Conservation Biology

Special Section: *Moving from Citizen to Civic Science to Address Wicked Conservation Problems*

Place-based and data-rich citizen science as a precursor for conservation action

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Abstract: *Environmental education strategies have customarily placed substantial focus on enhancing ecological knowledge and literacy with the hope that, upon discovering relevant facts and concepts, participants will be better equipped to process and dissect environmental issues and, therefore, make more informed decisions. The assumption is that informed citizens will become active citizens––enthusiastically lobbying for, and participating in, conservation-oriented action. We surveyed and interviewed and used performance data from 432 participants in the Coastal Observation and Seabird Survey Team (COASST), a scientifically rigorous citizen science program, to explore measurable change in and links between understanding and action. We found that participation in rigorous citizen science was associated with significant increases in participant knowledge and skills; a greater connection to place and, secondarily, to community; and an increasing awareness of the relative impact of anthropogenic activities on local ecosystems specifically through increasing scientific understanding of the ecosystem and factors affecting it. Our results suggest that a place-based, data-rich experience linked explicitly to local, regional, and global issues can lead to measurable change in individual and collective action, expressed in our case study principally through participation in citizen science and community action and communication of program results to personal acquaintances and elected officials. We propose the following tenets of conservation literacy based on emergent themes and the connections between them explicit in our data: place-based learning creates personal meaning making; individual experience nested within collective (i.e., program-wide) experience facilitates an understanding of the ecosystem process and function at local and regional scales; and science-based meaning making creates informed concern (i.e., the ability to discern both natural and anthropogenic forcing), which allows individuals to develop a personalized prioritization schema and engage in conservation action.*

Keywords: coastal, collective action, experiential learning, informal science, marine birds, sense of place

La Ciencia Ciudadana Rica en Datos y Basada en Localidades como Precursora para las Acciones de ConservaciOn

Resumen: *Las estrategias de educación ambiental le han otorgado habitualmente un enfoque sustancial al mejoramiento de la alfabetización y el conocimiento ecológico con la esperanza de que, una vez que se descubran hechos y conceptos relevantes, los participantes serán mejores en el análisis de información sobre los sucesos ambientales y en la toma de decisiones razonables sobre el ambiente. La suposición consiste en que los ciudadanos se volverán ciudadanos activos – que persuaden con entusiasmo para, y participan en, acciones orientadas a la conservación. Encuestamos, entrevistamos y usamos la información de desempeño de 432 participantes del Equipo de Observación Costera y Censado de Aves Marinas (COASST, en inglés), un programa científicamente riguroso de ciencia ciudadana, para explorar el cambio medible en y los enlaces entre la acción y el entendimiento. Encontramos que la participación en la ciencia ciudadana rigurosa se asocia con los incrementos significativos en el conocimiento y las habilidades de los participantes; una conexión mayor con el lugar y de manera secundaria con la comunidad; y una conciencia creciente por el impacto relativo de las actividades antropogénicas sobre los ecosistemas locales, específicamente por medio del incremento del entendimiento científico del ecosistema y los factores que le afectan. Nuestros resultados*

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sugieren que una experiencia rica en datos y basada en la localidad, enlazada explícitamente con temas locales, regionales y globales, puede llevar a un cambio medible en las acciones individuales y colectivas, expresado en nuestro estudio de caso principalmente a través de la participación en la ciencia ciudadana y las acciones comunitarias y en la comunicación de los resultados de los programas a conocidos y funcionarios electos. Proponemos los siguientes principios de alfabetización de la conservación con base en temas emergentes y las conexiones entre ellos, explícitas en nuestros datos: el aprendizaje basado en la localidad crea la construcción de significados personales; la experiencia individual anidada dentro de la experiencia colectiva (es decir, en la totalidad del programa) facilita el entendimiento de los procesos ambientales y funciona a la escala regional y local; y la creación de significados basados en la ciencia crea una conciencia informada (es decir, la habilidad de discernir tanto la fuerza natural como la antropogénica), la cual permite que los individuos desarrollen un esquema personalizado de priorización y se comprometan con las acciones de conservación.

Palabras Clave: acción colectiva, aprendizaje por experiencias, aves marinas, costero, ciencia informal, sentido de localidad

Introduction

To document, address, and adaptively manage solutions to today's conservation problems, scientists, resource managers, and policy makers need high-quality, geographically broad, fine-grain data collected over decadal time scales (Pimm et al. 2014). Based on the sheer scale of these needs, data collection tools that are both comprehensive and relatively inexpensive are paramount. Evidence exists that well-trained nonexperts can identify species taxonomically and collect data on abundance and phenology nearly as well as experts (Dickinson et al. 2010; but see Kremen et al. 2011). Accordingly, research involving the public, exemplified by citizen science, has become an increasingly popular practice within conservation (Elbroch et al. 2011).

