ORIGINAL PAPER

Marine invasive species: validation of citizen science and implications for national monitoring networks

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Abstract Approximately 1,000 volunteers assessed the presence of invasive (*Carcinus maenas* and *Hemigrapsus sanguineus*) and native crabs within the intertidal zone of seven coastal states of the US, from New Jersey to Maine. Identification of crab species and determination of the gender of the observed crabs was documented at all 52 sites across a 725-km coastal transect. Using quantitative measures of accuracy of data collected by citizen scientists, a significant predictor of a volunteer's ability was determined and eligibility criteria were set. Students in grade three and seven had the ability to differentiate between species of crabs with over 80% and 95% accuracy, respectively. Determination of gender of the crabs was more challenging and accuracy exceeded 80% for seventh grade students, while 95% accuracy was found for students with at least 2 years of university education. We used the data collected by citizen scientists to create a large-scale standardized database of the distribution and abundance of the native and invasive crabs. *Hemigrapsus sanguineus* dominated the rocky intertidal zone from Sandy Hook, New Jersey to Boston Harbor, Massachusetts while *C. maenas* dominated the northern extent of the sampled coastline. A citizen scientist of this monitoring network detected a range expansion of *H. sanguineus*. We identified obstacles to creating a national monitoring network and proposed recommendations that addressed these issues.

Introduction

More than 500 marine introduced species have been observed along the coast of North America and it is estimated that thousands of species are transported around the world every day (Carlton 1999; Fofonoff et al. 2003). Species often remain undetected or are usually only detected years after the initial colonization (Geller et al. 1997; Lohrer 2001), when the population size is large and eradication is no longer an option (Bax et al. 2001). Invasion ecology began as a true discipline in the later half of the 20th century and is still in its infancy (Elton 1958; Carlton 1979; Ruiz et al. 1997). In particular, marine systems are still greatly understudied, and so far, only a fraction of the invaders and their impacts have been recorded (Ruiz et al. 1997). Increased monitoring is beneficial

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since it increases the chance for early detection and thus offers the best chance for eradication (Myers et al. 2000; Bax et al. 2001; Lodge et al. 2006).

Comprehensive databases of spatial and temporal information for large geographic ranges of native and invasive species are integral to rapid assessments, testing scientific hypotheses, and validating predictive models (Ricciardi et al. 2000). Currently most databases are disjunct, disparate, incomplete, and often out-dated. Unfortunately, intense monitoring, as would be necessary to build comprehensive and up-to-date databases, rarely occurs due to resource limitations, such as the availability of funding and personnel. Volunteer-based monitoring is a potential solution to this problem and could supplement scarce resources (Fore et al. 2001; Lodge et al. 2006). For example, a statewide citizen science ornithological study provided more than 200,000 h of data collection that is valued at over a million dollars, even based on minimum wage (Bonney 1991). It has been shown that citizen science initiatives have not only contributed to reductions in costs associated with research endeavors, but have also been quite useful in previous environmental assessments (Greenwood 1994, 2003).

Citizen science has begun to contribute to the wealth of information about population structures, distributions, behaviors and to assist with the conservation of various organisms. Terrestrial and aquatic resource managers have taken advantage of volunteer networks for ornithology studies, reef ecology, stream and water quality monitoring (Darwall and Dulvy 1996; Ohrel et al. 2000; Bray and Schramm 2001; Fore et al. 2001). While many programs have already incorporated volunteers in environmental monitoring in Europe, fewer groups in North America have realized the value, both economic and educational, of citizen science (Greenwood 1994). The best North American example is the National Audubon Society's Christmas Bird Counts, which have been generating data for over 100 years about the distribution, range expansions, and other patterns of North American birds (National Audubon Society 2006). These initiatives are valuable both for the scientists, who gain increased personnel to collect more samples, and for the public, who benefit from hands-on learning experiences (Bonney and Dhondt 1997; Fore et al. 2001). With the aid of local volunteers, the program has been able to demonstrate

the feasibility of citizen science initiatives and applicability within large-scale bio-monitoring programs (National Audubon Society 2006).

