meets the eye (E)	● **Became a content expert (specific to study system)**[a] ● Took on new roles in different aspects of scientific work (eg. teaching others science content about the SES)[a] ● Connect own content learning to confidence and passion for the scientific work within the SES[a] ● Began to develop identity as someone who works for positive change (E)	• **Gained new perspective on importance of small changes they can make to systems - positive or negative, saw impacts of own actions on SES**[a] • **Expanded view of SES - sees ecosystem as part of social system and own community, sees own actions as part of the ecosystem (O)** • Learned to see healthy ecosystems as a community asset, so working in ecosystems is helping the community (E) • Took up mild pro-environmental behaviors outside of project (picking up trash) (E) • Specialization lead to opportunities outside of program (E)

Bold = prevalent across all three sites.
O = out-of-school sites only (prevalent also bolded).
E = EBAYS only.
L = LiMPETS only.
[a] Present across all three sites.

explained the relationships between sand crab populations and beach environmental factors, ecological relationships between sand crabs and food sources or predators, and improved understanding of and skills in field data collection focused on accurately collecting and measuring sand crabs. For example, one youth participant in the out-of-school LiMPETS site explained in her post-interview that she now has extensive knowledge of the parts of the system – the relationships between the sand crabs, birds, and parasites. For EBAYS, this meant youth first and foremost became aware of the creek as a local site of ecological importance. In addition, they explained a new understanding of water chemistry and demonstrated how to test it, how to identify macroinvertebrates, and their understanding of the differences between native and invasive species. Youth in both programs also demonstrated new understanding of human impacts on the ecosystem they studied; for LiMPETS this meant possible effects of human activities on the beach ecological communities and sand crabs in particular. All EBAYS participants described that at first they assumed the creek was healthy because plants grew there, but realized that trash and other human uses were affecting water quality, and even a healthy-looking creek could be unhealthy. In addition to the environmental science content knowledge, most youth at all sites demonstrated broader understandings of science as a discipline with specific norms and practices, such as realizing the importance of repeatable data collection, "cleaning" sand crab data, and of professional scientific presentation skills. For all three cases, youth either learned to use, or became more adept at using, spreadsheet programs, learning new functions like creating graphs or running statistical analyses. For LiMPETS, this was facilitated by youth manipulating the large overall program database.

3.3.1.2. Identifying areas of expertise within the environmental science discipline. We found evidence, either explicitly stated in the youth interviews or observed in field notes and student work, that eight of the nine focal youth identified an expert role for themselves within the CCS project or experienced a shift in their role (Table 3). The most prevalent across programs and sites for all youth was when they took on more responsibility or leadership for writing, analysis, and/or data collection. Specifically, two youth from the LiMPETS out-of-school program described how they found ways to "step up" and become a leader for the first time, in coordinating and supervising the data collection, or analysis as their small group inquiry work developed. Importantly, students from the in-school LiMPETS case, who only conducted field data collection once, did not report taking on new roles related to data collection, one reporting they, "…pretty much just took turns." However, alternatively, several youth working on the blogs for the in-school LiMPETS case saw themselves as taking on an expert or leadership role in the writing process. The youth in EBAYS each described how the experience of planning and presenting at a scientific conference helped them assume more responsible roles for communicating and explaining science to the public or community members. One youth particularly reflected on how he stepped up to explain the research and restoration project to community members who pass their creek field site. The other prevalent evidence in this category across programs was several youth at each out-of-school site described how they felt recognized as members of the scientific community because of their participation in science conferences. One youth in the out-of-school LiMPETS site explained, "I never would have imagined that such a young generation could communicate with, like, the older generation who have accomplished so much, and just…kind of be on a somewhat level playing field. Like they'll respect us despite being kids…" However, this was not true for the in-school LiMPETS site, who saw themselves more as presenting to the public rather than scientists.

3.3.1.3. Using CCS and environmental science as a foundation for change. While this was the least prevalent aspect of ESA among focal youth as evidenced in our interviews and observations, we did see evidence that participation in both programs helped some youth understand how to use CCS as a foundation for change in their communities and/or for the environment (Table 3). This manifested in different ways for the two programs. In both programs some youth saw their work with the program as something on which to build their own future interests and actions; in the out of school LiMPETS case, youth pointed out that they now see environmental science as a way to pursue their own personal goals for school or college, whereas one youth in the EBAYS case described how he used EBAYS work to launch into other internships focused on science and fellowship programs in nearby neighborhoods and internationally.