Schultz (2011, pp 1080) argues that the field of conservation biology has largely advanced science over practice and calls for a focus on the actions and the cultivation of those actions necessary to advance conservation practice. After all, he asserts, "conservation means behavior." Claims have been made that citizen science can positively impact volunteer behavior, leading to measurable action (Jordan et al. 2011). If so, how does citizen science participation then facilitate such action-oriented behavioral change? Recent work challenges the long-held assumption that conservation action––or more generally responsible environmental behavior––is simply related to learning and knowledge gain (Wals et al. 2014). Instead, the likelihood that individuals will adopt conservation actions may depend on both cognitive and affective learning about the ecosystem and the risks to it (Heimlich & Ardoin 2008). Taking action may also be motivated (Nolan 2010) by the degree of attachment to a system (Haywood 2014), a recognition of the potential for particular individual-level solutions to create positive change (Frick et al. 2004), and the ability of the individual––physically, emotionally, and within the social norms of the community––to commit to devising solutions (Stevenson et al. 2013).

We explored the ability of biodiversity-based citizen science to advance the practice of conservation by spurring individuals to action. We used the Coastal Observation and Seabird Survey Team (COASST) as a case study. We used this case to explore whether and how place-based, data-rich, and rigorously conducted citizen science can advance conservation literacy via two interlinked avenues: awareness and understanding of ecosystem processes and the factors affecting ecosystem function and conscious action to effect positive conservation outcomes regarding known impacts to the ecosystem. We placed our findings within two conceptual frames: models of behavioral change rooted in environmental education and models of scientific, ecological, and environmental literacy rooted in science education and environmental ethics.

Methods

The COASST program focuses on beached birds. Begun in 1999, the program has approximately 800 participants who collect data on 450 beaches from Mendocino, California, north to Kotzebue, Alaska (U.S.A.). The COASST training consists of a single 5-h session, conducted by a content expert, broken into 3 parts: an introduction to the COASST program providing information on geographic and temporal data collected and on data use in science and resource management; hands-on practice of carcass identification skills; and beach-survey sampling design and data-sheet completion. Attendees subsequently joining COASST are given a protocol, COASST field guide, data sheet, and tool kit and assigned a beach of their choice. Misidentifications caught by verifiers elicit a communication from the program that leads the participant through the correct identification steps in the field guide. Other forms of communication that further skills and content learning include the website, e-newsletters, biannual reports, and in-community public talks. In sum, by attending a training session, a (future) participant has had the opportunity to gain content

and skill-set knowledge. Upon joining the program and actively participating, a COASST participant has regular opportunities to deepen both of these elements. We focused on data collected by the COASST program on participant performance, and conducted a mail-in survey and in-person interviews of COASST participants.

COASST Program Data

We used program data from February 2012 to May 2014, the period for which participant-accuracy data existed and were verified. This data set represents 15,194 unique bird carcasses, 447 participants, and 1,970 surveys. Self-reported bird expertise (none, beginner, intermediate, advanced, or expert) was optionally provided by participants upon joining COASST. All identifications made in the field by participants are independently verified by experts. We used a single measure of accuracy, percentage of carcasses correctly identified to species. To highlight the effects of training and practice, we used an exponential regression to model participant accuracy as a function of the number of birds found over all participants who found birds within the study period.

Surveys

Two participant populations were surveyed: individuals participating in the COASST program for at least 1 year (active COASST participants) were surveyed, March–July 2012 ($n = 308$, 75% return rate), and individuals who had signed up for the program but had not yet been trained (pre-COASST individuals) were surveyed, February–June 2012, at one of 21 COASST training sessions ($n = 124$, 98% return rate). All individuals in the latter population subsequently became active COASST participants, which allowed us to test differences in knowledge, skills, and beliefs as a presumed function of COASST training and participation. Surveys were conducted under IRB number 37516.

We used 6 questions from the active COASST participant survey, 2 of which were common to both surveys. Short answers were coded into categories from an iterative analysis of the data to define synonyms (e.g., *debris* included marine debris, trash, garbage, refuse, and litter). Depending on the question, codes were aggregated into larger metacategories (e.g., all listed causes of marine bird mortality were categorized as anthropogenic, natural, or either). Category and metacategory coding activities were conducted by two independent coders trained on the same ($n = 50$ responses) pilot data set to >95% agreement. For questions common to both survey populations, response distributions were tested for differences with chi-square contingency tables to examine whether individuals with presumed similar motivation to join the program but without specific training or practice (pre-COASST population) expressed the same beliefs and knowledge as individuals who had both COASST training and at least 1 year of practice (active participant population).

Interviews

In the summer of 2013, 79 COASST participants (44% response rate) across 3 states (Washington, Oregon, and California) opted in to a one-on-one guided-tour interview ($n = 71$) or a focus group session (3 groups, $n = 14$): six people participated in both. Identical questions were posed, regardless of session format. Sessions were audio recorded (with permission) and transcribed verbatim. All participants were individually identified, allowing for subsequent analysis at the respondent level. Interviews were conducted under IRB permit 25391.

