Ecological Applications, 22(4), 2012, pp. 1201–1212

Expert variability provides perspective on the strengths and weaknesses of citizen-driven intertidal monitoring program

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Abstract. Citizen scientist programs are a means to efficiently conduct large-scale surveys of ecosystems or managed species, provided that concerns over the quality and use of data generated by nonexperts can be addressed. This study presents actions taken in a citizen science program to assure data quality and demonstrates the validity of citizen-generated data. In this case the accuracy of data collected by secondary school students as citizens in a program that quantitatively sampled benthic rocky intertidal communities at 13 sites on Maui, Molokai, Oahu, and Hawai'i island during the years 2004–2007 was evaluated. In 2007, two independent research teams collected data simultaneously with students at five sites on eight sampling dates. Comparisons of Shannon diversity and Bray-Curtis similarity values computed and simulated from student and researcher collected data revealed that nonexpert students accurately collect community-level data within the range of the variation that occurs between researchers. Students were, however, likely to misidentify cryptic and rare species. These findings have direct implications for the conservation goals of the monitoring program as the assessment reveals that students are likely to misidentify early alien introductions but are able to monitor the abundances of native and introduced species once they become established. The validity assessment designed for this investigation is unique in that it directly compares consistent errors made by citizens in data collection to expert variability to identify usage limitations and can be a guide for future studies that involve the efforts of trained volunteers.

Key words: *citizen scientists; community structure; data quality; diversity; ecological indices; education; Hawaii, USA; intertidal monitoring; trained volunteers.*

Introduction

Systematic monitoring of ecological communities is an essential component of conservation efforts. Monitoring provides a baseline from which to measure human impacts in the long term (Murray et al. 2006) and in the short term allows for early detection and potential eradication of invasive species (Simberloff et al. 2005). Furthermore, spatial descriptions of communities are needed for adequate design of reserves, as efforts are made to include sites that are representative of, or unique to specific areas (Airame et al. 2003). However, long-term monitoring or species surveys are difficult to implement as efforts often require numerous trained individuals and long-term monetary support to cover large spatial and temporal scales. Granting agencies tend to favor studies that rigorously test explicit hypotheses over monitoring; however, monitoring surveys are necessary to support conservation aims (Silvertown 2009). Citizen scientist programs are a creative way to educate and involve the local community, while providing monetary support and the manpower needed for scientists to gather baseline ecological information (Silvertown 2009).

Citizen scientist programs have successfully allowed for the survey of populations multiple times over large spatial scales (Silvertown 2009). These programs have surveyed diverse taxa including birds (Bhattacharhee 2005, McCaffrey 2005), amphibians (Genet and Sargent 2003), mammals (Ericsson and Wallin 1999), insects (Braschler 2009), subtidal fishes (Pattengill-Semmens and Semmens 2003), plants (Brandon et al. 2003), and intertidal crabs (Delaney et al. 2008). Well-known examples include National Aubudon Society's Christmas Bird Count and Reef Check. Most citizen scientist programs have surveyed terrestrial species. These programs tend to focus on either a single taxon, often a managed species, or on one assemblage group (i.e., birds, amphibians, and other groups) (Crall et al. 2010, Devictor et al. 2010). Citizen involvement in the collection of scientific data is growing in the marine realm and to date is mostly focused (but see Finn et al. 2010) on charismatic megafauna like mantas (information *available online*),[5] and sea turtles (information *available online*),[6] or introduced animals such as crabs

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Manuscript received 7 September 2011; revised 9 January 2012; accepted 10 January 2012. Corresponding Editor: P. K. Dayton.

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[5] http://www.mantapacific.org

[6] http://www.reef.org

(Delaney et al. 2008) or fishes (Darwall and Dulvy 1996, Pattengill-Semmens and Semmens 2003). Few of these citizen-driven programs have attempted to monitor complex marine communities, including both flora and fauna (but see Osborn et al. 2005, Goffredo et al. 2010; examples of these kinds of studies are *available online*).[7,8] Perhaps this disparity is due to the necessary training and equipment needed for water activities as well as the difficulty in training citizens in proper taxonomic identification of a wide variety of species and in ecological sampling methodologies.

Researchers (i.e., experts) often question the ability of citizens to document ecological change (Brandon et al. 2003, Bhattacharhee 2005, Silvertown 2009). A survey of 128 citizen scientist managers found many were concerned with the quality of data produced by their programs yet only 39% exhibited some form of quality assurance (volunteer training, expert validation of species identification, validation of species locations, and deletion of any suspect data; see Crall et al. 2010). Trained researchers can vary in their ability to detect, identify, or estimate measurements resulting in a degree variation from the "true" accurate value they are trying to capture (i.e., observer variation; Dethier et al. 1993, Benedetti-Cecchi et al. 1996, Murray et al. 2006). Although several published studies have assessed the use and accuracy of volunteer programs (Darwall and Dulvy 1996, McLaren and Cadman 1999, Bray and Schramm 2001, Engel and Voshell 2002, Brandon et al. 2003, Nerbonne and Vondracek 2003, Delaney et al. 2008), few have placed citizen-generated data in context with the variability among expert data collectors (but see Osborn et al. 2005), a necessary comparison for the identification of potential inaccuracies or deficiencies. Comparative evaluations of citizen-driven programs in a variety of habitats may elicit general patterns in successful designs that are usable by citizens and common pitfalls for less experienced data collectors.