The scientific community, however, seems reluctant to accept citizen science due to a current lack of certified audits to assess the validity of using such data in academic research and resource management decisions. Quality assurance and validation of these initiatives, through compliance to rigorous scientific methodology, is necessary for the scientific community to accept and utilize the data collected by citizen scientists (Boudreau and Yan 2004). Acceptance by the scientific community would also allow additional personnel to participate in bio-monitoring, and thereby increase our biological understanding of these species by creating large standardized spatial and temporal datasets (National Audubon Society 2006). Given the scarcity of knowledge related to marine introduced species (Ruiz et al. 1997) and the novelty of marine-focused volunteer bio-monitoring projects, this study was designed to validate the feasibility and accuracy of a large-scale marine invasive species monitoring network, named ''Citizen Science Initiative: Marine Invasive Species Monitoring Organization'' (CSI: MISMO 2007).

This study sought to assess the abilities of citizen scientists to compile data about the status and composition of the coastal biota. If, as hypothesized, it was determined that citizen science was a reliable method of conducting research, volunteers could aid in amassing knowledge about both native and invasive intertidal crabs, including the Asian shore crab (*Hemigrapsus sanguineus*) and the European green crab (*Carcinus maenas*). Certain variables were predicted to affect the accuracy of data collected by these volunteers, including the volunteers' age, education, group size, and size of the crab. We hypothesized that an accurate monitoring network is feasible with the assistance of citizen scientists, if eligibility criteria were determined and enforced. Data confidently generated by such efforts could then contribute to a large-scale, standardized database that would fill gaps in our current monitoring and increase knowledge of marine systems. The abundance and demographics of intertidal crab species could then be mapped to provide baseline data on the distribution of the current biota. The monitoring network could also provide early detection of other invasive crabs, such as the Chinese mitten crab (*Eriocheir sinensis*) and

the brush-clawed crab (*Hemigrapsus penicillatus*), both potential invaders to the coast of New England and other locations around the globe.

Study organisms

As widely distributed organisms, *Carcinus maenas* and *Hemigrapsus sanguineus* were logical choices for this new type of study and validation towards yielding the data needed for the progress of marine invasion ecology. These invasive crabs have many dispersal mechanisms, but the primary vector for these and other marine invaders from their native to invasive range has been via ship's ballast (Cohen et al. 1995). *Carcinus maenas* has invaded the coasts of North America, South Africa, Australia, South America and other places outside of its native range of the Atlantic coast of Europe and possibly northwest Africa (Carlton and Cohen 2003; Hidalgo et al. 2005). *Carcinus maenas* was presumably brought to the Atlantic coast of North America, in 1817, with solid ballast (Carlton and Cohen 2003). By 1989, it started colonizing the Pacific coast of North America starting in San Francisco Bay (Cohen et al. 1995). It was transported accidentally from the east coast by activities associated with the live food and bait trade (Cohen et al. 1995; Carlton and Cohen 2003). Establishment and persistence in these various environments is likely facilitated by its omnivorous feeding strategy and its ability to tolerate a wide range of temperatures and salinities (Crothers 1967; Ropes 1968; Cohen et al. 1995). A single brood of *C. maenas* can contain at least 185,000 eggs (Crothers 1967). High fecundity and the characteristics of a generalist allow *C. maenas* to inhabit a diverse range of marine ecosystems (Carlton and Cohen 2003) and therefore, reduce beta-diversity.

Similarly, *H. sanguineus* is a generalist, an omnivore, and a highly invasive brachyuran crab (Lohrer 2001). *Hemigrapsus sanguineus* is native to the western Pacific (Ledesma and O'Connor 2001) but has colonized multiple locations in Europe (Breton et al. 2002; Schubart 2003) and during 1988 it was first detected on the eastern coast of North America, in New Jersey (Williams and McDermott 1990). Traffic of foreign cargo vessels was presumably the vector that brought the Asian shore crab to North America (Lohrer 2001). In its native range, *H. sanguineus* inhabits waters that range from above 30 to below 5°C (Depledge 1984; Takahashi et al. 1985). With a high fecundity in the form of multiple broods of more than 50,000 eggs each breeding season, *H. sanguineus* has expanded its invasive range along the eastern coast of the United States, and has colonized from Oregon Inlet, North Carolina to Isle au Haut, Maine (McDermott 1998; Lohrer 2001; P. Thayer pers. comm.).

