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Citizen science benefits coral reefs and community members alike

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The field of coral gardening and active restoration has expanded rapidly over the past 2 decades in response to the rapid, global decline of coral reefs. Even with this expansion, the long-term success of coral restoration and ecosystem recovery will still depend on social action to mitigate the local and global stressors plaguing reefs. Rescue a Reef (RAR), a citizen science program, was designed to engage community members and catalyze action through hands-on, experiential opportunities as coral gardeners and restoration practitioners alongside trained scientists. While community-based coral restoration programs can be a powerful platform for education and increase project success, few programs utilize citizen science and even fewer measure and evaluate the long-term impacts of these activities. Here, we describe the benefits of citizen science for coral conservation identified through a mixed methods longitudinal evaluation of RAR after 8 years of citizen science programming. A survey was distributed to all program participants and responses were compared to historical pre-post survey responses of citizen scientists as well as to a control group. We found that despite the passing of time, citizen scientists largely retained their knowledge levels on coral reef-related topics and were significantly more knowledgeable on the topics than a control group. Additionally, RAR successfully developed a strong sense of community, coral stewardship, and program support among its participants. Most importantly, citizen science has the potential to act as a vehicle for positive social change with the majority of participants reporting changes in perceptions (70.5%) and behavior (60.1%) because of their participation in RAR. Thus, the untapped potential of citizen science as a tool for coral reef conservation, restoration, and stewardship must be realized. Furthermore, citizen science projects must embed evaluation in their activities to gather information and evidence on the effectiveness of their activities as well as potential areas for improvement.

KEYWORDS

coral reef, coral restoration, citizen science, education, social change, coral conservation, community engagement, community psychology

1 Introduction

Coral reefs are one of the most important ecosystems on our planet. They protect our coastlines, acting as a natural barrier that can mitigate erosion, storm surge, and hurricanes (Ferrario et al., 2014; Beck et al., 2018; Storlazzi et al., 2019). They support biodiversity, serving as refuge, feeding, and/or mating grounds to an estimated 30 percent of all marine species (Fisher et al., 2015). They sustain communities, providing a source of protein for over one billion individuals (Whittingham et al., 2003). Coral reefs also drive economies, supporting important sectors like tourism, recreation, research, and fisheries with the United States' reefs alone estimated to provide $3.6 billion in goods and services annually (Brander and van Breukering, 2013).

However, coral reefs have experienced dramatic declines in the past 40 years due to both local and global stressors (Bruno and Selig, 2007; De'Ath et al., 2012; Jackson et al., 2014; Lester et al., 2020). Globally, rising ocean temperatures due to anthropogenic greenhouse gas emissions are causing mass coral bleaching events and die-offs with increasing frequency and severity (Manzello, 2015; Hughes et al., 2018). Additionally, these excess emissions are causing increases in ocean acidity, making it more difficult for corals to grow and reproduce (Muehllehner et al., 2016; Richmond et al., 2018; Morris et al., 2022). Locally, coral reefs are being impacted by a combination of pollution, coastal development, overfishing, and disease (Precht et al., 2016; Cunning et al., 2019; Lapointe et al., 2019; Hayes et al., 2022). To address these declines, the field of coral gardening and reef restoration has expanded rapidly in the past 2 decades. There are now hundreds of coral restoration programs that have restored thousands of square meters of degraded reef habitat around the world (Boström-Einarsson et al., 2020).

The field of active coral reef restoration is constantly improving as scientists develop and implement innovative coral restoration tools, techniques, and strategies (Goergen et al., 2020). Recent advances have led to: 1) increased outplanting efficiency and effectiveness (Schopmeyer et al., 2017; Bayraktarov et al., 2020; Unsworth et al., 2021), 2) new species being integrated into gardening and active restoration (Forsman et al., 2015; Page et al., 2018; Rivas et al., 2021), 3) increased success with *in*- and *ex-situ* sexual reproduction as a tool to establish gene banks, bolster nursery stocks, and increase genetic diversity of restored populations (Petersen et al., 2006; Hagedorn et al., 2021; Henry et al., 2021; O'Neil et al., 2021), and 4) the identification of more resistant and resilient coral populations, species, and genotypes as well as methods to "harden" individuals to stressors like high light intensity and water temperatures for use in reef restoration (Silverstein et al., 2012; Cunning et al., 2021; Kaufman et al., 2021; DeMerlis et al., 2022). Coral restoration has been shown to significantly increase coral cover and structural complexity of reef restoration sites compared to unrestored sites (Hein et al., 2020). Staghorn coral has been shown to significantly enhance the wave-reducing capacity of a reef for coastal protection benefits (Ghiasian et al., 2021). Restoration has also been shown to significantly increase fish abundance and species richness post-outplanting (Opel et al., 2017). Despite these advancements, the long-term success of coral restoration and reef recovery will depend on social action to mitigate local and global stressors (Hoegh-Guldberg et al., 2019; Boström-Einarsson et al., 2020; Ferse et al., 2021; Kleypas et al., 2021; Suggett et al., 2023). While scientists have been calling for action on these stressors for decades, traditional methods of informing and educating individuals has not translated to meaningful social change (Moser, 2010).

Therefore, in 2015, we developed Rescue a Reef (RAR), a citizen science coral restoration program designed to act as a vehicle for public engagement, education, and social action. Led by coral researchers from the University of Miami, the RAR program hosts field expeditions that provide an educational, experiential opportunity for recreational SCUBA divers and snorkelers to participate directly in coral gardening and reef restoration efforts. Members of the public ("citizen scientists") work alongside coral scientists helping to maintain nursery structures, collect coral fragments, and outplant colonies to local reef restoration sites while learning about the importance and impact of the activities.

Citizen science is as it sounds: everyday citizens contributing to science. Public participants or volunteers work in collaboration with trained scientists to carry out research, data collection, and/or analysis for a scientific project (Bhattacharjee, 2005; Bonney et al., 2009). Citizen science projects are designed to be symbiotic, providing benefits to both scientists and citizens. Citizen science allows the scientists to advance their projects beyond their own capabilities, and it helps engage the public in science to promote literacy, knowledge, and stewardship (Brossard et al., 2005; Jordan et al., 2011; Crall et al., 2013). Citizen science projects are an ideal fit for scientific endeavors with important environmental and social implications, like coral conservation, because they can directly engage local stakeholders and help foster a sense of identity and connection with the project community over time (Dickinson et al., 2012; Jackson et al., 2015; Bela et al., 2016). This sense of community is critical as social change requires the empowerment of individuals and a shared mission that includes the voices of those impacted (Gruber and Trickett, 1987; Kloos et al., 2012; Bond et al., 2016; Dosemagen and Parker, 2019). Citizens in communities with community-based monitoring tend to be more engaged in local issues, community development, and civic duties (Conrad and Hilchey, 2011). The social impacts of citizen science are not exclusive to the citizens either. A review by Bela et al. (2016) of 14 case studies of citizen science initiatives found that more interactive, hands-on projects were able to facilitate a mutual exchange of knowledge between both the citizens and the scientists. This same review found that citizen science activities also allow scientists to acquire and improve their collaborations skills, a critical development with the growing need for interdisciplinary research to solve today's complex environmental issues.

Coral restoration has the potential to be a powerful platform for education, stewardship, and conservation strategies (Hein et al., 2019). Community-based participation in coral restoration can promote knowledge gains and strengthen decision-making of participants, and increase the success of overall project activities (Hernández-Delgado et al., 2014; Goergen et al., 2020; Suggett et al., 2023). A review by Hein et al. (2017) of 83 published studies on coral restoration identified six primary objectives, one of which was to "promote coral reef conservation stewardship" as practitioners recognized the need for community education and empowerment. After 2 years of programming, an evaluation of RAR citizen science activities showed that there was no significant difference in the survivorship of corals outplanted by participants compared to corals outplanted by experienced scientists (Hesley et al., 2017). Additionally, retrospective pre-post survey results showed that participants reported a significant increase in coral reef ecology and restoration knowledge following participation in an expedition. However, citizen science practitioners recognize that additional resources must be put into data-driven, measurable projects to assess potential long-term impacts of the activities (Brossard et al., 2005; Bonney et al., 2009; Posavac, 2011; Crall et al., 2013; Bela et al., 2016).

That is what this program evaluation sought out to do. As a community-based program, we have a responsibility to ourselves and the communities we serve to formally evaluate our activities and ensure we are reaching desired outcomes and realizing impact (Bela et al., 2016). Community-based program evaluation is a critical process that involves assessing the effectiveness, efficiency, and impact of the activities that the program is designed to address (O'Leary, 2005; Frechtling, 2007; Gill, 2010; Posavac, 2011). The RAR program was designed to raise awareness, develop a sense of community, and foster coral stewardship among its participants. After 8 years of citizen science activities, we launched a mixed-methods longitudinal evaluation using quantitative and qualitative data to better understand RAR's progress and the potential long-term impacts and benefits of the program.

To guide our evaluation, we used our RAR program's Logic Model (Supplementary Figure S1) as a framework. A Logic Model is a tool that describes an organization's theory of change underlying an intervention and outlines a project through four basic components: 1) inputs, or the resources that are brought to the project, 2) activities, or the actions that are undertaken by the project to bring about desired outcomes, 3) outputs, or the immediate results of an action, and 4) outcomes, or the changes that occur showing progress toward achieving the ultimate objectives and goals of the program (Frechtling, 2007). Logic Models can provide the scaffolding for a program evaluation by helping define and clarify what should be measured and when.

The RAR program's Logic Model helped establish the following guiding questions:

1) Have we fostered a sense of community and stewardship among participants?
2) Have knowledge levels changed over time?
3) Have perceptions and/or behaviors changed over time?
4) Was the evaluation process beneficial?