In an effort to describe ecological patterns, inform conservation efforts, and engage young students in science, a partnership was formed in the state of Hawaii between secondary school teachers and the authors in a monitoring program named Our Project In Hawaii's Intertidal (OPIHI) after a culturally important limpet, the opihi (*Cellana* spp.) (Baumgartner and Zabin 2006, 2008, Baumgartner et al. 2009). OPIHI is a citizen science program where trained volunteers perform research related tasks. In our case, the volunteers were secondary school students participating in OPIHI as part of their science education. Students from eight schools monitored 13 intertidal sites during the years of 2004–2007 to describe the distribution and abundance of native and introduced species, screen for new introductions, and examine yearly temporal variation in intertidal communities throughout the main Hawaiian Islands (access to data *available online*; T. E. Cox, J. Philippoff, E. Baumgartner, C. Zabin, and C. M. Smith, *unpublished manuscript*).[9]

The goal of this study was to provide a framework for other citizen scientist programs by outlining actions that can be taken to assure data quality and demonstrate the usefulness of conducting a careful validity assessment. Here we outline the steps we took to assess the quality of community level data generated by OPIHI and present the results of that assessment. We specifically asked the question: are students, using the OPIHI methods, able to identify and describe the abundances and distributions of introduced and native species in diverse and heterogeneous intertidal habitats accurately? We show that students generate quality community data that are similar to researchers by placing student collected data in context with researcher variation. Further, we demonstrate that trained student volunteers are able to monitor the abundance of established aliens but are likely to overlook or misidentify new introductions. The results from this assessment underscores the strength in conducting an informative and an appropriate evaluation of citizen-collected data and can guide future studies that rely on citizen involvement.

MATERIALS AND METHODS

Site description

Five rocky intertidal sites (Barber's Point, Diamond Head, Sandy Beach, Sand Island, Wai'Opae) located on the islands of Hawai'i and Oahu were selected for assessment of student-generated data from the nine sites monitored in 2007 and the 13 sites monitored by OPIHI (Fig. 1). These sites represent a variety of rocky intertidal habitats in Hawaii safely accessible by students. Each site spanned a minimum of 15 m along the coast and 10 m from the top of the *Littoraria* zone to the water's edge at mean low water.

School teacher participation and their preference for particular sites combined with researcher availability dictated which and how many of the sites were selected for the validity evaluation. Nine sites were scheduled for visitation by participating OPIHI teachers in 2007. Teachers scheduled visits based upon low tide events, school hours, curriculum, and bus schedules. They tend to prefer visiting sites that are located near to their school and are easy to access. Researchers were consulted for availability without knowledge of site visit. Sites were then selected for assessment inclusion if four qualified researchers confirmed they were available on scheduled monitoring dates. Also, numerous researchers are located on the island of Oahu, where the main campus of the University of Hawaii is located and where the managers of the program are based. Therefore, four sites included in the assessment are

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[7] http://www.limpetsmonitoring.org

[8] http://www.beachwatchers.wsu.edu

[9] http://evols.library.manoa.hawaii.edu/handle/10524/12259

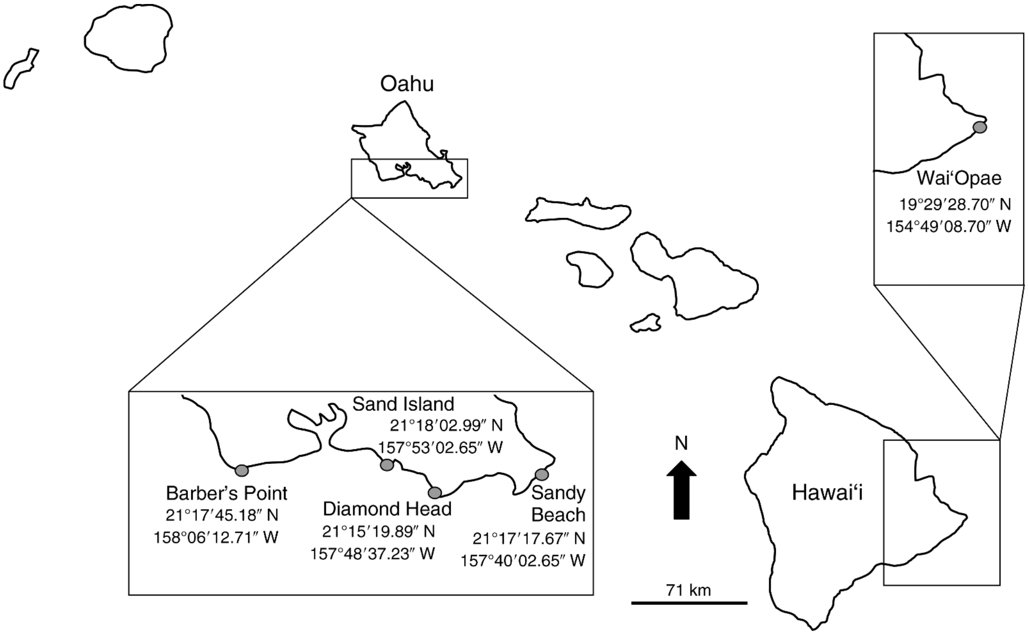

FIG. 1. Location of sites along the islands of Oahu and Hawai'i, in Hawaii, USA, that were included in the validation investigation

located on Oahu; however, Wai'Opae was located on the island of Hawai'i.

The sites included in the assessment allowed us to focus our efforts on the evaluation of data collected from sites that have been consistently sampled by OPIHI as early as 2004. Sandy Beach has been sampled by OPIHI since 2006 whereas the other three sites have been consistently sampled by OPIHI from as early as 2004 or 2005. Wai'Opae to date had never previously been sampled by the monitoring program.

All selected sites are gently sloped basalt or limestone bedrock benches, bedrock surrounded by patches of sand, or boulder- to cobble-sized rocky habitats with varying levels of sand (Table 1). Some sites such as Diamond Head have offshore reefs that provide protection from large waves. The Wai'Opae monitoring site is located within a Marine Life Conservation District where collection of any kind of marine life is prohibited.

Species richness varies among these intertidal sites (C. Zabin, *unpublished manuscript*). The few available examinations prior to this study have revealed that intertidal habitats in Hawaii are highly diverse (McDermid 1988, Smith 1992), and introduced species are visually abundant. Three species of introduced macroalgae (*Acanthophora spicifiera*, *Gracilaria salicornia*, and *Hypnea musciformis*) are particularly invasive in shallow water habitats (Smith et al. 2002) along with the barnacle *Chthalamus proteus* (Zabin et al. 2007).

Training of citizen scientists

Students who participated in OPIHI were in secondary grades 6–12 and enrolled in a science course at either a traditional or charter public school. Prior to sampling, students participated in core OPIHI curricula (*available online*).[10] This inquiry-based hands-on curriculum (Baumgartner and Zabin 2006, 2008, Baumgartner et al. 2009) was used to excite students about the goals of program, train students in field methodology and species identification, and was also used to connect the project to their broader science curriculum (Supplement).