We excerpted answers in 5 question blocks (Supporting Information) for analysis. Text blocks were coded using QSR N'Vivo software (version 2.10) to identify major themes, similarities, and differences among respondents. In particular, we inductively coded interviewee responses to questions about place (Q5 [Supporting Information]) into 5 nonexclusive attachment catalysts. We defined these catalysts as a suite of specific activities, interests, knowledge, or feelings associated with a place that facilitate place attachment and emerge from the meaning found there. Codes were developed iteratively during the coding process based on constant comparison of other text within the category and established theory on learning and action. Interview transcripts were coded by the first author.

Developing a Conceptual Model

Using emergent themes from our data, and with specific reference to possible intersections between adult learning, citizen science, and conservation action, we constructed a conceptual model (Fig. 1). Although many connections may be possible among these themes, we restricted our model to those for which we had evidence. We used the model to structure an integrated presentation of our quantitative and qualitative results, as well as to highlight what aspects of place-based, data-rich citizen science may contribute to advancing the conservation literacy of program participants and potentially lead to greater levels of individual and collective action.

Results

Concepts and Skills

Active COASST participants had a range of awareness, knowledge, and understanding of concepts of coastal ecosystem ecology and conservation. Initial interview questions (Q1–3 [Supporting Information]) elicited 209

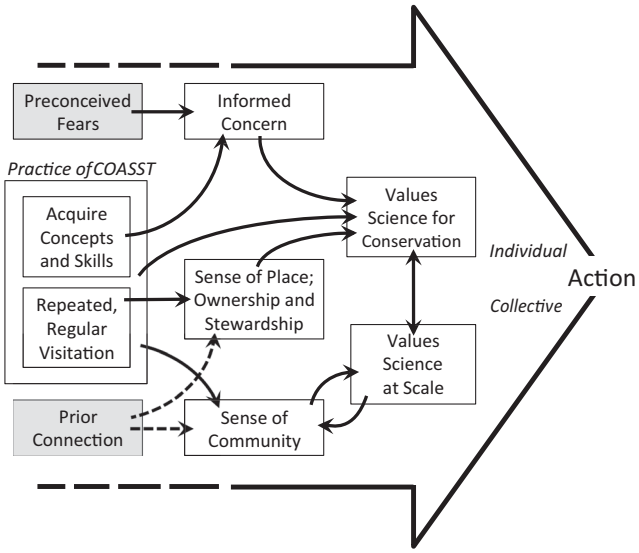

Figure 1. Conceptual model linking the learning experience of a citizen science participant to potential conservation action (gray boxes: ideas, values, or experience brought to the program by the participant; white boxes: engagement and learning as a consequence of the program; solid arrows: linkages made explicit by interview or survey data; dashed arrows: theorized connections) (Coastal Observation and Seabird Survey Team 2015).

examples of content or concepts and skills provided by 94% of the 79 respondents. Two concept themes emerged: bird biology, behavior, and ecology (82%, 61 of 74) and ecosystem components, structure, and processes (68%, 50 of 74). Bird biology, behavior, and ecology included discussions of species abundance, distribution, and status and threats to coastal birds; species identification; bird anatomy and morphology; natural history and life history; and phenology of specific species. Ecosystem components, structure, and processes included physical and ecological interactions that shape the beach environment and nearshore communities; marine species abundance and distribution; trophic interactions; bottom-up forcing (e.g., nutrient upwelling); tides and tide patterns; habitat and geology; and processes of change.

In addition to their self-reported system knowledge, active COASST participants quickly became very accurate in the required tasks—searching for carcasses and deducing species identity. Program-wide, 87% of carcasses found were correctly identified to species. An exponential model of accuracy as a function of the number of birds found ($Y = 0.0294 \ln(X) + 0.07637$; $R^2 = 0.17$) showed that, although the explained variation was low, average ability after training was almost 76% correct to species. Further, the program average was reached at approximately 38 birds or 5 months of surveying, despite the fact that the self-reported level of bird expertise of incoming participants was low (48% beginner or no experience; $n = 295$ respondents).

Beyond content or skills acquisition, we also coded 4 a posteriori categories regarding the benefits of hands-on practice of data collection (interview Q1–3 [Supporting Information]) (Table 1). Many COASST participants noted a pronounced difference between acquiring knowledge out of context (e.g., in a classroom or from a book or website) and the kind of deeper understanding that comes with experiential learning and the positive mental challenges inherent in the deductive aspects of the program. Some articulated gaining confidence in their abilities, whereas others spoke about self-directed exploration of science as a consequence of program participation. Almost 90% (70 out of 79) interviewees articulated one or more of these benefits.

Repeated and Regular Surveys

Participation in COASST requires monthly data collection. When asked about the value of participation for science or society (Q4 [Supporting Information]), 44% of interviewees spoke to why or how regular and repeated observations inform science and deepen personal learning.

> By going to the same place with some discipline, you become more observant, more of an expert in that area, more able to see things that are out of the ordinary and different . . . I can be the eyes and ears to support science.

Sense of Community

A weaker theme arising out of our initial interview questions (Q1–3 [Supporting Information]) was the self-realization among participants that they were part of a larger community of like-minded people all conducting the same repeated, regular surveys. Eighteen percent of interviewees identified the COASST community as composed of both other individuals within their geographic ambit (e.g., first quote below) and individuals they had not met but knew existed (e.g., second quote below).