Methodology

Systematic surveys, using randomly placed quadrats, were conducted from May through August, 2005, with approximately 1,000 volunteers across 52 sites (Fig. 1) from Sandy Hook, New Jersey (40°27.103N, 074°00.135W), to Machias, Maine (44°42.451N, 067°18.823W). Intertidal habitats suitable for the invasive crab species *H. sanguineus* and *C. maenas* were selected, and our sampling site was defined as a 30 by 30 meter area using two tape measures. The tape measures were run parallel (X) and perpendicular (Y) to the coastline, to allow X–Y coordinates to be identified. The top left corner of each one square meter quadrat was placed at the intersection of two randomly selected X–Y coordinates. Crabs were collected and removed from each quadrat, taking care to systematically examine under macrophytes and rocks. On site, volunteers were instructed to record the species, gender, and carapace width for each crab. Carapace width was measured between the antero-lateral teeth furthest away from the eye-stalks (Crothers 1968). Citizen scientists placed the crabs into buckets corresponding to the different species and gender combinations (e.g. male *C. maenas*, female *H. sanguineus*) for validation. All rocks were returned to their initial state to minimize any disturbance. This process was repeated for as many quadrats as was feasible during low tide.

The volunteers varied in age and education level, which allowed identification of volunteer eligibility criteria. The education level ranged from pre-kindergarten to Ph.D., and age ranged from 3 to 78 years old. The participants at each site were divided into subgroups (1–10 people). In total, 190 groups participated in the experiment. Before the sampling started, the research team introduced the volunteers to the methodology in an hour-long training session.

Fig. 1 The 52 sites that were monitored along the 7 coastal states of United States of America, New Jersey to Maine. The numbers correspond to the ''CODE'' in Table 2
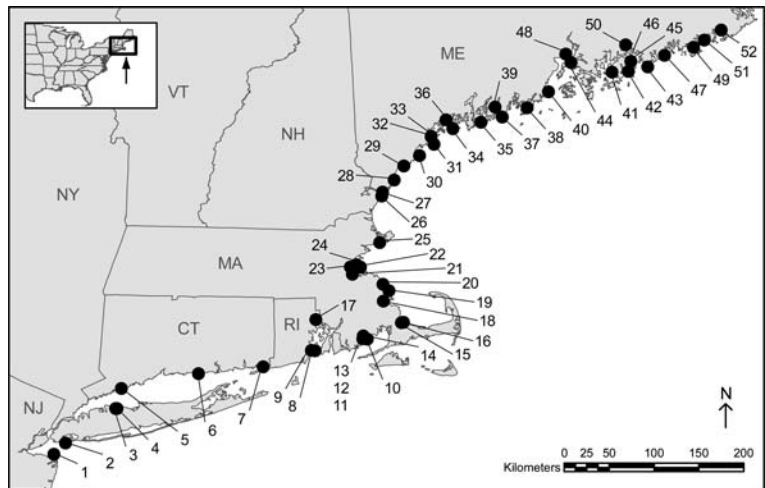
Participants were given magnifying glasses, buckets, rulers, as well as Massachusetts Institute of Technology Sea Grant's ''Hitchhikers Guide to Exotic Species'' and field guides, which served as teaching tools to increase the accuracy of citizen scientists monitoring at each site. After each sampling session, all of the crabs collected by volunteers were checked and re-counted by the research team to verify the degree of accuracy with which the citizen scientists had recorded the data.

Statistical approaches and issues

To develop eligibility criteria, we identified independent variables (age, education, and group size of participants, as well as the size of the crab) to examine their effect on the ability of volunteers to accurately determine crab species and gender. As expected, age and education were highly co-linear ($r = 0.813$). Therefore, only education was included in the analysis because it was assumed to be a more accurate predictor of citizen scientists' abilities. Further, of the 190 groups in the monitoring network, 135 of them had measured the carapace width for every crab that they had collected, and thus, these were the only groups included in the validation analysis. The volunteer groups were used as independent sampling units ($N = 135$), since our purpose was to validate the accuracy of volunteers.