An interactive presentation is used to (1) introduce the goals of the program, (2) provide a brief background on intertidal ecology, and (3) empower and excite students to collect quality data. Students are made aware that they have an opportunity to be real scientists who carefully describe an understudied yet exciting environment that has unique physical challenges. Students are also shown images of other students collecting data and told about previous findings. The presentation includes images of intertidal organisms and the class discusses possible challenges these organisms might encounter. They are also introduced to ecological terms and concepts such as competition, predation, desiccation, and species descriptors such as native, introduced, invasive, and endemic.

Species identification lessons include bringing organisms into the classroom or taking students into the field so that students can be exposed to different intertidal organisms and practice identification techniques. In the classroom and in the field students observe, identify, sketch, and make notes in a "species journal" about

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[10] http://www.hawaii.edu/gk-12/opihi/classroom_home.shtml

TABLE 1. Site description and visual estimate or point contact method used by two researcher (R) teams and one student (S) team to collect percent cover data at each site per visit and the number of same quadrats sampled by both researcher teams and one student team used in analyses of intertidal communities from the islands of Oahu and Hawai'i, Hawaii, USA.

Site name	Shore habitat type	Substrate composition	No. sampled visits	School grade(s)	Technique to determine percent cover	No. same quadrat locations sampled by R–S–R	
						Visit 1	Visit 2
Barber's Point (BP)	bench	limestone	2†	10–12th	visual estimate	14	28
Diamond Head (DH)	bench	limestone and basalt	2	9th	point contact	36	48
Sand Island (SI)	bedrock/cobble and sand	basalt	2	10–12th	visual estimate	30	48
Sandy Beach (SB)	sand and bedrock	basalt	1	10–12th	visual estimate	14	
Wai'Opae (WOP)	bench	basalt	1	6–10th	point contact	10	

Note: R–S–R refers to sampling of a quadrat once by a team of researchers, once by a different team of researchers, and once by a team of students.

† One out of two visits only had one research team for comparison.

different intertidal organisms. Often, students work in groups and are instructed to research intertidal organisms (e.g., around different phyla) and to share their findings with the class.

Science inquiry lessons are provided for students to learn about the concept of (1) a "sample," (2) different ecological sampling techniques, and (3) the importance of sample size and accuracy. In these lessons, students are shown a jar of different colored or shaped candies, and students discuss how they would determine the number of candies or candy types in the jar. Students each grab a handful of candy as a sample and count the number of different colors or shapes. Then the teacher guides a classroom discussion about sampling concepts such as sample size, precision, and accuracy. In an additional lesson, candies or colored cards are scattered about the room and students again discuss how they would sample the abundance or diversity of "species" (candy types) if these candies represented organisms in the intertidal zone. Students are introduced to sampling tools and methodologies as they sample the candy scattered about the room using the same tools they will use in the field. Students are also asked to compare the number of species sampled under variable conditions, for example, if different numbers of people searched for different amounts of time, or if sampling occurred at high tide vs. at low tide. This discussion enforces the importance of standardizing techniques.

To synthesize student's species identification and sampling skills, students practice quadrat sampling techniques on images of intertidal habitat, filling out data sheets and identifying organisms they will encounter in the field. A final practice of sampling methodology takes place on school grounds where students use sampling techniques to monitor a courtyard or similar area. If time and resources are available, participants are encouraged to visit an intertidal habitat prior to data collection to explore and experience the environment and diversity of organisms. Only once students have exposure to intertidal life, experience identifying species, and practice with scientific methods are they allowed to collect OPIHI data.

OPIHI monitoring tools and methods

Prior to sampling, students were given tools to assist in data collection. Students were given tailor-made laminated identification (ID) cards, data sheets, and the guide books by Hoover (2006) and Huisman et al. (2007) to assist in species identifications while in the field. ID cards included species dominant in the Hawaiian intertidal zone and species of special concern, such as invasive species, species that are harvested or collected, and those that are plausible indicators of environmental change. Data sheets included the scientific names of common species previously seen at each site and empty areas designated for other identified/unidentifiable species.

Students collected abundance as cover data for macroalgae and invertebrates using traditional ecological sampling methods. At each site, depending upon the number of students available and the geography of the site, three to seven transect lines were placed ~2 m apart, perpendicular to shore, and extended up to 30 m. Between 5 and 12 0.25-m^2 quadrats (each with five horizontal and five vertical strings, creating 25 intercepts) were placed at evenly spaced intervals along each transect. The percent cover of algae and invertebrates in each quadrat was sampled by one of two methods: visual estimation or point contact. Due to the dominant types of organisms in the Hawaiian intertidal and the student training focus, we emphasized area coverage sampling over individual counts. Some student groups sampled using both cover determination methods so they could compare the data generated by the different methods. Specific methods are described in detail in Baumgartner and Zabin (2006), and a pilot comparison of students sampling the same site on the same low tide with different methodologies (visual estimation or point contact) revealed similar results. In the point contact method students recorded the taxa or bare space that occurred under each of the 25 intercepts within the quadrats. In the visual estimation method, the grid was used as a reference to assist students in estimation of the percent cover of each organism or bare space encountered. Approximately 20–30 students worked in smaller teams that were supervised by an adult chaperone. These small teams had ~1.5 hours (the approximate time span of a low tide window) to collect data along one transect line. Chaperones were volunteer parents, secondary school teachers, former students in the OPIHI program, or graduate students and professors from various life science fields. Chaperones were instructed to ensure students were safe and stayed on task and were told not to collect data or identify species. Two OPIHI experts, usually the program manager and secondary school teacher, were on site to answer student questions, and to ensure appropriate methodology was executed.

Secondary school students identified species to the lowest taxon possible for their abilities in the field. Bare substrate was recorded as rock or sand along with other categorical data. Categories included "other/unknown algae," "other/unknown invertebrates," crustose coralline, brown-colored crust (which includes species of *Ralfsia* and *Peyssonnelia*), cyanobacteria, and algal turf (mixture of macroalgal species 1–2 cm tall). Most taxa were identified to the genus level. Students were encouraged by chaperones, teachers, and the program manager to use field guides (Hoover 2006, Huisman et al. 2007) to assist in identification of any species they were unable to identify using the ID cards and to come to an agreement on species identification as a means of cross-validation. Occasionally, hard-to-identify species were photographed or, if possible, a sample was collected for subsequent laboratory study and identification.