> One of the things that has really been a benefit for us is the ability to get together and have these kinds of conversations and have this community that has grown out of it.

> Other than the science aspect, I'm really a big believer in community and to have all these people, all these various people, working on a project from so many different places. And that is a community of people.

Community membership sometimes also included COASST staff and undergraduate interns and, more generally, inclusion in a community of science.

Table 1. Learning benefits of participation in COASST.

Process[*]	*Explanation*	*Example quotes*
Experiential learning (58%, 34%)	hands-on, field-based practice as a successful method of acquiring knowledge	"As much as you think you know your birds, try and get a dead one. So learning how to identify was really cool. We've had a lot of fatalities here, so I have some experience measuring different wing chords from the ones that I've tagged, and there is literally just 2 cm difference between some of the birds, which is really cool."
Gaining confidence (34%, 17%)	a sense of confidence emerging from the mastery of concepts and associated skills	" . . . since I've been going with the group for the last four years, I'm a lot more confident going through the process [of measurement and identification] and I feel like I do it a lot better. I can now look at a bird and, even before measuring, tell what it is without looking through the foot key."
Mental and physical health benefits (49%, 29%)	activating the mind or body; a deeply personal desire to learn in order to keep the mind fresh	"Something that I appreciate . . . is that instead of COASST just asking for a photograph showing as much as possible, they allow you to use your brain to say, I think this is this bird . . . I think this is what it is. They don't just come out and say, just shut up and send us a picture and we will make a decision."
Self-directed knowledge gain (36%, 20%)	enlarging the scope of knowledge; following up on emergent questions to gain contextualized knowledge of a place	"COASST has been a doorway into other areas of the physical sciences that had been an interest to us. I think COASST is like that nagging activity. You say, well, one of these days when I retire I'm going to do that or go see that thing. And then when you finally do it, you say, well gee, I wish I would have done that earlier. It leads to other things you didn't think about. A gateway drug."

[*] *Percentages in parentheses include the percentage of respondents (n = 79) followed by the percentage of responses (n = 106).*

> Being involved with a really dedicated group of researchers and volunteers is an enormous part of it. [. . .] I think you feel like you are part of a professional network, and you are a part of a professionally run study that makes a real difference.

> I hate it when someone else . . . asks to do my beach because that is my territory. I mean that pretty much in a fun way, but I'm pretty jealous of that. That is my beach. I've got to do it.

Sense of Place

Almost three-quarters (53 out of 79) of COASST participants interviewed described one or more instances of affective learning (106 instances total; responses to Q1–3 [Supporting Information]) that connected their engagement to feelings of the value or worth of the program data, concepts, and goals. One of the central themes to emerge was the link between the participant and the survey site, specifically that the scientific study of a place can both facilitate and enhance a sense of ownership of that place.

Seventy respondents (89%) identified one or more attachment catalysts (Table 2). Responses were especially strong with respect to the time and effort participants put into their surveys and the resultant level of familiarity with, and science-based knowledge of, the site. That is, repeated, regular sampling enhanced the sense of place.

Additionally, almost all interviewees (96%) used possessives (e.g., "my beach") when describing their work with COASST, placing their comments within themes of protection and stewardship.

Informed Concern

Both pre-COASST ($n = 122$) and active COASST ($n = 308$) survey respondents had concerns about anthropogenic impacts to their coastal environment. However, participating in COASST may temper concerns about the relative impact of human activities. Active participants were less concerned about the ecosystem impacts of human activities, assessed over all regions, than pre-COASST participants (2×2 contingency table, $\chi^2 = 3.12$, df $= 1$, $p = 0.0773$). Furthermore, when asked to list major causes of marine bird mortality, the pre-COASST respondents tended to favor anthropogenic mortality sources such as pollution (nonspecific), plastics, or oil, whereas active participants had a significantly higher tendency to list natural mortality sources (3×2 contingency table, $\chi^2 = 9.84$, df $= 2$, $p = 0.0073$) (Fig. 2), including winterkill, postbreeding mortality, or low production. This pattern was particularly accentuated for first responses (participants were able to list up to 5 mortality sources) (Fig. 2). Chi-square contingency tables, as a function of response order, indicated the distributions of response metacategories were highly different for only the first

Table 2. Examples of place-based attachment catalysts and their frequencies derived from interview responses to Q5 (Supporting Information).