In 2017, an evaluation of the RAR program established that citizen science benefits coral reef restoration activities (Hesley et al., 2017). Despite this, few coral restoration projects integrate citizen science into their activities and even fewer evaluate the long-term benefits. With these things in mind, we launched another evaluation to understand the potential latent social impacts on individuals in relation to our RAR citizen science activities. Our priority was to self-reflect, assess, and adapt in hopes of improving our activities and communicating the lessons that we have learned. Here, we describe our RAR program's outcomes, effectiveness, and impact.

2 Materials and methods

To formally assess the potential educational and behavioral impacts of our citizen science program, a mixed methods longitudinal evaluation of RAR was carried out. This included a within-group evaluation (i.e., reviewing retrospective pre-post surveys of the RAR program participants immediately following an expedition and again 1+ years later) and a between-group evaluation (i.e., establishing a control group to act as a baseline for comparison). As a community-based program, RAR's participants are one of the most inexpensive, accessible, and accurate data sources available and were therefore a priority of the evaluation (Posavac, 2011). There are limitations to only evaluating within-group information (e.g., sampling bias, reactive measures) so this assessment was anonymous and included multiple measures (i.e., a control group, mixed methods) to improve the validity of the evaluation.

The longitudinal evaluation was completed using a survey instrument developed in alignment with the NOAA Coral Reef Restoration Monitoring Guide sociocultural performance metrics (Goergen et al., 2020) (Supplementary Figure S2). The survey instrument was designed using Qualtrics and distributed via email to every individual who had previously participated in an RAR citizen science coral restoration expedition. The survey link was also shared on RAR's social media platform in case past participants no longer used or monitored their email. The timing of survey distribution (August 2021) gave us a unique opportunity to evaluate the long-term impacts of the citizen science activities as around a year had passed since RAR last hosted an expedition due to the COVID-19 pandemic. Hereafter we therefore refer to this group of individuals as "latent-expedition" or simply "latent" citizen scientists because of the time that had passed and the potential for enduring impacts.

This new longitudinal evaluation survey instrument was structured to mirror the standard survey that is distributed to participants immediately after the completion of each RAR citizen science expedition. Rescue a Reef expeditions feature a 30-min educational lecture and tutorial as well as hands-on coral husbandry and reef restoration activities within Miami-Dade County, Florida as described by Hesley et al. (2017). The standard survey shared after these expeditions has a retrospective pre-post format and consists of questions to assess Likert scale knowledge levels for both before (pre-) and immediately after (post-) restoration expeditions. Historical survey responses collected from individuals following participation in an expeditions between 2015–2020 were used for analyses here when applicable. This group contained both "pre-expedition" and "post-expedition" data due to the nature of the retrospective pre-post survey instrument, despite this survey only being distributed to individuals after participation in an expedition.

To establish a "control" group and create baselines for comparison, the latent-expedition citizen science survey instrument was modified slightly and distributed to individuals who had never interacted with our RAR program before (Supplementary Figure S3). This survey instrument was distributed by Qualtrics to a stratified random sample of Florida residents 18 years of age or older. Both the latent group and control group surveys were distributed in August 2021. All groups were informed that the surveys were voluntary and anonymous, and were designed solely for the purpose of evaluating the potential impacts of our activities as well as areas for improvement. For these reasons, the University of Miami determined that this project evaluation did not constitute human subject research requiring IRB review.

2.1 Survey design

The surveys consisted of multiple choice, Likert scale, rank order, and open-ended questions, dependent on what was being assessed (Supplementary Figure S2, S3). In brief, the questionnaires were designed to capture information on 1) demographics, 2) knowledge levels (perceived and realized), 3) program support, and 4) reported changes in perceptions and/or behavior, to empirically evaluate the sociocultural impacts associated with coral restoration projects (Goergen et al., 2020).

The demographics portion of the survey captured age, residency, education, level of engagement with RAR, among other things. The second section assessed their perceived knowledge levels on coral reefs, threats they face, and tools available for conservation as well as their confidence in communicating these topics to others via Likert scale and rank order questions. The third section sought to evaluate overall program belongingness and support. The fourth section aimed to determine their realized knowledge levels on the aforementioned topics via open-ended questions which can create rich opportunities for discovery of new concepts (Gioia et al., 2013). The final section aimed to assess reported changes in respondents' perceptions of coral reefs and/or behavior changes resulting from interacting with RAR as well as suggestions for improving our program.

2.2 Survey analysis

For each data set we removed individuals who completed less than 70% of the survey questions. We also removed individuals who we confirmed used online searches to populate their open-ended question responses (i.e., "cheated"). For the latent-expedition survey, we removed 39 individuals who indicated that they had not participated in an RAR expedition, likely a result of misunderstanding the instructions, as we were specifically assessing the impact of those who participated in the citizen science activities. We also removed those whose first expedition took place within a year of the latent survey distribution as they are more comparable to the retrospective post-expedition group than the rest of the latent-expedition group. For the control survey, Qualtrics quality checked the data to filter out bots and duplicates, and flagged responses that appeared insincere due to quick survey completion time/rushed responses or responses not based on the question or topic at hand. We reviewed these flagged individuals and agreed with the Qualtrics consensus, deleting them in addition to a few other low-quality responses.

All statistical analyses were conducted in R Studio Version 1.3.959. Shapiro tests were used to determine if the Likert-scale self-reported knowledge levels on coral reef-related topics were normally distributed across groups, and all mean comparison analyses required nonparametric tests. We did not use single 3-way means comparisons to compare knowledge levels between the control, post-expedition, and latent-expedition groups, as the post- and latent-expedition groups are more related from being drawn from the same population of RAR citizen scientists. We instead used separate Mann-Whitney U tests to compare 1) control to pre-expedition, 2) control to post-expedition, 3) control to latent-expedition, and 4) post- to latent-expedition separately. Histograms were used to assess if the shape of the knowledge level distributions were similar enough between groups to allow for interpretation of results as [non]significant differences between mean ranks. Knowledge level distributions were only similar enough across groups for survey questions about reef status and reef threats to warrant the interpretation of results as significant differences in mean ranks. Due to the variable distributions of Likert knowledge levels of reef ecology and conservation tools, we interpret these significant differences as stochastic dominance. Changes between pre-expedition and post-expedition Likert-scale responses were not statistically analyzed as these were the primary focus of a past evaluation (Hesley et al., 2017).

We also used Mann-Whitney U tests to compare the Likert-scale confidence communicating about coral reefs, comfort contacting "key coral reef organizations" (control) or "Rescue a Reef" (latent-expedition), and likelihood of supporting "coral conservation" (control) or "Rescue a Reef" (latent-expedition) in additional ways between 1) latent and control groups and 2) total number of RAR trips, as Shapiro tests and visualizations indicated distributions were significantly different from normal. Total number of RAR expeditions were pooled into groups representing 1 or 2+ expeditions due to small sample sizes. Questions about comfort communicating, contacting, and supporting RAR in additional ways were not asked in the retrospective pre-post survey and therefore these analyses did not include the immediate post-expedition group. The distributions of the results were similar enough between total RAR trip groups for all three questions and were similar enough for communication confidence between latent and control surveys, to warrant interpretation of results as a significant difference between mean ranks. The other comparisons must be interpreted as stochastic dominance.

We used chi-square tests to explore the influence of survey group on the ranking of coral reef conservation activities between control and latent groups, but not the post-expedition group as this question was not asked in the retrospective pre-post survey. We first did a frequency analysis of the top ranked item between groups, excluding fisheries management as a solution due to low expected frequency. Then for addressing climate change, coral reef restoration, and managing land-based pollution, we compared the frequency of respondents who assigned these actions the highest rank of 1, *versus* any lower rank (2+), between control and latent groups.

For the open-ended question responses, a blended approach of inductive and deductive coding was used to ensure we both gave voice to the respondents and stayed attuned to existing theories, respectively (Gioia et al., 2013; Elliott, 2018; Skjott Linneberg and Korsgaard, 2019). Three cycles of qualitative analysis to translate the various responses into specific codes were completed. The first-order analysis is meant to adhere to the phrases or terms used by the respondents themselves and can produce anywhere from 10 to 100 first-order categories. The categories that emerged were then reviewed and distilled into a more manageable number of themes reflective of the literature for second-order analysis. Completing the second cycle of coding with the second-order themes helped solidify the final codes to be used for analysis. The third and final cycle of analysis determined the response code as well as the total number of coded responses provided by each individual. Each unique response was only included in the single, most relevant theme. The open-ended question themes, codes, and code acronyms can be viewed in Table 1.

Chi-square tests were used to determine if there were significant associations between survey groups and frequency of the coded responses provided for both the ecosystem services and largest issues facing coral reefs. These analyses were run separately between 1)

TABLE 1 Resultant codes and themes produced from coding of open-ended question survey responses to (A) "What are the largest issues facing coral reefs?", **(B)** "What ecosystem services to coral reefs provide?", and **(C)** "Can you please describe what behavior/action(s) have changed (because of your interaction(s) with Rescue a Reef)?".