Data quality assurance steps and validity assessment rationale

Several steps were taken during the education of student citizen scientists during program implementation to assess and improve data quality. We outline these quality assurance steps to provide a framework for other programs and to present the rationale for the development of an instructive assessment to test the validity of similarly generated data (Fig. 2). During the development of the program (see Development, Fig. 2), goals were set and methodology developed in part via reference to a successful citizen science program LiMPETS: Long-term Monitoring Program and Experiential Training for Students (see footnote 7; described in Osborn et al. 2005). OPIHI managers partnered with secondary teachers to design educational curriculum, training materials, and tools that would be usable by 6–12th grade students and meet both the educational and scientific goals. These were qualitatively tested in the classroom and field to assure they met these goals. The initial training lessons allow for students to buy in to the program as it explains the goals and excites students (see Citizen buy-in and understanding, Fig. 2). This understanding and ownership of the program should allow for more careful data collection. Students must be trained to collect data (see Training, Fig. 2). The training includes practice and repeated experience and exposure to intertidal life to facilitate identification skills and the methodology to increase comfort and self-efficacy with tools and procedures. During data collection (see Data collection Fig. 2), oversight is provided by a chaperone, teacher, and a program manager. Students in small groups have to reach an agreement on species identity and cover estimate as a means of cross-validation and are asked to self-proof data sheets and their efforts. Sites are sampled multiple times within the same season by different sets of students, and often the same students resample the transect line using a different estimation method. In this manner the data produced can be compared by managers for precision. The input of data is overseen by a program manager (see Input of data set, Fig. 2). In the regular monitoring program, if a data sheet has numerous mistakes (i.e., the percent cover does not add up to 100%, or the metadata are missing), if a

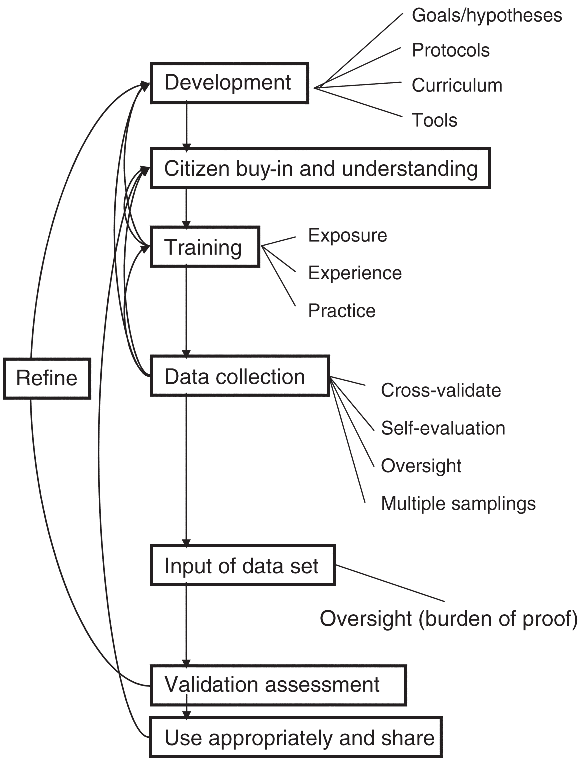

FIG. 2. Framework for assuring data quality based on the actions taken in the OPIHI (Our Project In Hawaii's Intertidal) program and the rationale for conducting an instructive validation assessment. An assessment of data validity should (1) evaluate the accuracy of the citizen-generated data, (2) identify any usage limitations, and (3) inform managers about how to improve future data collections. Arrows represent the order of actions; arrows back to previous steps would be conducted if anecdotal or quantitative evidence suggest a lack of success or further refinement needed.

program manager or teacher thinks students were sloppy in collection (goofing off or showing little interest), or if the data seem inaccurate, it is discarded. Even with these steps the burden of proof falls onto the program and the manager(s) to test whether the data are accurate so that it may be usable and suitable for publication. For this reason, we felt obligated to conduct a validity assessment (see Validity assessment, Fig. 2).

We developed the validity assessment to be informative to the general public and program managers. The assessment had to (1) evaluate the accuracy of the citizen-generated data, (2) identify any usage limitations, and (3) inform managers how to improve future data collections. This assessment needed to occur under stereotypical sampling conditions with the current methodology and not distract from the monitoring of intertidal habitats or the education of students. The methodology employed needed to eliminate and account for as much confounding variation as possible to isolate student accuracy. Possible sources of variation include (1) temporal (tidal, daily, seasonal) and spatial variation (site, habitat type, fine-scale location), (2) teacher influence, (3) student experience and age, and (4) observer variation. Furthermore, we needed to be rigorous and take a quantitative field and analytical approach that would define whether the OPIHI program accurately and successfully describes a variety of intertidal communities.

Validity assessment

In order to examine the validity of data generated by OPIHI, we had to account for the natural variation in data collection that can occur between observers (Dethier et al. 1993, Benedetti-Cecchi et al. 1996). To account for observer variation we deployed two teams of researchers, each composed of one or two individuals, to sites where students were in the progress of sampling to collect abundance data. Researchers used the same methods as students and were given identical sampling tools including data sheets, ID cards, guidebooks, and quadrats. To reduce spatial and temporal variation, researchers placed their quadrats at the same meter locations as students along the same transect lines. These quadrats were sampled either before or after the students sampled, during the same low-tide window. In further efforts to reduce variation when possible, students left their quadrats in place for researchers to sample. Each research team would independently start their collection of data along a different transect line and as they completed the sampling within quadrats along that line, they would move haphazardly to a different transect to collect more quadrat data. In this manner, each researcher team of one to two individuals would try to sample as many transect-quadrat locations as ~20 students who were working in small teams (three to four individuals) that were responsible for data collection along one transect line. However, two teams of researchers were often not able to sample the same number of quadrats as a class of students within the same low tide window. When this occurred only data collected from the same quadrat location by both researcher and student teams were used in comparative analyses. To maintain statistical independence, the researcher teams were not allowed to discuss or interact with each other or with student teams. Teams were also instructed to communicate in quiet voices, so neither students nor the other research team would be influenced by their identifications. In this manner, the variation between these two teams of researchers can thus be used as a benchmark to evaluate the accuracy of student generated data.