The experimental design has an issue of repeated measures, because each group collected multiple crabs and had unequal sample sizes. Thus, a randomization program selected an individual crab collected from each group at random, such that each group provided a single data point. Each multiple logistic regression served to test the relationships between the predictor variables (volunteer group size, education and crab size) and a binary dependant variable (correct identification of crab species or gender). The program randomized the predictor variables with respect to the dependent variables, and a multiple logistic regression on this randomized set created the null comparison point (Manly 1997). The program repeated this process 10,000 times, each time selecting, with replacement, a crab from each group. This allowed statistics to be calculated using all crabs in the dataset, thereby providing a better idea of the generality of the results and avoiding inflated Type I errors associated with non-independence from multiple measurements per group. For independent variables that were significant, the eligibility criteria to provide high levels of accuracy (80 and 95%) were determined using back-transformation from the averaged logistic model results.

Results

Validation of citizen scientists

Education was a highly significant predictor of the volunteers' ability to correctly identify both the species and gender of a crab (Table 1). Based on

Table 1 The *P*-values from the multiple logistic regression to determine the significance of the predictor variables, education, group size, and size of crab, on the two dependant variables the volunteers' ability to correctly identify the species and gender of a given crab

	Education	Group size	Crab size
Identification of Sex	0.007	0.355	0.153
Identification of Species	0.004	0.375	0.413

the data, it was concluded that third-grade students were, on average, at least 80% accurate when discerning the differences between the native and invasive crab species, while seventh-grade students were over 95% accurate. Determination of crab gender was more challenging requiring at least a seventh grade education to obtain 80% accuracy. Volunteers required 2 years of university education to exceed 95% accuracy. The analysis did not find that volunteer group size and crab size were significant predictors of a citizen scientist's ability to identify the gender or species of a crab correctly (Table 1).

Abundance, diversity and distribution

Once the statistical analysis provided eligibility criteria for participants of CSI: MISMO volunteers, the further analysis on crab distributions presented here used only the data of the citizen scientists who satisfied the requirements that exceeded 95% accuracy. These results depict the distributions and relative densities of *C. maenas* and *H. sanguineus* in their invasive range in the seven sampled northeast coastal US states (Fig. 2 and Table 2). Latitudinal correlation analysis showed a pattern of *H. sanguineus* abundance that was inversely proportional with a correlation coefficient of −0.583. The Asian crab dominated the rocky coasts from Sandy Hook, New Jersey (Site 1) to Quincy, Massachusetts (Site 21). At all sites north of Boston Harbor (Sites ≥25), *C. maenas* populations were larger than those of *H. sanguineus*. Several sites in the central locations, particularly New Bedford, Massachusetts (Site 11), East Providence, Rhode Island (Site 17) and Saco, Maine (Site 30), were relatively diverse with regard to native species (Fig. 2).

Finally, the volunteer network recorded a range expansion of *H. sanguineus*. The most northeastern observation is now a gravid female specimen, measuring 22.11 mm, on Schoodic Peninsula (Site 43), which is the northeast limit of Acadia National Park in Maine. This range expansion, discovered on July 21, 2005 by a citizen scientist of CSI: MISMO, is approximately 60-km northeast of previous records of *H. sanguineus* on Moores Harbor, Isle au Haut, Maine (Fig. 3).

Fig. 2 The size of the pie charts for each site are scaled to represent relative abundance of crabs at that site. Divisions in the pie charts indicated abundance of each species, *H. sanguineus*, *C. maenas*, and pooled native species