Code category	Open-ended response themes
A	
Pollution (POL)	Pollution (not marine debris), water quality, nutrient levels
Climate change (CC)	Climate change, global warming, sea level rise, extreme weather events
Ocean warming (OW)	Increasing ocean temperatures, coral bleaching
Humans (HUM)	Human-induced impacts at a local scale–marine debris, coastal development, sunscreen, irresponsible boating
Ocean acidification (OA)	Ocean acidification, accelerated erosion
Disease (DIS)	Coral diseases
Overfishing (OF)	Destructive fishing practices, poor fisheries management
Lack of education (LOE)	Lack of education, awareness, and stewardship
Population scarcity (POP)	Low coral populations, habitat fragmentation
No response (NR)	Left question blank, "I do not know," unrelated/incorrect response
B	
Habitat (HOM)	Home, habitat, shelter for marine organisms
Coastal protection (PRO)	Coastal protection, defense, wave attenuation
Food webs (FF)	Supporting food webs, source of food for marine life
Biodiversity (BIO)	Hotspot for marine life, supporting ocean health/ecosystem function
Human food source (EAT)	Food source for local and global communities
Water quality (CLN)	Water filtration, water cleansing
Economic driver (DOL)	Economy, tourism, recreation, fisheries, jobs, intrinsic value
Nursery (NUR)	Breeding grounds and nursery for marine life
Oxygen (OXY)	Oxygen production
Medicine (MED)	Medicine, pharmaceuticals
Wrong (WR)	Unrelated or incorrect response
No response (NR)	Left question blank, "I do not know"
C	
Advocacy (COMM)	Increased advocacy, communication, and education of others
Eco-friendly choices (ECO)	Lowering carbon footprint, choosing more eco-friendly products conscientiousness about sustainability
Reduce/reuse/recycle (RRR)	Reducing materialistic consumption, avoiding single-use plastics recycling more
Reef-safe sunscreens (SUN)	Using sunscreens without chemicals that harm coral reefs
Volunteering (VOL)	Volunteering, citizen science, donating to environmental organizations
Responsible diving (DIVE)	Proper buoyancy, avoiding spreading sand, not touching the reef
Responsible fishing (FISH)	More sustainable recreational fishing, safer boating practices
No response listed (NRL)	Left question blank

control and post-expedition, 2) control and latent-expedition, and 3) post- and latent-expedition, rather than running 3-way comparisons among the survey groups, as post- and latent-expedition groups are more related. McNemar tests could not be used to compare post and latent groups as this data is not paired due to the voluntary and anonymous nature of the surveys. Ecosystem services were only compared between control and latent groups as that question was not asked in the retrospective pre-post survey. Analyses were run separately for each service and threat category to avoid violating the assumption of mutual exclusivity, as several respondents listed more than one threat and/or service. We ran these analyses for the four most common threat categories (Pollution, Climate change, Ocean warming, and Humans) and all ecosystem services except for Medicine to avoid violating the assumption of expected values exceeding 5 in at least 80% of the cells.

We were also interested in comparing the total number of coral reef services and threats listed by survey respondents between surveys. To do so, Shapiro tests were used to determine if the number of coral reef services and threats listed were normally distributed across groups, and all mean comparison analyses required nonparametric tests. A Mann-Whitney U test was used to compare the number of ecosystem services listed between control and latent groups, but not the immediate post-expedition group as this question was not asked in the retrospective pre-post survey. The knowledge of threats question was asked in all three surveys, but as in the knowledge-level analyses, we did not use a single 3-way means comparison of number of threats listed between the control, post-expedition, and latent-expedition groups, because the post- and latent-expedition groups are more related. Therefore, we again used separate Mann-Whitney U tests to compare the number of threats listed between 1) control to post-expedition, 2) control to latent-expedition, and 3) post-to latent-expedition. Again, variance tests and histograms were used to assess if the shape of the distributions of number of threats and number of services listed were similar enough across groups to allow interpretation of results as [non]significant differences between mean ranks. We also used this same procedure to compare number of threats and services listed between individuals who had been on one RAR trip *versus* two or more trips. The variances of the number of services and the number threats listed between 1 RAR trip and 2+ RAR trips, and the number of threats listed between post- and latent-expedition groups were similar allowing interpretation as [non]significant differences in mean ranks for these comparisons. Finally, we used a chi-square analysis to determine if total number of RAR expeditions influenced whether an individual changed (i.e., binary Yes/No response) their perceptions and behaviors because of their interactions with RAR.

3 Results

We received 159 responses from the latent-expedition survey, 239 responses from the control survey, and had 263 responses available from the historical retrospective pre-post surveys (meaning we had 263 paired pre-expedition and post-expedition responses). After accounting for inconsistencies described previously, the final data set used for evaluation consisted of 95 latent-expedition responses, 209 control responses, and 253 pre-post expedition responses. However, not all questions received a response from every respondent as the entire survey was voluntary, and thus these samples sizes varied by question. Power analyses conducted in RStudio package "pwr" using a significance threshold of 0.05, power of 0.9, and effect sizes based on the data from Hesley et al. (2017) indicated that our sample sizes were sufficient for statistical analyses.

3.1 Demographics

Education levels between our latent citizen scientists and control population differed, but both groups' age range and occupation were similar. Only 1.1% of our latent citizen scientists reported "High school graduate, diploma, or equivalent" as their highest level of education whereas this constituted 28.7% of our control respondents (Supplementary Table S1). The largest proportion (41.1%) of latent citizen scientists were >45 years old with 25–34 years old comprising the next largest proportion (28.4%). Our control respondents' ages were very comparable, with most (45.7%) being >45 years old and 25–34 years old as the next largest proportion (24.3%). When asked "Is your schooling and/or job directly related to environmental research, conservation, education, advocacy, policy, or similar?" the majority of latent citizen scientists (64.2%) and control respondents (82.3%) answered "No". When asked if they were a current resident of South Florida., 82.1% of citizen scientists answered "Yes". We did not ask this question to our control respondents as being a Florida resident was a requirement for survey eligibility. Similarly, all latent citizen scientists had participated in RAR so, control respondents were asked "Have you participated in an environmental citizen science project before?" and 12.0% answered "Yes". The majority of the control group were not SCUBA divers (89.5%), and most latent citizen scientists had been on more than 50 dives (42.7%), with having logged 1–10 dives comprising the next largest proportion (29.3%).

Looking specifically at our latent citizen scientist audience, we asked how long it had been since they first interacted with our RAR program. There was a tie, with most respondents reporting that it had been either 2 or 3 years (both 35.8%) (Supplementary Table S2). We also asked "How have you interacted with Rescue a Reef?" (i.e., social media, public event, citizen science expedition) and prompted them to check all that apply. Excluding participation in an expedition (as this audience was specific to past participation), the largest proportion of additional program interaction was through social media (42.1%) followed by being an email subscriber (30.5%), presentation attendee (24.2%), donor (22.1%), and public event attendee (18.9%). We also asked how long it had been since their last RAR expedition, and most respondents (48.4%) indicated 2 years. When asked how they participated during their RAR expedition(s), majority (81.1%) of latent citizen scientists answered "SCUBA diver". When asked how many expeditions they have participated in total, majority (65.3%) answered that they had participated in one, 18.9% in two, 10.5% in three, and 5.3% in four or more. When asked if they were interested in participating in future RAR expeditions, majority (94.7%) answered "Yes".

3.2 Perceived knowledge levels

To assess how perceived knowledge levels on coral reef status, ecology, threats, and tools for conservation may have varied depending on group identity and time point, we compared survey scores between control, pre- and post-expedition, and latent-expedition respondents (Figure 1). There was no significant difference in perceived coral reef status between post- and latent-expedition respondents (mean = 2.4 ± 0.9, mean = 2.2 ± 0.7, respectively), but pre-, post-, and latent-expedition means were significantly lower than control response means (mean = 2.7 ± 0.9) (Mann-Whitney U, $p < 0.001$) (Supplementary Table S3). Pre-, post-, and latent-expedition respondents reported having significantly

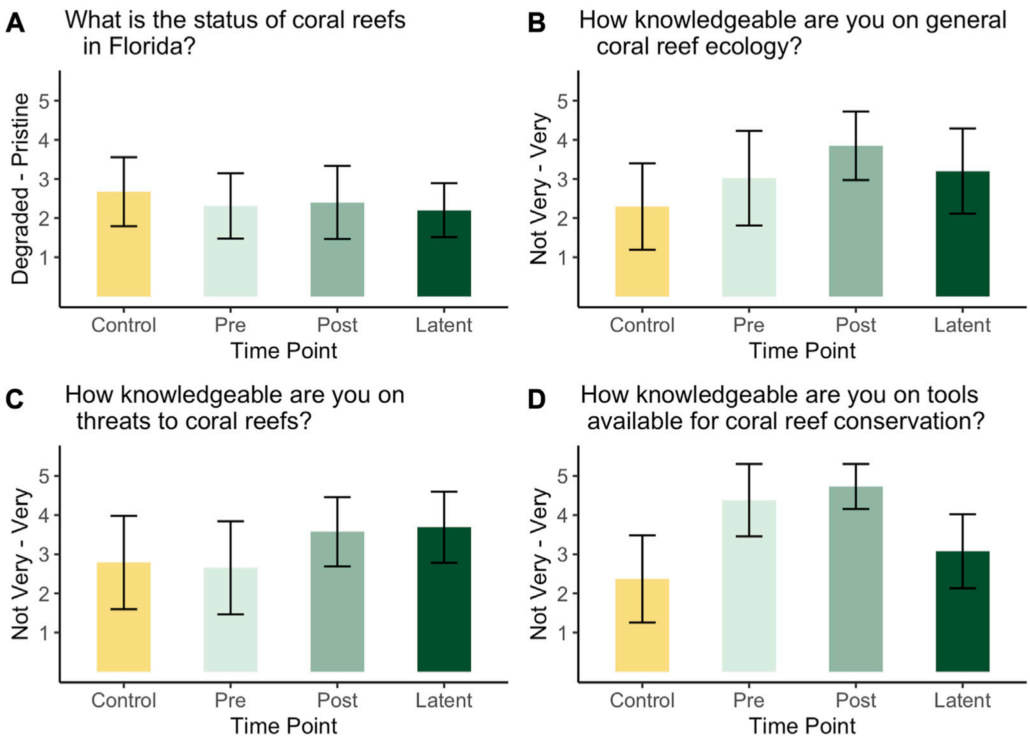

FIGURE 1
Averages (±S.D.) of Likert-scale responses to survey questions assessing perceived knowledge levels on coral reef **(A)** status, **(B)** ecology, **(C)** threats, and **(D)** conservation tools across groups/time points (i.e., pre-expedition, post-expedition, latent-expedition).