*Catalyst**	*Explanation*	*Example quotes*
Esthetics (26%)	the esthetic of physical appeal of the site	"It is a really enjoyable beach. So I have that kind of attachment to it. And the sunsets are beautiful, it is really just a very emotional connection."
Wildlife encounters (44%)	the site affords experiences with live wildlife, particularly birds	"I found on our beach, we had quite a bit of diversity because you not only get the pelagic species but you also get the birds that are in the bay. It is the perfect beach for seeing birds."
Personal investment (68%)	a strong emotional sense of pride because of the time, effort, and energy expended to conduct COASST surveys	"I've certainly clocked in more hours here . . . So I'm more attached because I've spent a lot of time on it so far. I've invested energy."
Site-specific knowledge (62%)	confidence that through repeated visitation participants can thoroughly and reliably document data and establish pattern and come to know that site better than most	"There is Snowy Plover habitat at my beach and it is a sensitive species habitat, and it is a very high use beach and so there is a lot of potential conflict. And I think it is really important that all of that gets documented. And COASST asks you to document beach use. So I started doing this six or seven years ago so that now I really know the beach and how it is used and can help protect it."
Familiarity, intimacy, and history (56%)	a sense of comfort that comes with familiarity and deeper connection to a place, leading to a sense of belonging	" . . . I have enjoyed so much becoming familiar with the beach; seeing the dynamics and observing these changes going on, the beach takes on a personality so to speak. And I would find it hard to move to a different one. We had one stretch about a year ago, we went four months without a new dead bird or refind, but the beach was different each time and we were seeing that. So that was as much as anything the motivation - let's go see what the beach looks like today."

*Percentages in parentheses are percentage of respondents ($n = 79$).

($\chi^2 = 22.26$, $p < 0.001$, df $= 2$) and second ($\chi^2 = 10.08$, $p < 0.001$, df $= 2$) responses.

Value of Science

Continued practice sharpened the value participants placed on science and on COASST data in particular. From the subset of interviewees indicating some level of attachment to their beach (70 out of 79), 46% alluded to the personal value they placed on program data or science concepts embedded in the program.

> Just contributing to the monitoring program, to share more data, even if it is a null, . . . that means something. I now understand that zeros matter too in science. I like that concept.

For many participants, data collection became a way to protect a valued place and the associated ecosystem; 66% (46 out of 70) of interviewees linked COASST data collection directly to conservation, stewardship, or protection.

> The neat thing about volunteering . . . is the amount of time I've accumulated looking at my beach . . . getting to know a place more deeply, to have a full sense of what it is like in different seasons and different parts of the tidal cycle. And that kind of deeper, richer knowledge of a place is something that I value. Being a part of COASST, I realize how useful that kind of information can be for the protection of the beach itself.

The survey returned similar results. Of 252 participants listing one or more concerns about their local coastal environment, 89 (35%) believed the program could address at least some of them (Fig. 3). All concern categories had some percentage of respondents indicating the COASST program was relevant to addressing the issue (highest responses for oil [48%] and fisheries [36%]).

Science at Scale

Following from a belief in the importance of science, interviewees described a sense of collective action or enhanced value of science as a function of its scale in space and time.

> Just knowing you are contributing to something that has some value is important. Because you've got an organization with almost 1,000 volunteers, the fact is that you are able to glean all sorts of information. That makes it purposeful and powerful.

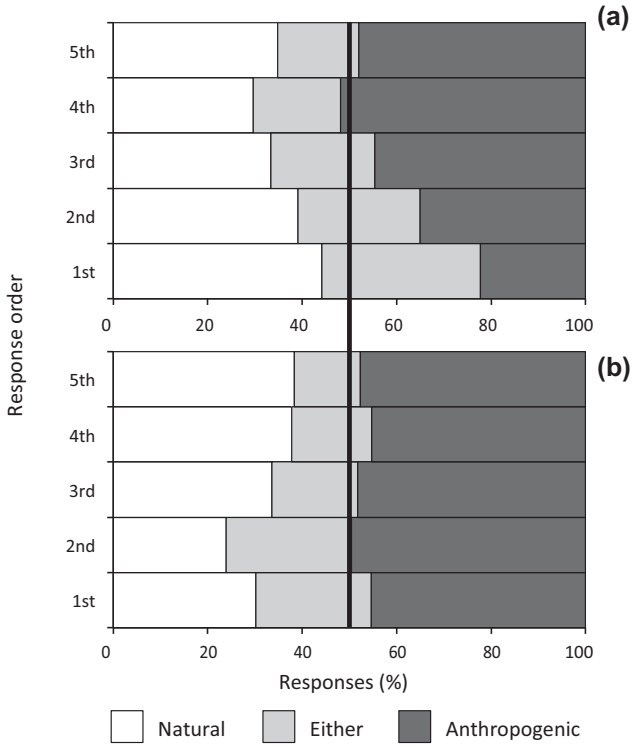

Figure 2. Distribution of responses to the question: "What causes marine bird mortality?" as a function of respondent population and response order (respondents could list up to five reasons): (a) active COASST participants (302 respondents and 1347 responses) and (b) pre-COASST participants (119 respondents and 544 responses) (vertical line, 50% mark). Causes cited were coded and binned into 1 of 3 metacategories: anthropogenic origin (e.g., oil spills), natural causes (e.g., postbreeding mortality), or could be either (e.g., starvation).