Researchers had to meet certain criteria to participate in this study. All researchers ($n = 9$) had completed an upper-level college course in Invertebrate Zoology and/or Phycology and had experience with the standard ecological sampling techniques. Four researchers had served as graduate teaching assistants in Phycology, Invertebrate Zoology, or Marine Biology at the University of Hawaii, Manoa, and seven had conducted research on invertebrates and/or marine macroalgae, including two who had focused their doctoral research on intertidal ecology. Prior to data collection, researchers were given online access to the OPIHI curriculum, protocols, data sheets, and species ID cards. These protocols were in place to ensure that the research teams were of similar experience to one another and that experience was at a level that would be expected of an experienced ecological researcher.

Students and researchers sampled the five sites selected for data evaluation during the months of April and May 2007 on low tides (less than -0.06 m). Some sites were visited more than once. During each visit, sampling was conducted by different teams of students and researchers for a total of eight student-to-researcher comparisons (Table 1). Students that participated in the study were also trained and led by five different teachers who varied from first time participants to those with more than four years of experience with the monitoring project. Students that participated in the study had not previously participated in OPIHI, and data used in these analyses were from their first field trip to quantitatively sample a site. All the students taught the OPIHI curriculum by these five participating teachers collected data on the eight sampling visits. However, not every transect-quadrat location sampled by students was used in this study, thus out of the 139 student participants 86 had their data included in the analyses. For perspective and as a reference on the scale and scope of this validation effort, in 2007, the OPIHI program participants made 12 sampling visits (eight included in this study) to nine intertidal sites (five included in this study) located on three islands (two island locations in this study) and had ~240 trained students (58% of the total trained participants are included in this study, 36% of participant data are included in analyses) led by nine different secondary school teachers, five of whom participated in this study.

Species composition and abundance data generated by the student and research teams were analyzed for differences using common community measures. We first examined the differences in diversity (Shannon indices) generated from student and research teams for each site visit. Second, we computed the similarity in student- and researcher-determined abundance data using the Bray-Curtis index of similarity and used a bootstrap simulation to statistically test the likelihood this similarity would be achieved by chance. Last, because community measures can be similar despite slight differences in composition and abundance of species and because we wanted to pinpoint potential student errors, we compared the researcher and student generated list of present species and their given abundances.

Shannon indices were used to calculate diversity values for each site from student- and researcher-generated data. Because we were interested in comparing variation, for each site we determined the difference between the researcher diversity values and the difference between the averaged researcher and student values. An average could minimize researcher variation in comparison with students, thus we also plotted raw diversity values to examine any differences. The difference between student- and researcher-determined Shannon values were initially screened for normality and homogeneity of variance, a paired *t* test was used to test for significant differences. Statistical results were not adjusted for multiple comparisons as such an adjustment would only bolster support for our hypotheses, that there is no difference between the ecological indices generated by researchers or those generated by citizen scientists.

To determine if student-generated abundance data were similar to researcher-generated data we determined the percent cover of benthic organisms per visit for each site for each research and student team. Thus each taxon/bare space had three overall site percent cover values for each visit, one from each research team and one determined by students. We examined the abundance data with and without bare space in our analyses. We generated Bray-Curtis similarity values between the data collected by both researcher teams and between the averaged researchers and students in the statistical package Primer-E (Clarke and Warwick 2001). Although the Bray-Curtis calculation already downweights common species, results were similar when data were square-root or fourth-root transformed, so we used untransformed data. These similarity values were screened for normality and homogeneity of variance. Paired *t* tests were used to assess whether the differences between researcher and student similarity values were statistically significant. In addition, a nonmetric multidimensional scaling ordination (nMDS) technique was used to examine the spatial arrangement of data collectors and sites. A two-way crossed multivariate analysis of similarity (ANOSIM, site × data collector) was used to examine whether differences were statistically significant.

We also investigated whether our similarity comparisons were not just due to chance alone using a simulated bootstrap technique. Determined abundance values were reshuffled without replacement between taxa found to occur at a site. Monte-Carlo analysis (in EXCEL pop-tools) was used to simulate the Bray-Curtis similarity values 10 000 times for each researcher–researcher and averaged researcher–student comparison. A 95% confidence interval was determined from the simulated similarity values. The similarity values observed from this validity assessment were considered reliable if they were above the simulated 95% confidence interval. A *P* value was calculated from the number of simulated values out of 10 000 that were higher than the determined similarity from field efforts.

To determine possible identification errors made by students we generated a species list for each site that compared both student- and researcher-generated data. Here we assumed student error based on the species lists generated by two researchers. To identify which species students overlooked, we determined which organisms were found by both researcher teams but not found by students for each site visit. We also determined which species students recorded but both researchers did not, as these are most likely species that students misidentified.

RESULTS

The difference in Shannon's index of diversity values indicates that while researchers' diversity values varied more, they were not significantly different than the variation seen between researchers and students (paired *t* test, $n = 7$, $P = 0.15$). For four site comparisons students were closer to the averaged researcher diversity than researchers were to each other (Table 1, Fig. 3).

The differences in community similarity values among data collectors were not statistically significant (Table 2; paired *t* test, $n = 8$, $P = 0.45$). Similarity values were higher when bare substrate was included in the analyses. A bootstrap analysis of similarity values found that researcher and student similarity values were often above the 95% confidence intervals for simulated data. However, when bare space was removed from analyses researchers were not more similar than chance for a one-time sampling at Sandy Beach. There was no statistical difference between community data collected by researchers and students (two-way ANOSIM, $R = 0$, $P = 0.58$; Fig. 4).