This area of ESA was also strongly evidenced in the EBAYS youth who saw their work as a part of the bigger picture of improving their local environment through conducting scientific research, built on through the direct creek restoration. One youth explained,

"we're doing something for a reason…with the investigation, that's how we know exactly what is wrong with the creek. We tackle some tough questions such as what's causing, let's say in this case, high levels of nitrate…We could look around the surrounding area and find out what's producing the nitrate. That could be cats…or it could be humans….".

Because they worked at the site over the course of 6 months (and for 3 years for one returning participant), youth in the program saw how a social-ecological system could change and came to realize that many members of the community did care about the creek and the group's work. However there were several youth that did not make a connection between their scientific work and the larger community, nor as a way they could make changes in their own lives. One youth in the out-of-school LiMPETS case explicitly said he doesn't see his community as connected to the beach he studied, another two youth in each program described a concern about litter pollution but stated they haven't changed their own behavior regarding trash pickup.

3.3.2. Processes that fostered environmental science agency

3.3.2.1. Ensuring rigorous data collection and analysis. We found that for five youth across the three sites who demonstrated all three aspects of ESA - from environmental science content learning, to identifying their own expertise and role in the discipline, to using their CCS work to take action - the focus of their activity was on maintaining a high level of data quality (Table 3). They explained unprompted the importance of data quality in the scientific enterprise, took on roles to regulate the data collection and quality of their peers, or with respect to how their work would be used by the scientific community, and saw high quality data collection as a foundation for environmental and/or community actions and change. Specifically we highlight one youth in the EBAYS case to show the trajectory in developing ESA through ensuring rigorous data. This youth explained early on that her role in the project was as someone who "just gets work done." In the project, this meant collecting water, testing water samples, and inputting data – all skills she learned during the project. This led to a particular expertise in water testing, becoming efficient at testing and developing her own techniques, setting multiple timers, looking for color matching of tests, calibrating her analysis by checking with other group members, throwing away a test and starting over if she wasn't satisfied with the rigor. She said "testing chemicals" is one thing she got better at during the program, along with her "science knowledge of what could happen to creeks." The scientist-educator came to rely on her to make sure tests were done accurately. Though quiet and reserved, she took on the lead role in teaching new student and adult volunteers about how to test the water, explaining what the chemical values meant. As she transitioned into a second-year participant of the program, she leveraged her specialty to playing a role in session planning and site selection for water testing. Ultimately, she said EBAYS influenced her confidence in her science content knowledge about the chemicals in the creek, but more importantly, she said she said EBAYS affected how she thinks about making choices, weighing options, thinking ahead about the implications of her choices.

3.3.2.2. Disseminating research findings and communicating science and project work. For seven of the youth across the three sites, we found that the process of disseminating their research findings to an external audience was key to their developing ESA (Table 3). Across programs, whether the audience was scientists at a national conference or the public reading their blog reports, nearly all the youth described ways that being accountable to these external audiences drove them to learn new content and skills, take on new roles and expertise, and realize how those skills gave them power to take action to improve their own lives, for their communities or for the environment. In one example, one youth in the in-school LiMPETS case was fairly quiet and less assertive during fieldwork, and in pre-interview was not overly confident about her performance in science in school. But she was excited about the blog project in the pre-interviews, and then took a lead role in the writing aspects for her group's blog, organizing her peers and the document to communicate their research findings. She shared her scientific work with her family and explained, "It (the blog) was good because I know that we didn't make mistakes, and so we could give the public an accurate reading of what we found…I was happy because I was publishing something that could help…or inform other people, which is really exciting." Not only did the blogging provide an opportunity for her to take on the leadership role in writing, but it helped her see a way into science for herself as a possible future, stating, "…Before (science) was a drag, like, 'oh it's biology', there's no relevance to it, but now I′m finding that it is relevant and it's things that we see in our day to day…the sand crab (project) helped me see that I like researching, so that might influence on what I am going to do in the future and whether or not I want to go into that work."

3.3.2.3. Investigating complex social-ecological systems. This process was not prevalent across sites, but was evidenced most in the out-of-school case study youth (Table 3). For all of the EBAYS focal youth, we found evidence that engaging with the human and ecological aspects of the system during their work at the creek provided opportunities for them to gain new knowledge about the SES (like a healthy-looking creek could be disguising poor water quality), take on roles and expertise within the monitoring and restoration tasks, and transform their understanding of their own abilities, future role and efficacy in improving the health of the system. Two of the youth specifically remarked that they didn't realize how many people in the neighborhood cared about the creek, and were excited that their research and restoration work sparked others to start devoting resources to the problem. After repeated visits to the beach, one youth in the out-of-school LiMPETS case became knowledgeable about the relationship between sand crab life histories and beach conditions. He saw himself as taking the lead on reading scientific journal articles for his group's investigation of the LiMPETS dataset specifically because, "now I have a purpose, I have a reason (to read them)…"; he said he felt valued for doing it. Ultimately, he explained how he saw his science work contributing to understanding the larger social-ecological system:

"…being in the program for a while I started to realize that LiMPETS is important because it helps us understand how we as humans interact with (the beach system)…I mean just…toxins, some of that can harm the sand crab population….And therefore that could affect the whole entire food chain. So it's important to understand how everything is doing…now I realize that by affecting the beach, we affect sand crabs, (which)…affects the whole entire ecosystem…".