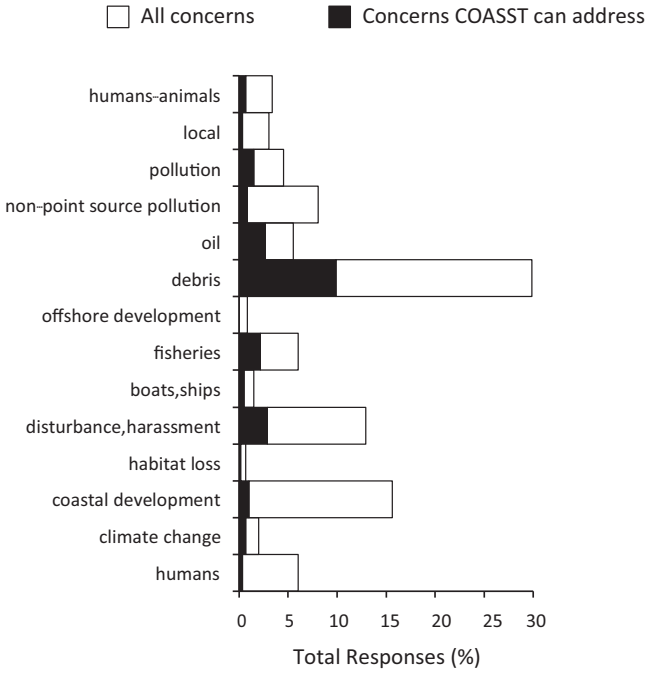

Figure 3. Distribution of the top 3 responses (n = 596 responses and 308 respondents) of active COASST participants to the questions: "When you think about your coastal area (the beaches in your vicinity), are there human activities or their consequences that you are concerned about? . . . please list up to three issues that concern you." and "If you think the COASST program has addressed any of [these] issues, please check the box beside the issue(s)" (unshaded, percentage of all responses within a category; shaded, subset of respondents who thought COASST could address that particular concern). Responses beyond the first 3 per respondent were not included. All responses were coded into a posteriori categories.

In addressing the public value of what participants were doing in COASST (Q1 [Supporting Information]), 92% of the 79 interviewees noted the aggregate data as one of several principal public benefits of the program—emphasizing the importance of their own role as part of a larger collective and the power of that combined information. Several subthemes emerged.

Thirty-eight percent of interviewees called out the value of standardized, systematic, and independently verified data as creating collective value.

> That is what I think is so important about the protocols and the way it is checked is that this is a real scientific project and it has much longer arms because it has more people who follow all the same rules.

A total of 74% of interviewees spoke directly to the long-term or longitudinal nature of the COASST data set, and 83% specifically identified the concept of a baseline as centrally important.

> If you don't know what you had, you don't know what is changed, or lost, or gained. And so having a baseline is key. [H]aving people out there that can monitor and recognize issues across a wide area, I think it is critical. It's why I value participating."

Action

Participants realized several levels of conservation action at the individual level arising from their involvement in the program, including maintaining or increasing their participation, communicating to others about the program, and engaging in other tasks, programs, or opportunities. Although not specifically asked whether they performed more than the minimum level of required

effort (i.e., monthly surveys), 27% of interviewees indicated taking on a deeper level of COASST data collection following their initial engagement in the program, including more frequent surveying and adopting additional survey sites. Participants also expanded their on-site efforts beyond COASST, most often by removing debris, the environmental issue active participants cited as their number one concern (Fig. 3). Of the 72 interviewees (91%) who identified trash or debris as an environmental concern on their beach, 83% stated that they had begun to clean the beach during their surveys, although this has never been a requirement, or even suggestion, of the COASST program.

> When I first started the bird surveys I didn't pick up trash, I was more occupied with the birds. Now I feel like it is my beach. I do feel more ownership and now it is just a given that I pick up trash.

A total of 98% ($n = 306$) of active COASST participants surveyed self-reported communicating to others about the program, including explaining the program (36%), sharing information about a recent survey find (38%), sharing science or resource management outcomes of COASST data (14%), and engaging individuals in a conversation about joining COASST (12%). Of the 51 interviewees who indicated that they encountered other people while conducting their surveys, 71% reported engaging in on-the-beach teaching, including sharing information about program goals, beach- and program-level findings, and aspects of natural history, ecology, or conservation. Of all interviewees 30% (24 out of 79) reported successfully recruiting another person to COASST.

Survey respondents were also asked how often they communicated about COASST with specific sectors of their community, ranging from individuals who were well known to them (e.g., neighbors) to persons of power (e.g., politicians) (Fig. 4). At least 20% of respondents indicated that they had spoken to the latter about COASST findings. Given the participant corps, this scales to more than 100 people speaking with politicians, resource managers, and the media about COASST, assuming the 75% survey-response population is indicative of active participants as a whole.

Just under half (48%) of interviewees identified some additional action outside of COASST, arising out of their participation in COASST. Of these 38 individuals, 63% had begun to participate in a regional (e.g., Coastwatch and Beachwatchers) or national (e.g., Christmas Bird Count) citizen science program they learned about from other COASST participants. Eighteen percent reported taking a class to enhance their understanding of a topic raised in COASST (e.g., coastal geomorphology or ecology). Finally, a small number of individuals (3 [8%]) became engaged in community organizing efforts (e.g., strengthening local ordinances that regulate beach use).