higher knowledge levels on coral reef ecology (mean = 3.0 ± 1.2, mean = 3.8 ± 0.9, mean = 3.2 ± 1.1, respectively) when compared to the control group means (mean = 2.3 ± 1.1) (Mann-Whitney U, $p < 0.001$). However, latent-expedition perceived knowledge levels of status were significantly lower than post-expedition respondents (Mann-Whitney U, $p < 0.001$). There was no significant difference in perceived knowledge levels of threats to coral reefs between control and pre-expedition citizen scientists (mean = 2.8 ± 1.2, mean = 2.7 ± 1.2, respectively) nor between post- and latent-expedition citizen scientists (mean = 3.6 ± 0.9, mean = 3.7 ± 0.9, respectively), but both post and latent groups again had significantly higher means than control response means (mean = 2.8 ± 1.2) (Mann-Whitney U, $p < 0.001$). Lastly, pre-, post-, and latent-expedition respondents reported having significantly higher knowledge levels on tools available for coral conservation (mean = 4.4 ± 0.9, mean = 4.7 ± 0.6, mean = 3.1 ± 0.9, respectively) when compared to the control group means (mean = 2.4 ± 1.1) (Mann-Whitney U, $p < 0.001$). However, latent-expedition perceived knowledge levels were again significantly lower than post-expedition respondents (Mann-Whitney U, $p < 0.001$). While the means of the control group and pre-expedition group were significantly different for coral reef status, ecology, and tools for conservation, the groups compared similarly as both identified reef status as below average (mean ≤3) and identified themselves as average-below average in coral ecology (mean ≤3). Additionally, their means for knowledge on threats facing coral reefs were not significantly different.

To assess perceptions on coral conservation actions, we asked both our control group and latent citizen scientists to rank a set of solutions adapted from Kleypas et al. (2021) in order of importance (1 = most important, 6 = least important) (Figure 2). There were six solutions presented to the respondents: land-based pollution reduction, coral reef restoration, addressing climate change, marine protected areas, public education and stewardship, and fisheries management. The top ranked coral conservation action was significantly dependent upon survey group (Chi-square, $\chi2 = 49.45$, $p < 0.001$) (Supplementary Table S4A). Addressing climate change was ranked as the most important action by the majority (55.8%) of latent citizen scientists and was significantly more likely to be assigned a rank of 1 *versus* any lower value (2+) by the latent group (Chi-square, $\chi2 = 34.306$, $p < 0.001$), whereas it was the third most important action according to the control population (mean = 3.3 ± 1.7). Land-based pollution reduction was the second most important action according to latent citizen scientists (mean = 2.8 ± 1.3). Most control respondents (30.1%) ranked land-based pollution reduction as the most important action and were significantly more likely to assign pollution reduction the highest rank of 1 *versus* any lower value (2+) (Chi-square, $\chi2 = 9.763$, $p < 0.05$) (Supplementary Table S4B). The control group was also significantly more likely to assign reef restoration a rank of 1 *versus* any lower value (2+) (Chi-square, $\chi2 = 11.635$, $p = 0.001$). When considering the mean rank values, coral reef restoration was the top priority for control respondents (mean = 2.5 ± 1.3) and land-based pollution was second (mean = 2.6 ± 1.5). Latent citizen scientists ranked coral reef restoration third (mean = 3.5 ± 1.5), public education and stewardship fourth (mean = 3.7 ± 1.8), marine protected areas fifth (mean = 3.9 ± 1.3), and fisheries management sixth (mean = 4.9 ± 1.4). Control respondents also ranked fisheries management sixth but re-prioritized fourth and fifth.

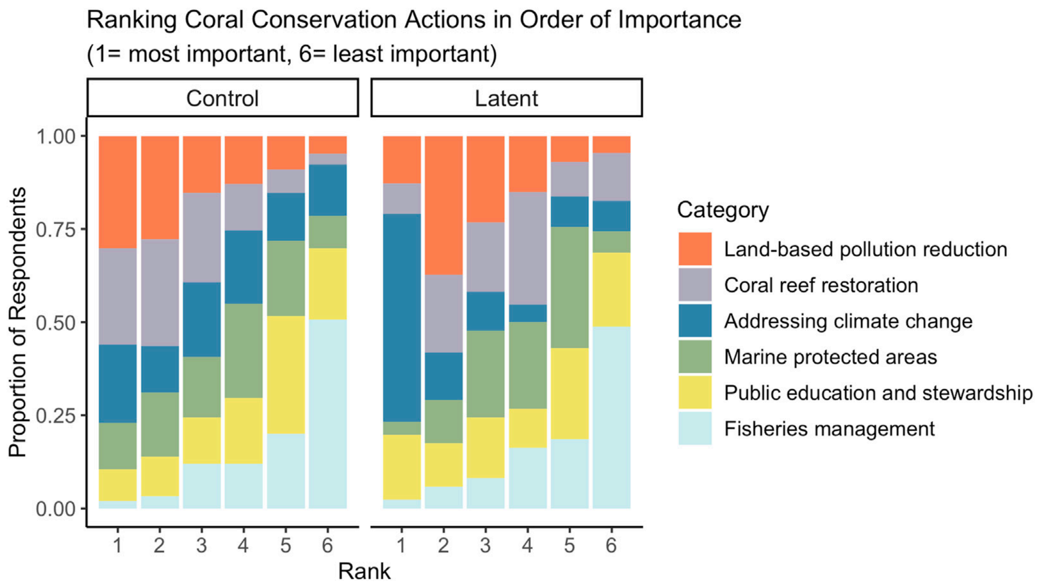

FIGURE 2
Proportion of survey respondents that ranked various coral conservation activities in order of importance from 1 (most important) to 6 (least important), compared between the control and latent citizen scientist group.

3.3 Knowledge levels

To assess knowledge levels on the issues facing coral reefs as well as the ecosystem services they provide, we asked both our control group and latent citizen scientists to provide specific examples through open-ended questions. We were also able to source survey responses from post-expedition citizen scientists on the topic of coral reef threats but not services.

When asked "What ecosystem services do coral reefs provide?", the greatest proportion of both the control group and latent-expedition respondents answered habitat (HOM) (26.3% and 46.3%, respectively) (Figure 3A). A high proportion (45.3%) of latent-expedition respondents also answered coastal protection (PRO), followed by supporting food webs (FF) (20.0%) and providing food for humans (EAT) (16.8%). No other response was above 15%, and 25.3% could not produce an answer. After habitat for marine organisms, the control group said coral reefs support biodiversity (BIO) in the next highest proportion (18.2%). No other response was above 15%, and 22.0% could not produce an answer. Comparing between groups, the frequency of a service being listed by latent citizen scientists was significantly higher for habitat, coastal protection, human food source, economic driver (DOL), and nursery (NUR) (Figure 3A) (Chi-square, $\chi2 = 11.896$, $p < 0.001$, Chi-square, $\chi2 = 66.251$, $p < 0.001$, Chi-square, $\chi2 = 8.54$, $p < 0.05$, Chi-square, $\chi2 = 14.96$, $p < 0.001$, Chi-square, $\chi2 = 16.99$, $p < 0.001$, respectively) (Supplementary Table S5A). The frequency of a service being listed by the control group was significantly higher for biodiversity and oxygen (OXY) as well as for wrong answers (WR) (Chi-square, $\chi2 = 3.79$, $p = 0.05$, Chi-square, $\chi2 = 4.698$, $p < 0.05$, Chi-square, $\chi2 = 5.41$, $p < 0.05$, respectively). The frequency of food webs and water filtration (CLN) being listed as well as the frequency of no services listed (NR) was independent of survey group (Chi-square, $\chi2 = 3.41$, $p > 0.05$, Chi-square, $\chi2 = 0.33$, $p > 0.05$, Chi-square, $\chi2 = 0.39$, $p > 0.05$, respectively). Our retrospective pre-post expedition survey does not include this question so their knowledge levels on this topic could not be assessed.