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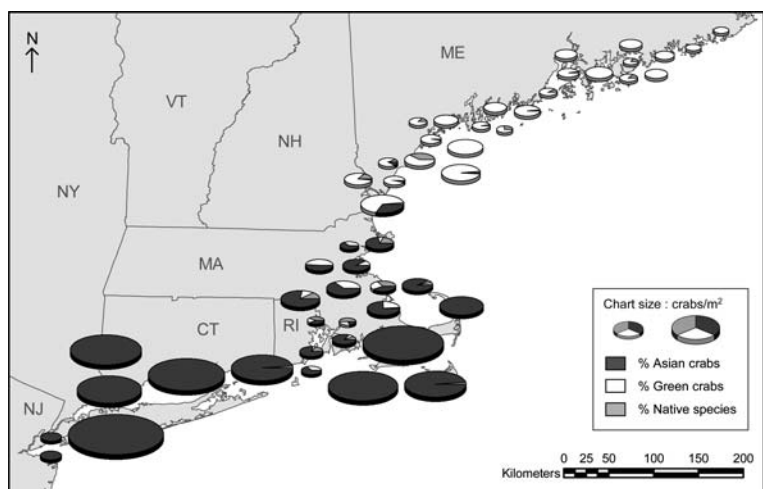
Table 2 For each site, a number from 1 to 52 is assigned according to its location from South to North ("CODE"), the latitude ("LAT"), longitude ("LONG"), and the density of crabs, including the total density of all crabs ("CRABS"), the individual densities of the invasive *Hemigrapsus sanguineus* ("ASIAN"), *Carcinus maenas* ("GREEN") and the pooled density of all native species ("NATIVE"), are given as crabs per square meter

Code	LAT	LONG	Crabs (Crabs/m^2)	Asian (Crabs/m^2)	Green (Crabs/m^2)	Native (Crabs/m^2)
1	40°27.103N	074°00.135W	2.19	2.19	0.00	0.00
2	40°33.683N	073°52.951W	2.11	2.11	0.00	0.00
3	40°54.384N	073°22.673W	24.60	24.60	0.00	0.00
4	40°54.401N	073°22.051W	43.83	43.83	0.00	0.00
5	41°06.664N	073°19.739W	20.00	20.00	0.00	0.00
6	41°14.971N	072°32.556W	28.25	28.25	0.00	0.00
7	41°19.646N	071°54.311W	18.50	18.25	0.25	0.00
8	41°29.347N	071°23.012W	1.97	1.26	0.71	0.00
9	41°29.485N	071°25.270W	2.63	2.06	0.13	0.44
10	41°36.178N	070°51.799W	7.38	5.69	0.92	0.77
11	41°36.369N	070°54.211W	1.40	0.28	0.40	0.72
12	41°36.550N	070°54.265W	18.24	17.91	0.00	0.33
13	41°36.567N	070°54.285W	2.76	2.32	0.20	0.24
14	41°37.985N	070°54.150W	23.46	23.46	0.00	0.00
15	41°46.278N	070°31.068W	9.38	9.38	0.00	0.00
16	41°46.406N	070°29.973W	31.70	31.65	0.05	0.00
17	41°48.059N	071°22.636W	1.36	0.57	0.22	0.57
18	41°59.214N	070°41.947W	5.16	3.83	1.25	0.08
19	42°05.501N	070°38.546W	4.50	4.08	0.17	0.25
20	42°09.434N	070°42.262W	3.10	1.30	0.70	1.10
21	42°18.226N	071°00.838W	3.67	1.89	1.78	0.00
22	42°19.830N	070°55.820W	1.75	1.10	0.65	0.00
23	42°19.865N	071°01.775W	5.58	3.50	2.04	0.04
24	42°21.311N	070°58.111W	3.65	3.26	0.39	0.00
25	42°34.572N	070°44.227W	3.86	2.80	0.33	0.73
26	43°02.506N	070°42.890W	3.70	0.09	3.06	0.55
27	43°04.866N	070°42.526W	8.93	2.86	5.93	0.14
28	43°12.268N	070°35.413W	2.21	0.13	2.08	0.00
29	43°20.651N	070°29.686W	1.82	0.19	1.46	0.17
30	43°26.811N	070°20.167W	4.38	0.00	2.63	1.75
31	43°33.934N	070°11.942W	7.33	0.14	7.05	0.14
32	43°38.281N	070°13.313W	1.60	0.00	1.37	0.23
33	43°38.876N	070°13.545W	2.00	0.06	1.94	0.00
34	43°43.064N	070°00.173W	5.93	0.00	5.93	0.00
35	43°47.027N	069°43.283W	1.58	0.00	1.53	0.05
36	43°48.511N	070°04.291W	2.85	0.00	2.85	0.00
37	43°50.189N	069°30.447W	1.23	0.00	0.88	0.35
38	43°55.553N	069°15.507W	3.23	0.00	3.17	0.06
39	43°56.081N	069°34.759W	2.60	0.00	2.60	0.00
40	44°05.401N	069°02.805W	1.57	0.00	1.41	0.16
41	44°17.087N	068°24.529W	3.63	0.00	3.63	0.00
42	44°17.711N	068°14.598W	1.55	0.00	1.33	0.22