Discussion

In the decades since Roth (1992) first proposed the notion of environmental literacy, scholars in environmental science and education, resource management, and conservation biology have placed substantial emphasis on increasing citizen literacy to both ameliorate human–environment conflicts and enhance the sustainability of socioecological systems (McBride et al. 2013). Environmentally, ecologically, and scientifically literate individuals display knowledge and understanding about the earth, ecosystems, and scientific processes (Aikenhead et al. 2011), develop an ecological understanding via a systems thinking approach, and cultivate critical and holistic thinking skills within local, regional, and global contexts (Jordan et al. 2009). Such individuals possess the knowledge and skills necessary to understand and advance effective conservation strategies (Trombulak et al. 2004), solve specific environmental problems (Coyle 2005), and negotiate such decisions at multiple scales and contexts (Hollweg et al. 2011). A literate person in this context is "someone who, both individually and together with others, makes informed decisions concerning the environment; is willing to act on these decisions to improve the well-being of other individuals, societies, and the global environment; and participates in civic life" (Hollweg et al. 2011:2–3). Our work suggests that COASST produces literate participants. By engaging the whole person, the program cultivates contextual ecological understanding, practical skill development, and provides the prerequisites of individualized and collective action. Based on our data, we propose 5 tenets of applied conservation literacy: place-based learning, knowledge of ecosystem processes and science at scale, informed concern, prioritization of ecological impacts, and action.

Place-Based Learning

Conservation literate citizens assimilate knowledge about the environment locally, through interactions with the natural world in the places and spaces that have a particular meaning for them, places they are attached to and return to on a regular basis (giving them the opportunity to assess change). Almost three-quarters of interviewees articulated a deepened sense of place arising out of their regular participation in COASST surveys. Although some referred to nonscientific catalysts, such as esthetic enjoyment, over half made the connection between their beach and science or the science of COASST (e.g., personal investment and site-specific knowledge), and almost 60% connected their participation to a sense of stewardship. A deepened sense of place can arise from participation in action-oriented research (Manzo & Perkins 2006), which may simultaneously build community capacity and agency (Minkler & Wallerstein

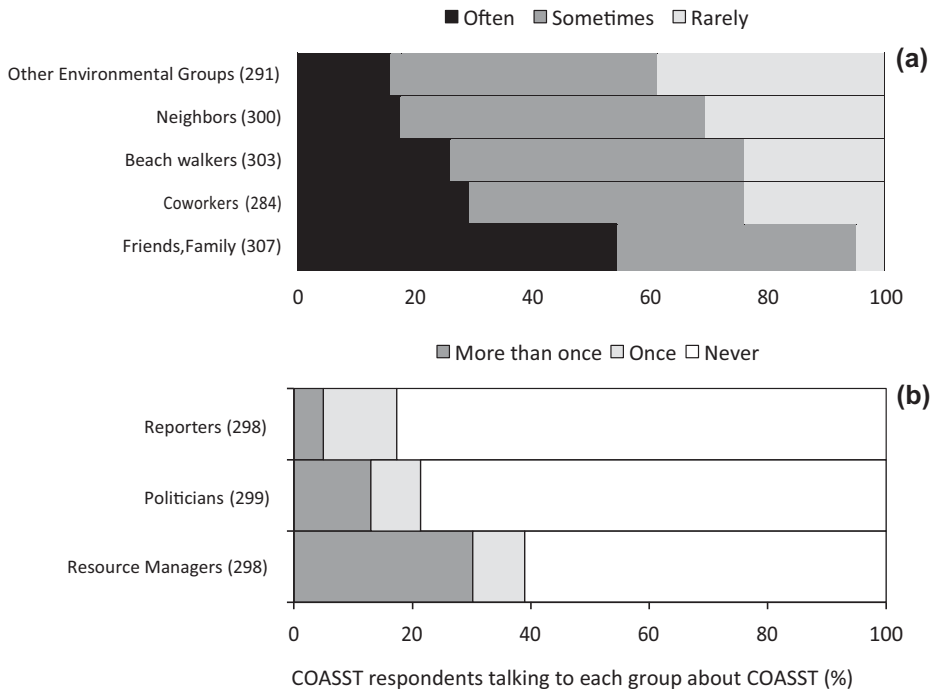

Figure 4. Self-assessed frequency of communication from active COASST participants with other members of their community since joining COASST: (a) individual participants interact with regularly (beach walkers were defined as individuals encountered while on COASST surveys) and (b) individuals with potentially greater reach with respect to conservation action and top-down decision making. Sample size (in parentheses) ranges as a consequence of respondents electing not to address a given subquestion.

2008). This, in turn, can build support for environmental policies, conservation, and protection (Ryan 2005), as well as engagement in environmental volunteering and advocacy (Vaske & Kobrin 2001).