When asked "What are the largest issues facing coral reefs?", majority (55.6%) of post-expedition respondents answered pollution (POL) whereas most (48.4%) of the latent-expedition citizen scientists said ocean warming (OW) specifically (Figure 3B). The greatest proportion (40.2%) of the control group also felt pollution was one of the largest threats facing reefs. Post-expedition respondents then answered climate change (CC) in the second highest proportion (41.7%) followed by ocean warming (36.1%) more specifically and then humans (HUM) (29.2%). No other response was above 20%, and 16.7% could not produce an answer. After ocean warming, latent-expedition answered climate change (45.3%), pollution (42.1%), humans (29.5%), and ocean acidification (OA) (22.1%) in the highest proportions. No other response was above 20%, and 17.9% could not produce an answer. After pollution, the control group said humans were the largest issue facing coral reefs (30.1%). No other response was above 20%, and 15.8% could not produce an answer. Comparing between control and post-expedition respondents, the frequency of a threat being listed by post citizen scientists was significantly higher for pollution, climate change, and ocean warming (Chi-square, $\chi2 = 5.127$, $p < 0.05$, Chi-square, $\chi2 = 31.427$, $p < 0.001$, Chi-square, $\chi2 = 32.340$, $p < 0.001$, respectively) but not for humans (Chi-square, $\chi2 = 0.024$, $p > 0.05$) (Supplementary Table S5B). Comparing between control and latent-expedition groups, the frequency of a threat being listed by latent citizen scientists was significantly higher for climate change and ocean warming (Chi-square, $\chi2 = 43.375$, $p < 0.001$, Chi-square, $\chi2 = 64.523$, $p < 0.001$, respectively), but not for pollution nor humans (Chi-square, $\chi2 = 0.09905$, $p > 0.05$, Chi-square, $\chi2 = 0.014$, $p > 0.05$, respectively) (Supplementary Table S5C). The frequency of no threats listed (NR) was independent of survey group (Chi-square between control and post, $\chi2 = 0.03$, $p > 0.05$, control and latent, $\chi2 = 0.21$,

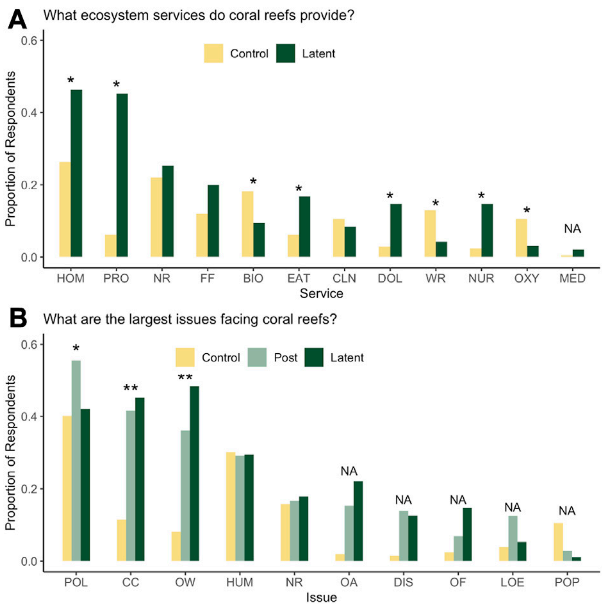

FIGURE 3
(A) Proportion of survey responses across groups/time points mentioning each theme to open-ended questions on ecosystem services provided by coral reefs: 1) HOM = habitat, 2) PRO = coastal protection, 3) NR = no response, 4) FF = food webs, 5) BIO = biodiversity, 6) EAT = human food source, 7) CLN = water quality, 8) DOL = economic driver, 9) WR = wrong, 10) NUR = nursery, 11) OXY = oxygen, 12) MED = medicine. Single asterisks (*) indicate a significant relationship between frequency of the category listed and survey group (control *versus* latent) per Chi-square analyses. **(B)** Proportion of survey responses across groups/time points mentioning each theme to open-ended questions on largest issues facing coral reefs: 1) POL = pollution, 2) CC = climate change, 3) OW = ocean warming, 4) HUM = humans, 5) NR = no response, 6) OA = ocean acidification, 7) DIS = disease, 8) OF = overfishing, 9) LOE = lack of education, 10) POP = population scarcity. Single asterisks (*) indicate a significant relationship between frequency of the threat listed and control *versus* post-expedition groups, and double asterisks (**) indicate a significant relationship between the threat listed and both 1) control *versus* post-expedition groups and 2) control *versus* latent-expedition groups. "NA" labels indicate that expected values were too small to run Chi-square analyses.

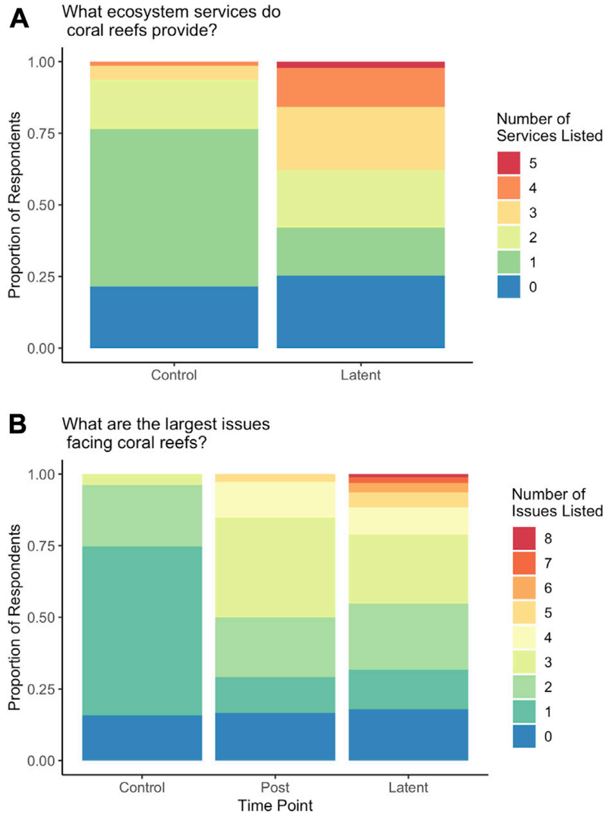

FIGURE 4
Proportion of the total number of accurate responses provided by survey respondents to open-ended questions on both **(A)** ecosystem services provided by coral reefs and **(B)** largest issues facing coral reefs compared between survey groups/time points.

$p > 0.05$, post and latent, $\chi 2 = 0.04$, $p > 0.05$). Comparing threat frequencies between post- and latent-citizen science groups did not produce significant results (Supplementary Table S5D).

Counting the total number of responses provided allowed us to assess the breadth as well as the depth of their knowledge levels. When asked about the ecological services coral reef provide, latent citizen scientists were able to provide significantly more answers than the control group (mean = 1.9 ± 1.5, mean = 1.1 ± 0.8, respectively) (Mann-Whitney U test, $p < 0.001$) (Supplementary Table S6A). While majority (57.9%) of latent-expedition citizen scientists produced two or more answers, only 23.4% of the control group was able to (Figure 4A). Majority (55.0%) of the control group produced one answer. The total number of services listed was not significantly dependent upon how many RAR expeditions (one *versus* 2+) an individual had participated in (Mann-Whitney U test, $p > 0.05$) (Supplementary Table S6A).

When asked about the issues facing coral reefs, both post- and latent-expedition citizen scientists were able to provide significantly more answers (mean = 2.2 ± 1.4, mean = 2.4 ± 1.8, respectively) than the control group (mean = 1.1 ± 0.7) (Mann-Whitney U test, $p < 0.001$) (Supplementary Table S6B). The greatest proportion of both the post-expedition (34.7%) and latent-expedition (24.2%) citizen scientists produced three threats facing coral reefs whereas majority (58.9%) of the control group only produced one answer (Figure 4B). Furthermore, majority of both post-expedition (70.8%) and latent-expedition (68.4%) respondents produced two or more answers, while only 25.4% of control respondents were able to. The total number of RAR expeditions an individual participated in (one *versus* 2+) did not significantly impact the number of issues listed by latent citizen scientists (Mann-Whitney U test, $p > 0.05$) (Supplementary Table S6B).

3.4 Social change

When asked how confident participants are in their ability to communicate coral reef-related topics to others on a scale of 1 = Not very to 5 = Very, latent citizen scientists were significantly more confident than the control group (mean = 3.3 ± 1.1, mean = 2.6 ± 1.3) (Mann-Whitney U test, $p < 0.001$) (Supplementary Table S7A). Nearly half (42.7%) of latent citizen scientists felt confident in their communication skills compared to only 24.9% of the control group

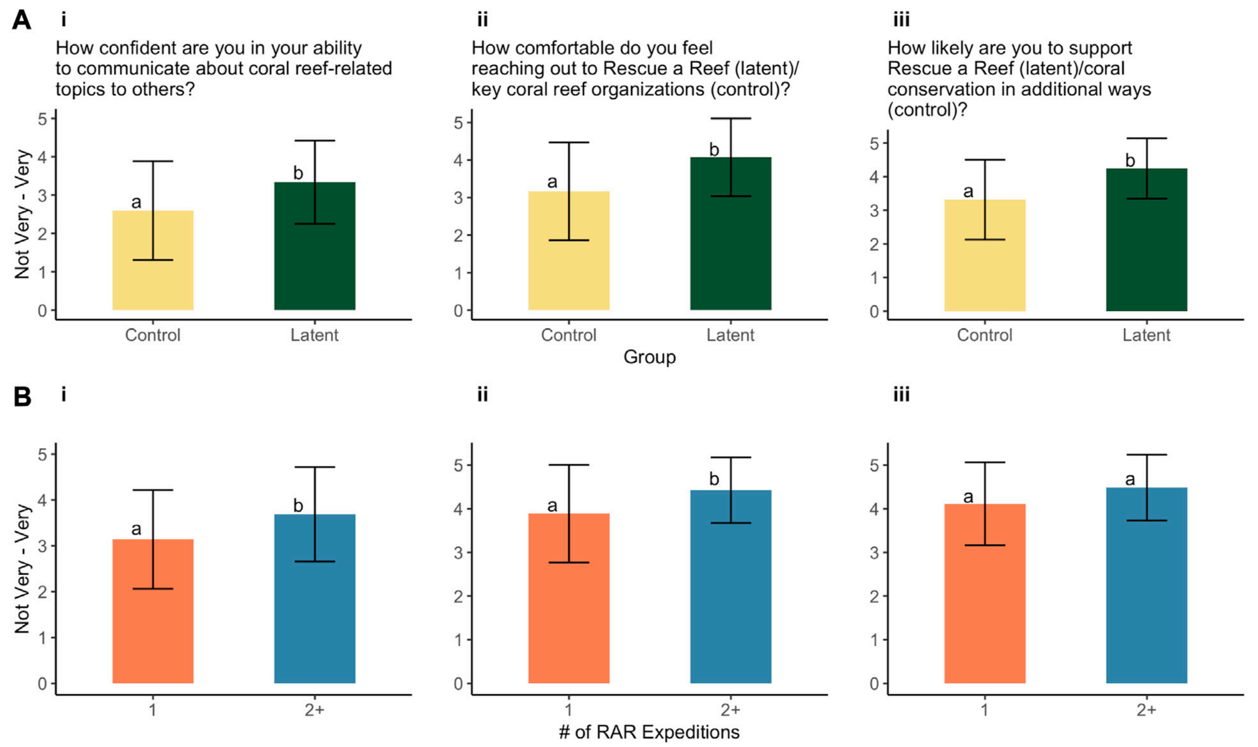

FIGURE 5
Averages (±S.D.) of Likert-scale surveys response across **(A)** groups and **(B)** total number of Rescue a Reef expeditions participated in for **(i)** comfort communicating coral reef-related topics to others, **(ii)** comfort reaching out to Rescue a Reef/coral conservation organizations, and **(iii)** likelihood of supporting Rescue a Reef/coral conservation organizations in additional ways. Letter annotations indicate a significant relationship between survey groups/number of RAR expeditions and Likert-scale responses per Mann-Whitney U tests.