Table 2 continued

Code	LAT	LONG	Crabs (Crabs/m^2)	Asian (Crabs/m^2)	Green (Crabs/m^2)	Native (Crabs/m^2)
43	44°20.281N	068°03.200W	2.42	0.00	2.42	0.00
44	44°22.897N	068°49.168W	2.12	0.00	2.06	0.06
45	44°23.726N	068°13.219W	1.1	0	0.9	0.2
46	44°23.963N	068°12.587W	2.41	0	2.41	0
47	44°27.426N	067°52.833W	1.83	0.00	1.83	0.00
48	44°28.267N	068°52.458W	2.35	0.00	2.35	0.00
49	44°32.075N	067°35.585W	1.17	0.00	1.17	0.00
50	44°33.506N	068°16.446W	0.04	0.00	0.04	0.00
51	44°36.619N	067°28.976W	0.40	0.00	0.40	0.00
52	44°42.451N	067°18.823W	1.11	0.00	1.11	0.00

Fig. 3 An aerial photograph of Maine from Moores Harbor, Isle au Haut to Narraguagus Bay. The circles that are numbered are sites that have been monitored in this study. While Moores Harbor was the previous known northernmost extent of *H. sanguineus*, current findings suggest that it is now found as far northeast as Schoodic Peninsula, Maine
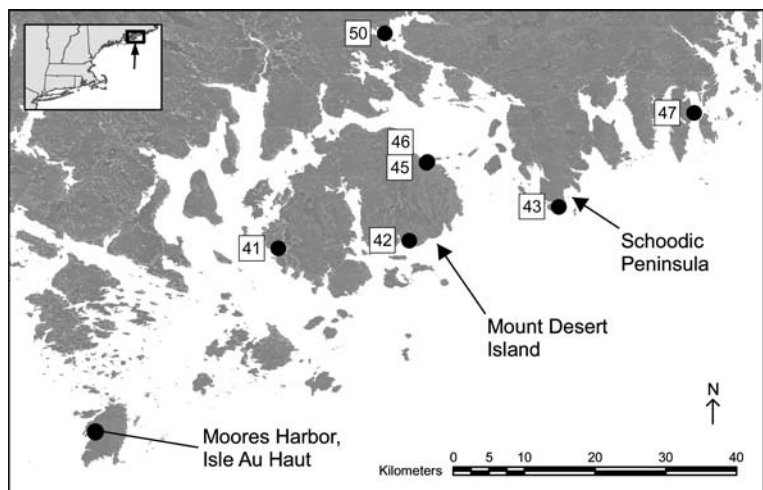
Discussion

Eligibility and implications for a national monitoring network

Based on this study, we have established a large-scale, standardized database and eligibility criteria for citizen scientists monitoring marine introduced species. Now we will outline the issues that may arise in the future for monitoring to be successful and for extending to other marine introduced species. The utilization of citizen scientists could face issues concerning the endurance of citizen scientists' patience. For example, in this pilot study, some volunteers failed to complete the size measurements of all their crabs because they found it to be too difficult or tedious. However, all groups did record the species and gender of the crabs, which is extremely useful information for early detection and helps to fill in the gaps in current monitoring by professionals (Fore et al. 2001). Early detection has been recognized by invasion biologists and the US Government to increase the probability of successful eradication (US Congress OTA 1993; Myers et al. 2000; Lodge et al. 2006).