Importantly, not all youth made these kinds of connections between their CCS participation and the larger SES. At least one youth in each of the LiMPETS cases explicitly said they did not see a connection between their work in the program and impacts on the human or ecological community, and didn't see themselves pursuing any future activities in this area outside the program. An in-school participant said the beach they visited was not near his house, so didn't see any actions he could take there, whereas the out-of-school participant reported that she saw their work as important for understanding sand crabs and their ecosystem, but didn't make any connection to human activity.

4. Discussion

Our findings indicate that youth-focused CCS can result in two of the main outcomes described by Kapos et al. (2008), conservation research and management, and conservation learning and action. Specifically, we found that the connection between youth-focused CCS programs and concrete impacts on conservation can be both immediate and direct, and long-term through capacity building for youth in the form of developing their environmental science agency. However, these impacts are only possible if the CCS programs have clear mechanisms for their scientific outputs to be realistically and specifically used for conservation science, and have conditions and structures in place that help to foster ESA for youth participants.

4.1. Implications for CCS programs to contribute to research and management for conservation

The two key mechanisms through which the case study programs impacted site and species management were via informing the resource managers and agencies with relevant data and through direct stewardship activities by the youth participants. Both programs have clear and explicit relationships and communication, through their program coordinators, with the organizations they hope will use their data, whether the federal Marine Protected Area staff or the local city Department of Environmental Services. This indicates programs wishing to involve youth should make sure data quality assurance and control procedures are in place to ensure the data will be useful to partner organizations and agencies (McKinley et al., this issue). Secondly, we found through the EBAYS case that a CCS program can integrate stewardship activities that build from the data collection and citizen science work of the program in this case, monitoring the water quality of the creek led to restoration activities to improve creek health and water quality, which led to more monitoring, as well as to community interaction and additional opportunities to disseminate research findings. Their restoration activities not only improved creek health, but it had the additive effect of inspiring local officials to contribute to the effort. The program's iterative process also allowed youth to see the connections between their science work, their place, the ecosystem, and the impacts of their own actions on the environment, reflecting the reframing of environmental education as a part of building resilience social-ecological systems (Krasny et al., 2014).

4.2. Conditions that influence development of environmental science agency

Numerous factors outside the bounds of this study might have influenced whether and how youth developed environmental science knowledge and skills, identified roles for themselves in the environmental science work of the program, and took on this work as a foundation for change in their own environments and communities, including socio-economic factors, parent backgrounds, school contexts, among others. However, our findings suggest that CCS program conditions, structures, and strategies influenced whether and how some youth developed ESA over time. Looking across programs, the ability of the programs to support the key processes above were influenced by three conditions of CCS implementation: the time youth spend participating, relationship to the place they are studying, and whether or not youth perceive the science they are doing is real or authentic.

4.2.1. Time youth spent participating in the program

While the experiences of youth in these three case study sites were not typical for most youth-focused CCS programs in terms of the duration of participation, we found that extended time working on the same project with the same group was essential; allowing youth to specialize, identify their own expertise, and take leadership roles in different aspects of the project – even seemingly small aspects like sample analysis. This is consistent with Barton and Tan's (2010) findings when students took ownership of and persevered during a community energy project, and with recommendations to use long-term project-based learning for effective conservation education and stewardship (Jacobsen et al., 2006; Krasny et al., 2014; Krasny and Tidball, 2010).

4.2.2. Youth relationships to place

The cases where youth explained that they did not feel their CCS work connected to their own social and ecological community because it wasn't near their own homes, highlight the importance of young people's pre-existing relationship to the places they study in CCS programs. Place identity, place attachment, and whether their study sites are distant or nearby, novel or familiar, considered recreational or dirty and dangerous, can all mediate the outcomes and processes we describe above (Kudryavtsev et al., 2011). Further, their relationship to place in some cases changed over time, and participation in the CCS program clearly impacted some youths' perceptions and relationship to the places they studied, including the creek and beaches and neighborhoods that surrounded them.