Ecosystem Process and Science at Scale

Conservation literate citizens understand the basics of ecosystem structures and processes (here incorporating natural history and life history in holistic knowledge) operating in a specific place. Knowledge is gained through the practice of repeated, regular observation and standardized data collection couched within a larger programmatic and scientific context that includes content and concept learning opportunities. Individuals realize scales of time (development of the baseline at their own site) and space (compare their site-specific findings with larger patterns arising from a collective data set). Citizen science programs collecting data that contribute to larger scientific studies are one means of situating learning in authentic scientific practice (Krasny & Bonney 2005). Clearly, COASST participants quickly master the skills needed to accomplish the task of identifying bird carcasses on the beach and derive satisfaction from knowing they have achieved this goal (Table 1). To many COASST participants, a central value of the program is the scale of the information generated through collective action and that these data have a public use.

> I like to think that all the effort that we all do has an even further life beyond the program; that once it all comes together it is available for others to use, like the marine consortium or Hatfield [Marine] Science Center. People use what we have learned to make educated decisions, and I appreciate that.

Informed Concern

Following from an increased understanding of ecosystem process and function, a conservation literate citizen is aware of, and can sort out, natural forcing factors from anthropogenic ones, and can connect natural forcing to ecosystem processes. Within the realm of facilitating environmentally responsible behaviors, knowledge of the system and impacts affecting it are one prerequisite (Frick et al. 2004). As participants engaged in COASST surveys, they appeared to become less concerned with the impacts of humans on the system (e.g., Fig. 2). Because pretraining survey respondents embody COASST participants prior to active engagement in the program, these results can be interpreted to mean that the participant knowledge of the system and factors affecting it is increasing. For instance, pre-COASST participants failed to ascribe bird mortality to common natural sources such as postbreeding stress or winterkill, whereas COASST participants with >1 year of active participation correctly cited these sources when asked to list reasons marine birds die. Thus, although active participants clearly had concerns about the impacts of human activities on coastal environments (Fig. 3), they did not ascribe all population or system change to human actions.

Prioritization

As a result of the ability to distinguish between natural and anthropogenic forcing and an understanding of the

scalar nature of environmental processes and a deepened sense of place garnered through authentic scientific experience, conservation literate citizens develop a schema to prioritize impacts to their local environment, which allows them to move from a nonspecific sense of fear about environmental degradation to a sense of which action or actions are practicable and efficacious. Such a schema might be based on the greatest impacts at a larger scale (regional and global), the greatest impacts at the local scale, or impacts the individual has some ability to combat. Although active COASST participants listed a wide range of concerns about particular human activities and their consequences, from nonspecific worry about humans to extremely pointed local worries about coal trains and crows, for example, the greatest general concern was debris (Fig. 3). This result is not surprising because, 10 months prior to the survey's distribution, the 2011 tsunami in Japan swept away entire coastal communities and deposited hundreds of tons of debris along the western North American coastline. Slightly over one-third of respondents thought the program could address the issue of marine debris. However, with the exception of debris, high-ranking concerns across the active participant population were not necessarily those that individuals believed COASST could address.

Action

With capacity and commitment to act responsibly (Stevenson et al. 2013) comes specific knowledge of actions that can be effectively taken (Frick et al. 2004). Concern about a place or ecosystem of personal value may motivate an individual to take stewardship action (Haywood 2014). Based on their contextual knowledge, conservation literate citizens identify paths toward, and may take, concrete action. Identification of these pathways allows them to act on their concerns. Action does not necessarily equal advocacy (in the political sense); action may be limited to personal behavioral change and nonactivist public action in the scientific sphere, including participation in one or more citizen science programs focused on biodiversity. In COASST, the most basic conservation action is continued participation in the data collective, as this single act was seen by 35% of active COASST survey respondents as addressing one or more of their concerns about coastal environmental health (Fig. 3). Actions outside of the COASST program were cited by just under half of the interviewees, most often including joining another citizen science effort. Although not all are specific to conservation in the narrow sense of protection of biodiversity and ecosystems, the collection of "next steps" suggests that informed, involved people will do more, even if they are not explicitly asked to do so. Participants also exhibited a willingness to act, as exemplified by proactive communication of program findings to decision makers (Fig. 4b). Johnson et al. (2014) found similar levels of communication within Indian citizen science participants and suggest a diffusion model of environmental learning via social networks and formal and informal teaching. This social value, or community capital (Jordan et al. 2011), of citizen science may be essential for empowering participants (Price & Lee 2013). As such, participant agency is enhanced by engagement, rather than set exclusively by prior attitudes and community externalities that presuppose action as the ultimate goal (Berkowitz 1997). With millions of citizens involved in biodiversity-based citizen science programs (Theobald et al. 2015), this collective may hold the potential for creating a more conservation literate community. Conservation professionals "do not have the time to wait for . . . discoveries to 'trickle down' to the public through the filters of textbooks and other media" (Brewer 2001, pp 1203). Citizen science, we aver, is a remarkably effective way of opening up this trickling spigot so that conservation research and applications are directly produced, disseminated, and enacted in collaboration with the public in local to global contexts.

Supporting Information

Survey and interview questions and coding and grading (Appendix S1) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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