For better management of introduced species, not only is there a need for more data but also it is crucial to have the data readily available to managers. One solution is the use of global technologies such as the worldwide web and geographical information systems as a means for data entry and sharing. A dynamic database linked with online mapping technology (e.g. Google Earth) would make an ideal medium for the first completely graphical global

database of the native and introduced ranges of species. To make such a database comprehensive, it would need to incorporate data from already established databases such as the Global Invasive Species Database (GISD 2007), Marine Invader Tracking Information System (MITIS 2007), National Institute of Invasive Species Science database (NIISS 2007), and the USGS Nonindigenous Aquatic Species information resource (USGS NAS 2007). Another approach, as used by the NISbase, is to link decentralized databases through a single-user interface (Ricciardi et al. 2000; NISbase 2007). This option also has great potential but requires a level of standardization by the creators of the individual databases that has been quite elusive. Thankfully, this appears to be slowly changing. No matter what medium, a comprehensive, up-to-date internet-based database will be vital because it will enable global accessibility to standardized data that facilitates rapid response, increasing our probability of successful eradication. It will provide information to all the stakeholders such as researchers, resource managers, policy makers, educators and the public.

Another challenge will be the sustainability of the monitoring network itself given issues of limited funding and the challenge of large-scale coordination and training. CSI: MISMO and the National Park Service produced a video to train citizen scientists and raise awareness of people all along the coasts of North America, while keeping the investment of time and money for traveling and training expenses at a minimum. Sustainability is possible with the right tools, and high quality data can be maintained by enforcing the eligibility criteria determined in this study. For example, education was a significant predictor variable but the size of the crab was not a significant dependant variable for the abilities of citizen scientists to identify the species or gender of a crab correctly. There are a few possible hypotheses to explain this surprising result. One explanation is that citizen scientists did not collect the smaller size classes of crabs and therefore, did not extensively encounter the threshold size of crabs at which citizen scientists could not discern the gender or species. Another possible factor is that citizen scientists used magnifying glasses to identify smaller crabs, and therefore, size was not an important factor.

Although there are issues with using citizen scientists, given proper training, they can collect data with high accuracy (Darwall and Dulvy 1996; Fore et al. 2001; Boudreau and Yan 2004). Citizen scientists are a valuable source of information for early detection (Lodge et al. 2006). In fact, the first Asian shore crab in North America was discovered by a college student (Williams and McDermott 1990). Unfortunately, discoveries by citizen scientists are not usually published or disseminated to resource managers and scientists, with the possible exception of ornithological studies (Lodge et al. 2006; National Audubon Society 2006). The presence of *H. sanguineus* in Massachusetts first came to the general attention of invasion ecologists and New England marine biologists in 1993 because of the specimens collected by the students of the Children's School of Science (J. T. Carlton pers. comm.). In South Portland, a 9-year old child discovered the first site colonized by *H. sanguineus* in the state of Maine (J. Sandler pers. comm.). This study sets a baseline for eligibility of citizen scientists and lays the groundwork to extend and validate monitoring for other marine introduced species. Given the low eligibility needed to identify crab species and gender correctly, it is quite feasible that citizen scientists can accurately monitor less conspicuous introduced organisms.

It would be unrealistic, however, to believe that validation of citizen scientists' abilities to collect data is the only element necessary for the establishment of a national monitoring network. Creating a large-scale network is a multi-year, tiered process, requiring a great deal of investment in order to enable it to flourish, expand, and remain sustainable. Necessary investments include time, dedication, and financial backing. Since data quality is an important issue, state-level supervision could play an important role. We propose the ideal groups for this would be programs funded by National Oceanic and Atmospheric Administration (NOAA), such as the National Sea Grant College Program, a university-based research program located in 30 states. NOAA already funds LiMPETS (Long-term Monitoring Program and Experiential Training for Students), which uses students and other volunteer groups to monitor various marine habitats of five west coast national marine sanctuaries (Pearse et al. 2003; Osborn et al. 2005). NOAA has already set the framework for a national program monitoring introduced aquatic plants (Crawford et al. 2001). Comprehensive

national monitoring of aquatic systems for all introduced organisms would be the logical expansion of this work and NOAA is best prepared for this monumental challenge. Collaboration between NOAA and other established groups, such as the National Park Service, NGOs (e.g. Salem Sound Coastwatch) and extension programs (e.g. Cornell Extension Program of Suffolk County), would be beneficial and these partnerships would serve to promote the use of local experts in confirming the data for their area, to create the first national marine monitoring network (M. Raczko, C. Smith, and B. Warren pers. comm.).