(Figure 5A). Furthermore, only 2.2% of the latent group said they were "not very" confident in their abilities whereas 23.9% of the control group felt this way. Interestingly, individuals who had been on 2 or more RAR expeditions were significantly more confident in their ability to communicate on coral reef-related topics compared to individuals who had only been on one trip (Mann-Whitney U test, $p < 0.05$) (Supplementary Table S7B).

When asked how comfortable they feel reaching out to "key coral reef organizations" (control) or "Rescue a Reef" (latent-expedition) if they have a question, latent citizen scientists were significantly more comfortable than the control group (mean = 4.1 ± 1.0, mean = 3.2 ± 1.3) (Mann-Whitney U test, $p < 0.001$) (Supplementary Table S7A). Majority (70.5%) of latent citizen scientists felt comfortable contacting RAR with 46.3% saying they were "very" comfortable, whereas 41.6% of the control group felt they could reach out to another similar coral conservation organization with only 19.6% saying they were "very" comfortable (Figure 5A). Conversely, only 1.1% of latent citizen scientists said they were "not very" comfortable reaching out to RAR. Notably, individuals who had been on 2 or more RAR expeditions were significantly more comfortable reaching out compared to individuals who had only been on one (Mann-Whitney U test, $p < 0.05$) (Figure 5B) (Supplementary Table S7B).

When asked how likely they are to support "coral conservation" (control) or "Rescue a Reef" (latent-expedition) in additional ways (i.e., volunteering, donating, advocating), latent citizen scientists were again significantly more likely to compared to the control group (mean = 4.2 ± 0.9, mean = 3.3 ± 1.2) (Mann-Whitney U test, $p < 0.001$) (Supplementary Table S7Aa). Majority (75.5%) of latent citizen scientists said they were likely to support RAR in additional ways with over half (52.1%) saying they were "very" likely to, whereas only 20.1% of the control group said they were "very" likely to support a coral conservation organization (Figure 5A). Zero percent of latent citizen scientists said that they were "not very" likely to support RAR again, and only 3.2% said they were unlikely to. Likelihood of supporting RAR in additional ways was not significantly impacted by number of RAR expeditions (Mann-Whitney U test, $p > 0.05$) (Figure 5B) (Supplementary Table S7B).

To determine our program's impact on citizen scientists 1+ years after they participated in our coral restoration expedition, we asked them to candidly reflect on if and how their perceptions and behaviors changed because of RAR. When asked "Have your perceptions of coral reefs changed because of your interaction(s) with Rescue a Reef?", majority (70.5%) of latent citizen scientists answered "Yes" and 26.3% answered "No" (3.2% did not answer). Those who answered yes were asked to describe what perception(s) have changed. A few common themes emerged such as a realization of the importance of corals:

> "When you are able to hands-on interact with coral you begin to understand how the coral is extra special/unique and when placed within its ecosystem how it serves the piece of the larger picture,"

> "I have an even greater appreciation for our reefs than I had before and I want to help make a difference,"

> "Made me more aware of importance of reefs as well as impact from global warming on reefs (and thus I did more research) . . . Participating in reef restoration made me feel more connected and protective of reef ecosystems,"

> "Increased appreciation for the importance of a healthy reef system and our ability to restore and grow reefs in affected areas,"

The need for action to through advocacy and stewardship:

> "[My perceptions] changed in a way that we must continue to strongly advocate for our oceans the same way we do for other issues that exist in our society,"

> "I've realized the reefs need more attention than I was aware of, and that we can all make changes that will help,"

> "How important we humans are to protect the coral reefs,"

And a newfound hope for their future:

> "Prior to participating, I had very little knowledge of coral restoration–I now feel more hopeful about our collective ability to help restore reef ecosystems,"

> "I better understand how coral reefs support not only life in the ocean, but how they also support life on land by providing habitat for our food and protection of our coastlines. Rescue a Reef taught me tangible ways to help and support reef health and provides hope for the future,"

> "I have more hope for the future of coral reef health and conservation."

When asked "Have your behaviors/actions changed because of your interaction(s) with Rescue a Reef?", the majority (61.1%) of latent citizen scientists answered "Yes" and 34.7% answered "No" (4.2% did not answer). Those who answered yes were asked to describe what behavior/action(s) have changed. Most (35.2%) responded that they were better advocates for coral reefs (COMM) following their experience with RAR (Figure 6). This included increased communication, advocacy, and knowledge-sharing with others. The next most common behavioral change was living an eco-friendlier lifestyle (ECO) with 18.5% of respondents. This included answers related to lowering their carbon footprint, choosing more eco-friendly products and brands, and increased conscientiousness on sustainability. Latent-expedition citizen scientists also reported volunteering (VOL) (16.7%), reducing, reusing, and recycling (RRR) (13.0%), and reef-safe sunscreens (SUN) (16.7%) as new behaviors taken up because of interacting with RAR. It should be noted that roughly one-fifth (20.4%) of those who reported a behavior/action change did not provide a response (NRL), negatively skewing the other categories' proportions. Nonetheless, of those who reported a behavior/action change, 31% listed two or more changes.

The total number of RAR expeditions had a significant influence on perception change, with individuals who had participated in 2 or

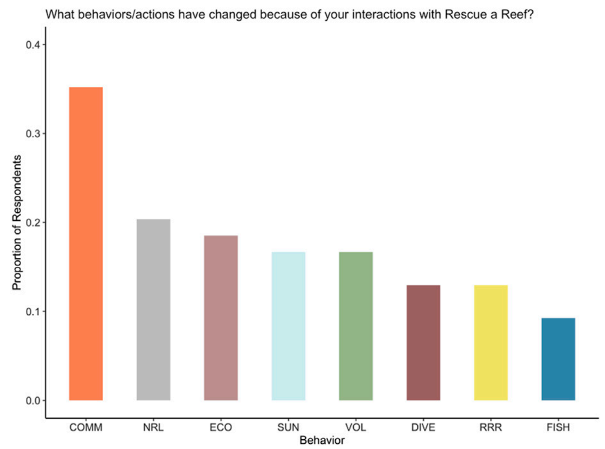

FIGURE 6
Proportion of latent citizen scientist survey responses mentioning each behavioral theme that changed because of their interaction(s) with Rescue a Reef: 1) COMM = advocacy, NRL = no response listed, ECO = eco-friendly life choices, SUN = reef-safe sunscreens, VOL = volunteering, DIVE = responsible diving habits, RRR = reduce/reuse/recycle, FISH = responsible fishing/boating habits.

more excursions indicating that their perceptions had changed as a result of interacting with RAR (Chi-square, $\chi2 = 5.89$, $p < 0.05$) (Figure 7A). There was no significant association between reported behavior change (Yes/No) and total number of RAR expeditions one had participated in (Chi-square, $\chi2 = 0.796$, $p > 0.05$) (Figure 7B).

4 Discussion

This longitudinal evaluation of the RAR citizen science coral restoration program serves as an important first attempt to assess the long-term impacts of the activities. While community-based restoration programs can be a powerful platform for education and stewardship as well as increase project capabilities and success, few programs utilize citizen science and even fewer evaluate the impacts (Hernández-Delgado et al., 2014; Hein et al., 2019; Goergen et al., 2020; Suggett et al., 2023). Here, we attempt to model how nature-based citizen science activities can benefit coral reefs and community members alike.