The student and researcher species lists, which contained a combined total of 65 taxa, reveal specific discrepancies in identifications. Students missed 10 species that were recorded by both research teams (Table 3A) and identified 17 species as occurring at sites when researchers did not indicate their presence (Table 3B). Six out of 10 taxa not recorded as present by

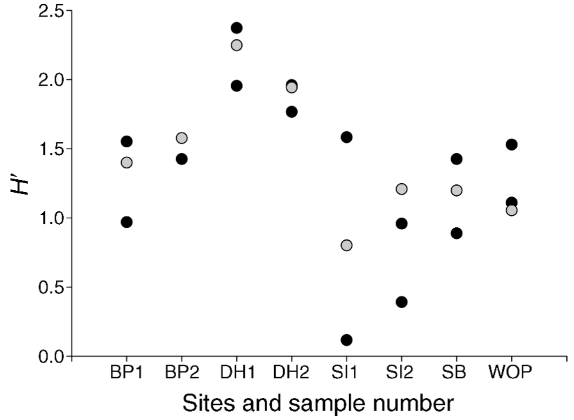

FIG. 3. Researchers' (black circles) and students' (gray circles) Shannon diversity values (H') for site comparisons. H' for the site is determined from data collected by researcher and student collectors pooled from 10–48 quadrats placed at the same location. Site abbreviations are as follows with value(s) in parentheses representing the number of quadrats pooled per visit: BP, Barber's Point (visit 1, 14; visit 2, 28); DH, Diamond Head (visit 1, 36; visit 2, 48); SI, Sand Island (visit 1, 30; visit 2, 38); SB, Sandy Beach (14); WOP, Wai'Opae (10).

students and 15 of 17 included by students but recorded as absent by researchers were estimated to occur at <1% cover. Three of the species missed by students are small (tube-forming mollusk, *Dendropoma gregaria*) or cryptic (crust-forming macroalgae *Lobophora variegata*, and coralline species). *Montipora fabellata*, a coral species, was also not identified by students. Three of these taxa (*D. gregaria*, *L. variegata*, and *M. flabellata*) were not on the ID cards, but students did record "unknown coral species" and "other algae," two categories not utilized by researchers. Three species identified by students as occurring at abundances between 1% and 8% but not by researchers are algal species that are invasive in Hawaii's intertidal: *A. spicifera*, *H. musciformis*, and *G. salicornia*.

DISCUSSION

Our analyses confirm the validity of student-generated data from the citizen scientist program OPIHI and demonstrate the strength in conducting an instructive assessment of data quality. The developed assessment identified that in diverse and heterogeneous marine habitats, students generated data that were similar to that generated by researchers. OPIHI data can now confidently be used to describe and manage the Hawaiian intertidal community. Further, the assessment protocol identified the strengths and limitations of the data. The strength of the program lies in the ability of citizens to rapidly and with minimal cost collect data that identifies and describes the abundance of common species from multiple sites over fairly large spatial scales. The limitation of the program is with current training; students misidentify or overlook cryptic or rare species. These findings have direct implications for the conservation goals of the monitoring program as the assess-

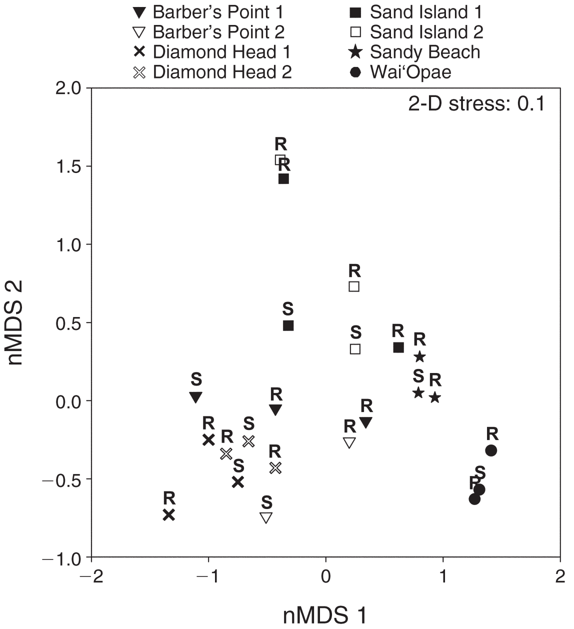

FIG. 4. The nMDS of similarity values among sites comparing data collected by researchers (R) and students (S). The site × data collector value is based on Bray-Curtis similarity index calculated from percent cover data that were pooled from 10–48 quadrats placed at same location; see Table 1 and Fig. 2 for number of quadrats sampled per visit by both researcher and student teams. Stress is a metric that gauges how well the multidimensional relationships among samples are represented in the 2-D (two-dimensional) ordination plot. A fairly low stress value of 0.1 indicates that this is a reliable representation of similarity relationships.

TABLE 2. Comparison of community measurements (Shannon Diversity value H' and Bray-Curtis percentage similarity) collected by student (S) and researcher (R) teams at sampled sites.

Site	R H' difference	R–S H' difference	R–R similarity (%)	S–R similarity (%)	R–R similarity bootstrap P	S–R similarity bootstrap P
BP	0.07	0.18	80.3 (50.6)	70.7 (57.0)	<0.005 (0.05)	<0.001 (<0.01)
DH 1	0.20	0.20	86.1 (74.5)	80.9 (65.1)	<0.001 (<0.001)	<0.001 (<0.001)
DH 2	0.32	0.05	79.6 (74.0)	80.2 (65.0)	<0.001 (<0.001)	<0.001 (<0.001)
SI 1	0.12	0.09	83.9 (83.9)	85.5 (86.5)	0.001 (0.001)	<0.001 (<0.001)
SI 2	0.01	0.02	84.1 (84.1)	87.2 (83.9)	0.005 (<0.001)	0.004 (<0.004)
SB	0.57	0.04	86.6 (24.0)	90.3 (43.4)	<0.001 (0.95)	<0.001 (<0.01)
WOP	0.46	0.18	77.3 (77.3)	72.0 (72.5)	<0.001 (<0.001)	0.02 (0.02)

Notes: Values in parentheses are the results from analyses without bare space included. See Table 1 for site names.

TABLE 3. Possible taxa misidentified.