4.2.3. Doing science that is real

We found that students' perception of the project as contributing to "real" science influenced the degree to which they moved toward environmental science agency. Many wonder, if community and citizen science in some contexts is intended and critiqued as a means of truly democratizing science by involving those without voice in scientific knowledge generation (Ottinger, 2010), how could youth, who are often certainly powerless in schools and rarely decision-makers outside of school, be in control of a rigorous scientific process (Calabrese Barton, 2012)? In this study, we found they attributed value to their contribution and legitimate participation in the scientific and local communities, which has implications for ways youth-focused CCS might represent a "community of practice" as defined by Lave and Wenger (1991). Participating in real, complex scientific efforts offers a wide variety of entry points for youth to pursue different interests and roles that authentic science requires (Sadler et al., 2010), from dirty wet field work, to writing for the public, to digging into complex datasets, to talking to new people. However, it is important to note that "realness" of their work was not perceived and appreciated by all students, and was associated with many aspects of project work, not just the official use of data by professional scientists. The indirect effects that students also saw their of scientific research were often key to students' claims of contribution:

restoration efforts that created visible changes in the landscape, changes in the community behavior, use of data by other students at far-away schools.

4.3. Implications for CCS programs to help foster environmental science agency in youth

There are important implications from our findings for those designing youth CCS programs. First, working with data was a key process through which youth developed a sense of agency, ownership and skills they saw as being useful to accomplish their goals related to environmental science and their community. Though working with data is the most typical part of the science process in which CCS programs engage youth, the key process we identified was when youth were responsible for ensuring rigorous data. This means that many CCS programs are poised to be able to facilitate this experience for youth if they build in structures that support roles and responsibilities for youth to train others, check protocols, and check accuracy. These findings are consistent with recommendations for developing critical science agency in youth through taking on leadership roles and a sense of responsibility for the outcomes of the scientific work (Basu and Barton, 2010). Second, we saw that a key part of the scientific process that fostered ESA (particularly youth seeing themselves in the discipline and taking up roles with the scientific community) happened during and because of their work to disseminate their findings to the public, decision-makers, or scientific community. This is not a stage of most CCS programs or other student-scientist partnerships that typically includes youth (Sadler et al., 2010). On one hand this might limit the applicability of our findings, but on the other hand it offers a key lesson for those who wish to have a transformational impact on youth: it is worth the investment to design ways for youth to authentically participate in and lead on the dissemination of findings from the project.

5. Conclusions

Most assume youth have little power or impact when it comes to direct conservation impacts; they can't vote or do extensive volunteer work, usually don't lobby policy-makers, and don't make large household purchasing decisions. However, we learned from this study that youth do have the power, ability and agency to contribute to conservation immediately as a collective, with site management impacts including informing city managers of ongoing pollution problems, conducting concrete restoration activities, and collecting data that directly contributes to the management of Marine Protected Areas.

However, conservation impacts through education often mean we must bank on the future actions and decisions of youth, hoping for measureable outcomes in twenty years. Our findings regarding environmental science agency, therefore, have particular importance. The CCS programs we studied seem to uniquely provide youth with not only ways to learn environmental science practices and content, and about the connections between human and ecological systems, but also a wide range and depth of opportunities to identify and practice their own roles and areas of expertise within science and conservation. It's likely that some of the youth in this study began the project with an interest in science, or writing skills, or public speaking skills; so the measure of impact is not whether they gained in those skills and knowledge, but that they were allowed to practice and develop those skills in the context and for the purposes of conservation and science work.

Not all youth evidenced all aspects of developing ESA in these programs; and most conservation activities by young people were often in the company of adult educators, which may yet limit the extent to which youth are able to address conservation issues and take up science for themselves. CCS is not a panacea for all youth conservation education and stewardship efforts. Further, our study design means that extrapolating our findings across similar projects might be limited, and further research is needed to further develop this framework. However, we identified some of the key processes and conditions under which youth did take up science and conservation knowledge, skills, roles, and actions for themselves, which all lay the foundation for future conservation behaviors in ways that shorter-term, isolated, constrained conservation education activities might not. By providing 1) longer-term CCS programs, 2) repeated experiences to build connections to a place, and 3) ways to contribute explicitly to authentic science research, CCS practitioners can provide fertile conditions for youth to develop ESA. In addition, our findings suggest CCS programs should provide opportunities for youth to take ownership and responsibility for 1) rigorous data collection and analysis, 2) disseminating and communicating findings to relevant public and scientific audiences, and 3) understanding their own social-ecological system and ways they can take actions to improve its health and resilience. As the field of citizen science grows, we hope these findings will help conservation scientists, managers and educators to be intentional and strategic in choosing goals and activities that will impact conservation in the near and long term.

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