First, our evaluation revealed a strong sense of community and coral stewardship among our RAR latent citizen science participants, with the majority of individuals having engaged the program for three or more years. Additionally, majority were comfortable contacting us if needed and reported that they were very likely to support RAR in additional ways (i.e., volunteering, donating, advocating) (Figure 5A). Importantly, the high likelihood to continue contributing to RAR in additional ways was not significantly affected by number of RAR expeditions they participated in which suggests strong support for the program and its mission after only one interaction. This was further emphasized by the vast majority (94.7%) responding that they were interested in participating in a future RAR citizen science expedition. In addition to joining us on an expedition, most also follow RAR on social media with many also having subscribed to the

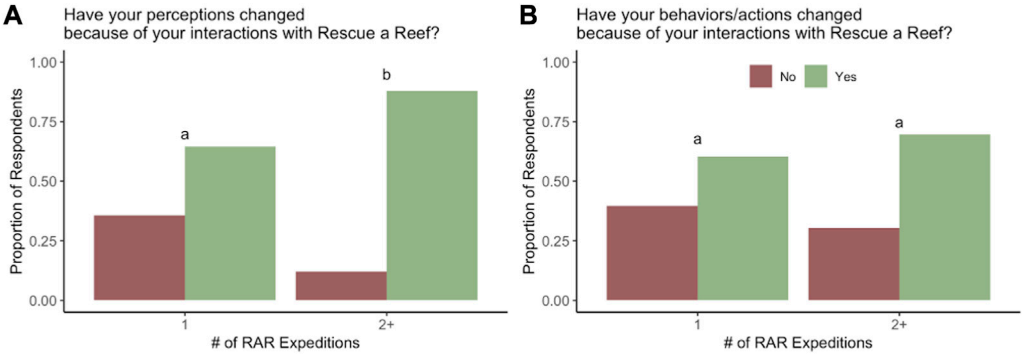

FIGURE 7
Proportion of survey respondents that indicated if they changed their **(A)** perceptions and **(B)** behaviors/actions because of their interactions with Rescue a Reef. Letter annotations indicate a significant relationship between number of Rescue a Reef expeditions and change (Yes/No) per Chi-square analysis.

email list, attended public presentations, and/or donated to RAR. Latent citizen scientists have also become strong stewards with most reporting that they were better advocates for coral reefs following their interactions with RAR and feeling significantly more confident in their ability to communicate coral reef-related topics when compared to the control group. The high retention rates, sense of community, and increased stewardship observed here among participants are all essential metrics of success for building capacity within a community-based coral restoration program (Goergen et al., 2020).

Second, we demonstrated that our latent citizen scientists largely retained their knowledge levels on coral reef-related topics despite the passing of time. Hesley et al. (2017) established that there were perceived knowledge gains by citizen scientists following participation in a RAR coral restoration expedition so it was important to assess if these gains were sustained over time. The latent citizen scientists had significantly higher self-reported knowledge levels on coral reef ecology, threats, and tools available for conservation when compared to the control group. The same was true when comparing post-expedition citizen scientists to the control group. This would suggest that our citizen scientists maintained above-average knowledge levels (mean ≥3) on these topics even though 1–6 years had passed. Conversely, our control group reported below-average knowledge levels (mean ≤3) on coral reef ecology, threats, and tools available for conservation suggesting a need for more community engagement with the general public through citizen science activities like RAR. Importantly, our post- and latent-citizen scientists also better understood the degraded status of coral reefs compared to the control group, who assigned them a significantly higher health score. When asked about the ecological services coral reefs provide, latent citizen scientist respondents were able to provide significantly more correct answers than the control group. In fact, majority were able to produce two or more and accurately identified habitat, coastal protection, human food source, economic driver, and nursery as ecological services at a significantly higher frequency than the control group. This was also observed when asked about the threats facing coral reefs, with latent respondents providing significantly more correct answers and listing climate change and ocean warming at a significantly higher frequency than the control group. Again, a majority of the latent citizen scientists produced two or more responses while only 25.4% of the control group did so. Conversely, there was no significant difference between the frequency of responses provided by post- and latent-expedition citizen scientists when answering threats facing coral reefs suggesting that knowledge was largely retained.

Third, our evaluation illustrated the potential of citizen science to act as a vehicle for social change, positively reshaping participant perceptions and behaviors. The majority of our latent citizen scientists reported that they have had changes in perceptions because of their interactions with RAR. This included, but was not limited to, their understanding of coral reefs, emotional connection to the cause, and hope for the future. This is important as how messaging and citizen science experiences elicit emotion and make people feel plays a critical role in fostering future environmental engagement (Moser, 2010; Dean et al., 2018). Our evaluation suggests RAR activities are promoting this engagement among participants as a majority of latent respondents reported that they have changed their behavior because of their interactions with the program. When asked what behaviors/actions changed, most responded that they were better advocates for coral reefs through increased communication, advocacy, and knowledge-sharing with others. They also reported changes in their lifestyle and sustainability choices, volunteer contributions, and reduce, reuse, recycle habits. While these actions may seem insignificant, individuals can feel overwhelmed and/or helpless when confronted with climate change and the issues it causes so meeting them where they are is an important first step (Moser, 2010; Gifford, 2011).

4.1 Fostering community and stewardship

Citizen science and community-based organizations like RAR exist to serve the needs of the community. But building a sense of community and stewardship does not happen overnight, it requires time and community buy-in (Kloos et al., 2012). When individuals feel a sense of belonging within these organizations, they become more invested in its goals, influential in its direction, emotionally connected to the cause, and responsible for its success (Arnstein, 1969; McMillan and Chavis, 1986; Kloos et al., 2012; Bela et al., 2016; Goergen et al., 2020). Community members are more likely to change their perspectives and actions if they are able to understand and reflect on their relevant behaviors and roles in the organization (Bonney et al., 2016).

However, the historical focus of restoration practitioners on the short-term ecological benefits of coral restoration has limited the potential for socio-ecological benefits through public engagement, participation, and collaboration (Suggett et al., 2023). While many coral restoration practitioners emphasize the need to consider social, economic, and cultural factors in the evaluation of restoration projects, few actually do in praxis (Hein et al., 2017; Ferse et al., 2021). This represents a juxtaposition as key-informant interviews with coral restoration project stakeholders identified “socio-cultural benefits” as the most frequently mentioned product of coral restoration programs (Hein et al., 2019). Furthermore, the stakeholders directly involved in those restoration activities reported significantly higher project appreciation and positive experiences, highlighting the potential impacts of hands-on participation. Conversely, the same study identified “disconnect with local community” as the second-most frequently mentioned problem with coral restoration projects. And while a survey by Ferse et al. (2021) of 50 coral transplantation projects found that over half included some form of education and public awareness, the level of community engagement was unclear and not ubiquitous leading the authors to suggest it be made an integral part of any coral restoration project. As observed here, addressing this disconnect presents a unique opportunity for restoration practitioners to realize additional socio-ecological benefits and reach critical coral conservation goals.

An important factor of citizen science is the transition from casual contributors to sustained community members. Jackson et al. (2015) described an arc of participation, beginning with knowledge acquisition, then knowledge dissemination, and finally increased participation, ultimately leading to program success and impact. Evidence suggested that many participants first volunteered for the citizen science project to develop a sense of identity and connect with the project community. As the participant continued to engage with the project community their self-efficacy improved leading to additional engagement. The authors noted that participants gradually start to identify with the underlying project ideology and begin to feel part of the community. Our evaluation supports this as latent citizen scientists who had participated in two or more expeditions were significantly more comfortable reaching out to RAR and significantly more confident in their ability to communicate coral reef-related topics than those who had only participated in one. Furthermore, latent respondents who had participated in two or more expeditions were significantly more likely to report that their perceptions had changed as a result of interacting with RAR. This suggests that sustained engagement and participation in RAR citizen science activities can foster community, confidence, and social change.

While Hein et al. (2019) found that a majority of coral restoration project volunteers and interns in their study were visiting tourists, a majority (82.1%) of our latent citizen scientists were Florida residents. This is important as community-based restoration projects can heighten community awareness and foster stewardship for local reef resources (Kittinger et al., 2016). This was observed in our evaluation too as latent citizen scientists were significantly more confident in their ability to communicate coral reef-related topics than the control group. Furthermore, increased communication and advocacy for coral reefs was the most common behavioral change reported by citizen scientists. Our results suggest their role as communicators could have meaningful, positive impacts on the greater community too as latent citizen scientists were able to provide significantly more correct open-ended responses overall and in higher frequencies on the importance of coral reefs and the issues they face when compared to the control group. Citizen science is capable of fostering a community of “opinion leaders” or individuals who are motivated to address issue-specific concerns by taking concrete action and advocating on the issues (Johnson et al., 2014). This form of communication and dissemination can be “contagious” too, leading to higher overall community awareness. Scientists have been sounding the alarm on climate change for decades under the assumption that informing and educating the public would lead to action but the unique nature of the climate problem (i.e., invisible causes, distant impacts) has defied this assumption (Moser, 2010). Instead, scientists must work to address these problems through relevant communication and supporting mechanisms, which we demonstrate here through direct community engagement and citizen science. By building community and confidence among citizen scientists, there is the potential to mobilize individuals in a more far-reaching and impactful way.

A common criticism of citizen science is that volunteers tend to be self-selected and may not well represent the entire population (Jordan et al., 2011; Crall et al., 2013). Therefore, if a project seeks to improve attitudes and/or behavior it must engage new audiences who are not as knowledgeable on the subject and reframe it from a volunteer effort to a community-led effort (Brossard et al., 2005; Bela et al., 2016). Our evaluation suggests RAR had some success on this front as majority of latent citizen scientists said that their schooling or job was not related to environmental research, conservation, education, or otherwise. This was in part due to a concerted effort by RAR to engage non-environmental community groups and stakeholders like the veterans of The Mission Continues, Royal Caribbean Group of the cruise line industry, private sector entrepreneurs at WeWork, among others. Rescue a Reef also strives to increase the accessibility of its citizen science opportunities by significantly subsidizing the typical costs associated with snorkel or SCUBA dive excursions through external sponsors and by collaborating with groups working to build diversity and dismantle barriers in marine science like Black in Marine Science. Collaborating with both diverse and local communities is critical to addressing inequalities and inefficiencies in both coral and citizen science (Bela et al., 2016; Suggett et al., 2023). One of the most valuable components of citizen science programs is the relationship between the practitioners, the citizens, and the process of their work (Bond et al., 2016). The work itself creates a dialogue through which important issues are identified and addressed collaboratively, much like symbiotic relationships in nature (Bela et al., 2016). By integrating research with action, our citizen science-based work is better able to understand and enhance the quality of life for individuals, communities, and societies we serve.