Taxa	Group	Type	Location	No. visits	Cover (%)†
A) Taxa both research teams found but students did not					
Dendropoma gregaria	invertebrates	native	DH	1	6.7, 7.7
Montipora flabellata	invertebrates	native	WOP	1	3.6, 1.3
Dictyota acutiloba	algae	native	WOP	1	3.6, 1.3
Lobophora variegata	algae	native	SI	1	1.1, 0.2
Crustose coralline algae	algae	native	DH	1	0.7, 1.2
Microdictyon setchellianum	algae	native	DH	1	0.7, 0.2
Dictyosphaeria cavernosa	algae	native	DH	1	0.3, 0.7
Barnacle	invertebrates	native/introduced	DH	1	0.2, 0.2
Acanthophora spicifera	algae	introduced	SI	2	0.1, 0.3, 0.7, 0.4
Jania spp.	algae	native	SI	1	0.1, 0.1
B) Taxa students found but both researcher teams did not					
Acanthophora spicifera	algae	introduced	DH	1	7.9
Hypnea musciformis	algae	introduced	DH	2	1.6, 1.0
Gracilaria salicornia	algae	introduced	DH	2	1.5, 1.0
Dictyosphaeria verslusyii	algae	native	DH, SI	2	0.9, 0.9
Unidentified coral	invertebrates		WOP, SB	2	0.9, 0.4
Sargassum spp.	algae	native	SB	1	0.4
Other algae	algae		DH	1	0.4
Serpulorbis spp.	invertebrates	native	SI	1	0.4
Avrainvillea amadelpha	algae	cryptogenic	SI	1	0.3
Dictyota spp.	algae	native	BP	1	0.2
Echinometra oblonga	invertebrates	native	SI	1	0.2
Littoraria pintado	invertebrates	native	DH	1	0.2
Asparagopsis taxiformis	algae	native	SI	1	0.1
Botrycladia skottsbergii	algae	native	DH	1	0.09
Morula granulata	invertebrates	native	SI	1	0.08
Echinometra mathaei	invertebrates	native	SI	1	0.04
Bornetella sphaerica	algae	native	BP	1	0.003

Note: See Table 1 for number of quadrats sampled at each visit.

† In panel (A), cover is measured by researchers; in panel (B), cover is measured by students.

ment reveals that students using these methods are likely to misidentify early introductions but are able to monitor the abundances of established introduced species and common natives. The developed validity assessment used by OPIHI identified future actions that can be taken to improve the accuracy of citizen data. This evaluative assessment of citizen-based data is unique in that it is a robust examination of marine community data generated by citizen scientists placed in the context of researcher variation. Although this evaluation is specific to OPIHI, the education and training provided, the developed validity assessment protocol, and the data quality assurance steps all produced a successful outcome of quality, usable data that support scientific monitoring goals and thus can guide other citizen-based programs.

Based on our results and on previous assessments it is clear that researchers and students benefit from participating in this citizen-driven intertidal monitoring program. Student conservation awareness increases after participation in OPIHI (Baumgartner and Zabin 2006, 2008, Baumgartner et al. 2009). Researchers benefited (see Dickinson et al. 2010) because citizen scientists allowed for the collection of ample data in a limited amount of time; this is an important benefit in Hawaii where the low tide window only occurs for a few hours and seasonal and sporadic waves often limit safe access to the shore. For example, in this study ~20 students working in teams were able to either sample the same number of quadrats in a shorter time span (~1.5 h compared to ~2.0 h) or sample 10–60% more quadrats during the low tide window than each researcher team. The volunteer support from secondary school students and their teachers minimized costs. The costs incurred would have been greater if multiple researchers needed to travel to each site. However, there was still cost incurred for transportation of program managers to each island, for students that need to be bused from their school to the intertidal zone, and for supplies and teacher donated time. Without this type of massive concentrated effort these types of data would be difficult to gather. Similarly, many other programs have benefited from the efforts of coordinating numerous volunteers to collect meso-to-large scale data (Bhattacharhee 2005, McCaffrey 2005, Oscarson and Calhoun 2007, Cohn 2008, Delaney et al. 2008, Braschler 2009, Silvertown 2009, Devictor et al. 2010, Goffredo et al. 2010).

Although students in this study were successful in describing the distribution and abundance of common species (those species occurring >8%), the validity assessment revealed students were prone to misidentify cryptic species, those species occurring at low abundances, or taxa not included on identification cards. Furthermore, when students could not identify an algal species they were more likely to misidentify it as a known invasive. During the educational component of OPIHI, the potential impact and awareness of invasive species were heavily emphasized and students often expressed verbal excitement when they encountered these species. This observation may explain why the identification of unknown or difficult to identify specimens were identified by students as invasive species. In addition, most partnerships focus the efforts of citizen scientists on monitoring one population or assemblage of organisms (Silvertown 2009) as a means to minimize training or the need for taxonomic expertise. This single taxon approach (Silvertown 2009) combined with skepticism by professionals about the quality of citizen-gathered data (Crall et al. 2010) suggests that for citizens there is a trade-off in the quantity vs. quality of data. However, based on these findings and efforts by Osborn et al. (2005) we surmise that citizens can collect quantity and quality usable data if the limitations of the data are understood. Also managers need to provide proper oversight and make accommodations for certain types of data which could be more difficult for volunteers to collect. An awareness of these limitations or common pitfalls of citizens is of value to any researcher seeking to embark on a citizen-science partnership and stresses the need for a validity assessment.

The results from this study were similar to other evaluative studies conducted in different habitats and can be instructive when organizing a citizen monitoring program. Osborn et al. (2005) found that for the similarly organized LiMPETS program, trained students collected cover and density estimates of key intertidal species similar to those determined by professional researchers. Brandon et al. (2003) found citizen scientists were similarly successful in describing the community structure of terrestrial plants but were unable to distinguish among species with few differing morphological characteristics. Nerbonne and Vondracek (2003) examined the data generated by citizens sorting invertebrates from streams to find that they were more likely to misidentify species if they did not occur on the taxonomic key or if they were rare in occurrence. Although Delaney et al. (2008) found that accuracy in identification of invasive intertidal crabs was correlated with education level achieved, in this study grade level appeared to be unimportant for accuracy. In surveys of invasive water fleas (Boudreau and Yan 2004) and reef fishes (Darwall and Dulvy 1996) citizens collected more accurate data after more experience. From years of observation and data handling, OPIHI managers encourage classes to visit the intertidal zone at least twice for both a more rewarding educational experience, and so on the second trip students can focus on the collection of quality data. However, multiple trips are often not an option for teachers with limited fees for buses or with time limitations due to full curricula. Although longer duration spent on OPIHI curriculum and experience in the field may improve data quality, the pitfalls among students tended to be similar regardless of the duration of student participation. This study adds to the growing body of evidence to suggest that citizens are similar to researchers and that with appropriate data quality assurance actions such as tested protocols, training, practice, experience, and exposure citizens collect usable data.

The protocol developed to conduct the validity assessment allows us to make specific recommendations to improve future data quality and guide data usage. These recommendations include (1) targeted, and repeated exposure to the subtlety between similar looking and cryptic organisms or alternatively, managers could take a conservative approach and lump similar looking taxa into less resolved taxonomic groups for data analyses, (2) the continued use of site-specific ID cards modified for better identification of mis-IDed taxa, (3) provide and encourage post-processing time for students to identify "unknown species," and (4) modify the curriculum to not only underscore the identification of alien species but also to emphasize the negative consequences of misclassifying native species.

A comparison between data generated by different researcher and student teams in this study revealed that most collector variation was minimal and likely to be present in "all" ecological sampling; however, some comparisons had larger observer discrepancies. This is contrary to the conclusions by several researchers (Ericsson and Wallin 1999, Genet and Sargent 2003) who suggest variation is greater among citizen scientists compared to professionals. The discrepancy may be due to methodology, in previous studies, citizen-collected data were not compared to the expert variability when using the same methods. Few studies have examined collector variation among researchers, yet in long-term monitoring it is likely that numerous researchers or research teams may be involved in data collection. Benedetti-Cecchi et al. (1996) investigated collector variation in ecological sampling in subtidal habitats and found statistical variability. Dethier et al. (1993) found visual estimation methods of abundances to be more repeatable with less observer variation, but in this study observer variation tended higher between collectors when visual estimation methods were used. We sought to account for observer variation and limit this variability through our use of trained researchers and by using two teams as a baseline to compare with trained and practiced student collectors. Some collector variation was still observed and it can be argued that such variation would exist in studies conducted only by experts. Observer variation needs to be considered when assessing long-term ecological change or when assessing the abilities of citizens to collect accurate data.

There was a large discrepancy between data collected by researchers on a sampling visit to Sand Island. There are a number of possible reasons that could account for this discrepancy. Researchers were trying to complete the work of 20 students in the same low tide window and there was often a delay between sampling by the data collectors. If the students did not leave the quadrat in position, researchers would use the meter location along the transect line to position the quadrat in the same location as students. During this lag time between sampling variation is introduced. Transect lines can be slightly moved by wind or water. Researchers may not have positioned the quadrat in the absolute exact manner. Furthermore, this site has rocks that can move with an incoming wave or with the help of a curious student thus changing the composition in the quadrat. There is a lot of "bare space" at this site making estimation more difficult. Last, the researchers may have been more rushed at this site and thus they were not collecting the most robust data. All of these are possible reasons that could have contributed to such divergent values generated from experienced researchers. Nonetheless, this was only one instance out of eight with a wide variation between researchers. Furthermore, these same reasons could account for the student observations of species that were not observed by researchers for this site, such as species of *Echinometra* (an urchin species that can be large and obvious). These divergent values stress the importance of careful data collection for both experts and trained volunteers, and this suspected observer variation is the reason why two research teams were used as a benchmark for evaluating student data. In this study a substantial difference did not occur between researchers and citizen scientists.

Conclusions

Secondary students, as citizen scientists, can accurately describe and monitor diverse intertidal habitats with more than 60 species. This successful outcome was made possible by taking certain actions to assure data quality and was determined by conducting an assessment that not only evaluated quality but was also informative for program managers and the continuation of OPIHI. By placing citizen-generated data in context with researcher variation we were able to evaluate the limitations and strengths of this citizen scientist program and the monitoring outcomes. With an understanding of the limitations of these data, efforts are currently underway to test explicit hypotheses from data generated by OPIHI during the years of 2004–2007. To continue to foster conservation and provide much needed baseline information and reduce any negative stigma associated with citizen-collected data, we would recommend that more citizen scientist programs follow the framework we have provided and carefully evaluate the quality of their data and make these results available to a scientific audience. With more instructive evaluations, researchers can evaluate the training needed, the types of questions or surveys citizens can conduct, and whether some habitats or organisms better suit the abilities of citizen scientists to gather accurate ecological data (Dickinson et al. 2010). Without these evaluations, data collected by these programs are likely to be neglected, which could hinder conservation aims by causing disillusionment in the general public, particularly for students involved in their science education.

Acknowledgments

We acknowledge the NSF-funded GK–12 fellowship (DGE02-32016) for providing financial support for this study. We thank Chela Zabin, Brian Popp, Peter Vroom, and Alison Sherwood for early reviews of this manuscript. We also thank John Pearse and an anonymous reviewer for their assistance with the manuscript. Also we give credit to C. Zabin who helped to initiate and develop this citizen scientist program. We thank the students at the following Hawaii schools for collection of data: University Laboratory School, Farrington High, Kalama Intermediate, Connections, and Waters of Life. We especially thank the teachers who allowed us to enter their classrooms and partnered with us: Mari Tiara, Dawn Bishop, Diane Banks, Juniper Krog, Sara Haney, Nicole Wynick, and Jason Thorpe. We particularly thank many graduate students and professors in Ecology, Evolution, and Conservation Biology Program who volunteered as chaperones or researchers on the data collection trips. Lastly, we thank Kelly Boyle and Pat Aldrich who guided us through many statistical analyses.

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SUPPLEMENTAL MATERIAL

Supplement

Description of OPIHI (Our Project In Hawaii's Intertidal) curriculum in three parts: (1) introduction to OPIHI intertidal species identification, (2) introduction to sampling, and (3) measuring abundances (*Ecological Archives* A022-065-S1).