4.2 Knowledge gaps

The majority of latent citizen scientists ranked addressing climate change as the most important action for coral conservation, the frequency they answered climate change as a threat to coral reefs was significantly higher than the control group, and they were significantly more likely to rank it as the most important action *versus* any lower value (i.e., 2+). However, this was third most important action according to the control group. Instead, most control respondents considered land-based pollution reduction the most important thing to address and were significantly more likely to rank it as the top priority over other coral conservation actions. The fact latent citizen scientists identified addressing climate change as the most important tool is significant, as expert consensus maintains that mitigating greenhouse gas emissions is both essential to coral reef survival and the most wide-reaching, effective, and achievable action (Kleypas et al., 2021). Furthermore, it addresses a common criticism among the broader coral scientist community that coral restoration practitioners frame their activities as the most important action for coral recovery. However, our latent citizen scientists importantly identified the need to act on both local and global stressors in conjunction with reef restoration. We prioritize this messaging both during and following our expeditions as studies have shown procedural learning is strongly associated with increased support for marine conservation and new behavioral intentions (Dean et al., 2018). This was borne out through the open-ended questions too, with most (48.4%) latent citizen scientists answering that ocean warming specifically is the largest issue facing coral reefs, followed by climate change (45.3%) more broadly, pollution (42.1%), direct human impact (29.5%), and ocean acidification (22.1%) in the next highest proportions. This presents an important shift in priorities as majority of post-expedition citizen scientists answered that land-based pollution was the largest issue facing reefs, not climate change, suggesting latent citizen scientists are now in better alignment with coral expert consensus (Hoegh-Guldberg et al., 2019; Boström-Einarsson et al., 2020; Ferse et al., 2021; Kleypas et al., 2021; Suggett et al., 2023).

There was no significant difference in the perceived status of coral reefs between post-expedition respondents and latent citizen scientists, with both groups identifying coral reefs as “degraded”. However, both post- and latent-expedition means were significantly lower than the control group’s mean, suggesting there is a slight disconnect between our RAR community members and Florida residents. Nonetheless, this evaluation and previous literature indicate that Floridians have a fair understanding of the degraded state of coral reefs (Hesley et al., 2017; Allen et al., 2021). This would suggest that coral scientists, managers, restoration practitioners, *etc.*, should refocus their communication strategies to the specific threats facing reefs and associated tools available for conservation and recovery through “ocean optimism” messaging rather than doom and gloom (Knowlton, 2021). This is further emphasized in our findings that latent citizen scientists reported significantly lower knowledge levels on tools available for coral conservation than the post-expedition respondents, suggesting they felt less certain over time about what they could do to address coral reef degradation. But by completing this evaluation and identifying this disconnect, we can work to adapt and improve our communication strategies and conservation toolkits.

Another disconnect we observed between the latent citizen scientist and control responses was how they viewed and valued coral reefs. Many (45.3%) latent respondents said that coral reefs are important for coastal protection whereas only 6.2% of the control respondents produced that answer. Furthermore, latent citizen scientists listed habitat, coastal protection, human food source, economic driver, and nursery at significantly higher frequencies than the control group. This could suggest a need for improved educational strategies like citizen science to convey the roles and value of Florida’s Coral Reef to residents. The U.S. ranks within the top 10 of countries in the number of people that may receive risk reduction benefits from reefs with an estimated 3 million individuals (Ferrario et al., 2014). Furthermore, the annual value of flood risk reduction provided by U.S. coral reefs is more than 18,000 lives and \$1.8 billion dollars (Storlazzi et al., 2019). There is a need to broaden public discourse to include our growing understanding of ecosystem services’ role in the safety and wellbeing of communities if we hope to see a shift perceptions and values (Costanza et al., 2017). The practical portion of our program (i.e., coral gardening and reef restoration) is aimed at providing community members with the opportunity to actively help mitigate impacts and recover depleted resources which has been shown to develop ownership of said resources and the empowerment of learners, a critical component of social change (Phillips et al., 2019).

4.3 Need for evaluation

It is not enough to assume a service is achieving intended benefits and/or changes are realized. There is a clear need for citizen scientist practitioners to better understand the importance and implications of addressing social issues through research and action (Brossard et al., 2005; Bonney et al., 2009; Crall et al., 2013). Program evaluation can consume time and resources but can also help validate the services provided as well as the intended outcomes (Gill, 2010; Posavac, 2011; Bela et al., 2016). Without evidence of a project’s outcomes, practitioners are left with a critical gap in understanding the effectiveness and potential impact of the activities (Gill, 2010; Posavac, 2011; Bela et al., 2016). Over a decades-worth of coral restoration data has proven the process effective (Schopmeyer et al., 2017). Then, Hesley et al. (2017) demonstrated the ecological contributions citizen scientists can have when working in collaboration with trained restoration practitioners. Here, the sociocultural impacts observed create a more comprehensive evaluation of the effectiveness of citizen science for coral conservation and restoration in social-ecological dimensions (Hein et al., 2017; Goergen et al., 2020).

Coral reef restoration activities must consider the relationship between stakeholders, goods and services, and the environment itself when measuring success (Goergen et al., 2020; Suggett et al., 2023), something that is only achievable when communicating and collaborating with community members through avenues like citizen science. Continued investment into coral restoration activities requires evidence of its benefits and value, not least of which are the social impacts as described here. These long-term benefits of integrating citizen science coral restoration activities make a strong argument for additional investment by local governments and stakeholders alike (Ferse et al., 2021; Suggett et al., 2023). Citizen science can also act as an important vehicle for closing funding gaps through other direct (i.e., volunteers, donations) and indirect (i.e., in-kind contributions, media ad equivalency) sources of support (Hesley et al., 2017; Bayraktarov et al., 2020; Ferse et al., 2021). This evaluation helps highlight the numerous strengths and benefits of RAR's community-based programming as well as the justification for increased and sustained support.

Between 2015–2017, community members who participated in a RAR citizen science expedition reported significant improvements in coral reef ecology and restoration knowledge post-expedition (Hesley et al., 2017). Additionally, corals outplanted by citizen scientists showed the same survivorship as those outplanted by trained coral restoration practitioners. Both are important metrics of success for building capacity and stewardship through education and outreach within a community-based coral restoration program (Goergen et al., 2020). To date, RAR has hosted >100 citizen science expeditions with >1,000 community members having helped restore >10,000 coral colonies onto Florida's Coral Reef. What is not considered in this evaluation of RAR's citizen science activities is the thousands more individuals regularly engaged through their education, outreach, and online activities like classroom presentations, laboratory tours, and social media campaign. Through these activities in combination with their citizen science expeditions, the RAR program has successfully fostered a broad community of coral reef champions. It is difficult to formally assess the value or worth of this, but one can easily recognize its potential as a powerful platform for raising awareness and promoting action for the conservation and restoration of our oceans. We hope the information and impact observed through this program evaluation will motivate more individuals, organizations, and institutions to incorporate community engagement and citizen science into their activities to advance their own mission and goals.

4.4 Moving forward

Globally, we are seeing environmental and ecological collapse due to our changing climate. This is a humanitarian crisis as the planet's ecosystems, environments, and biodiversity are essential to the sustainability of our species. The biodiversity of tropical rainforests and coral reefs provide critical support for drug discovery and the availability of life-saving medicines (Mendelsohn and Balick, 1995). Mounting evidence indicates that high biodiversity and ecosystem function frequently prevent disease transmission among humans, animals, and plants (Keesing et al., 2010). Maintaining both species and genetic diversity increases commercial crop yields, fodder yields, and fisheries stability, providing food for billions (Cardinale et al., 2012). Plant species diversity has been shown to increase aboveground carbon sequestration, oxygen production, and nutrient mineralization; all essential to planetary sustainability (Cardinale et al., 2011). Natural environments and species biodiversity has a significant, positive effect on leisure, culture, mental health, and aesthetic value for communities and human wellbeing (Tribot et al., 2016). And natural resources, environmental services, and biodiversity play an important role in reducing disaster risk and in post-disaster relief and recovery (Storlazzi et al., 2019). Without immediate, drastic action to reduce our reliance on fossil fuels and the associated carbon emissions, the future of our species and planet is in peril. To solve an issue of this magnitude will take individual, community, public-, and private-sector action. There must be a significant increase in engagement, support, and action for climate solutions and policy.

Our hope is that researchers realize traditional modes of science dissemination will not be sufficient to solve these environmental issues. By better marrying science and society through community engagement and citizen science, practitioners can both further their research and findings while simultaneously empowering communities to act as champions on the subject (Brossard et al., 2005; Jordan et al., 2011; Crall et al., 2013). Research is conducted to produce knowledge and enact change, but that change is not feasible unless there is measurable public support, participation, and action. The sciences are becoming increasingly isolated from the general public creating a disconnect and even a distrust, but citizen science can act as a powerful tool to build trust and democratize science (Bela et al., 2016). To bring science and society closer is creating a "scientific citizenship" where individuals are more engaged in environmental issues leading to decision-making, ownership, and action (Conrad and Hilchey, 2011; Dickinson et al., 2012; Jackson et al., 2015). Scientists can no longer rely on knowledge discovery and dissemination alone to create change. They must roll up their sleeves and co-create change with the communities who have an equal amount at stake. Rescue a Reef was designed to do just that: advance coral conservation, restoration, and stewardship through community education, outreach, and citizen science activities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

DH, MK, and DL contributed to the conception and design of the study. DH and MK organized the database. MK performed the statistical analysis and created the visualizations. DH wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1250464/full#supplementary-material

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