The creation and proliferation of ''bio-blitzes'', with volunteers gathering samples to be identified by scientists, could be an ideal avenue for sustained citizen science monitoring. These are heavily used by the National Park Service and many other conservation groups. The Boston Harbor Islands National Park has already organized such ''bio-blitzes'' that brought together personnel from the Harvard Museum of Comparative Zoology and CSI: MISMO in which professionals were coupled with volunteers to monitor native and invasive invertebrates of various Boston Harbor islands. Other events organized by the National Park Service conduct a survey of *Coleoptera*, *Formicidae*, and *Lepidoptera* diversity in Acadia National Park and complete inventories such as the 'All Taxa Biodiversity Inventory' in places such as the Great Smoky Mountains National Park (D. Manski pers. comm.). These all serve to demonstrate that interest in public monitoring events facilitates the interaction of professional scientists and resource managers with citizen scientists who share mutual goals (Fore et al. 2001). Due to the large work force needed to monitor these huge areas, citizen science is a vital component for the success of properly monitoring the spread of invasive species.

This study sought to demonstrate that a large group of people working together could collect enough scientifically valid data for use in detecting the spread of recently introduced non-native species. Increased monitoring is beneficial since it increases the chance for early detection that offers the best chance for eradication, which is the most cost-effective management option (US Congress OTA 1993; Bax et al. 2001). Increased knowledge about baseline biota could not only enable the prediction of future marine invaders but also allow more informed policy decisions for the prevention of future bioinvasions and the management of introduced species (Leung et al. 2005). It is no revelation that collecting this data is an overwhelming feat to achieve and requires large numbers of individuals. Citizen scientists are a key solution to limited funding and personnel needed to carry out such research. Given proper training, citizen scientists are able to monitor their coastlines for these species, and help scientists by providing additional data on the distribution of marine introduced species, especially in areas scientists cannot monitor themselves. Such efforts would improve the efficiency of detecting new introduced species and serve to compile baseline information about the changing biota of the intertidal zone.

Distribution of invasive crabs

Abiotic factors can explain many of the observed large-scale patterns of crab distribution and abundance. *Hemigrapsus sanguineus* is significantly less abundant as latitude increased. This is probably due to many factors but latitude could act as a rough proxy for one of the most important factors, water temperature, which decreases from New Jersey to Maine. Lohrer et al. (2000) revealed that habitat complexity is another important predictor of abundance, with more complex sites offering more shelter and supporting higher densities of crabs. For example, high densities of *H. sanguineus* were found within the abundant cobble of Centerport (Site 3 and 4), but low abundance was found in the muddy areas of East Providence (Site 17) and Taunton Bay (Site 50), and in the varied but largely sandy substrate of Roque Bluffs, Maine (Site 51).

Biotic factors, in addition to abiotic factors, appear to influence the patterns of distributions and abundances of these crabs. Initially, researchers believed that *H. sanguineus* was exploiting a niche previously unoccupied by other brachyurans, but it was later found that this invasive crab interacts and can outcompete and exclude *C. maenas* (Lohrer and Whitlatch 2002). The overlap of these two species is not clearly defined, but it appears that *H. sanguineus* is far more aggressive than any other crab and can exclude all other species from the rocky intertidal zone as seen in the southern sites. In northern New England, *C. maenas* still dominated the intertidal zone (Fig. 2).

Logistical issues and environmental heterogeneity can also influence the observed crab abundances. The crab abundances found in this study were almost certainly underestimates due to logistics involved in sampling the rocky intertidal zone and monitoring a mobile organism. Many sites (e.g. Sites 1, 2, 11, and 37) were comprised of large, immovable rocks with only small crevices, and sampling was difficult at times. Given the mobile and evasive nature of the crabs, even in more accessible locations, it was arduous to capture all crabs in any given quadrat and the densities recorded are probably lower than the actual densities. In addition, sampling large 30 by 30 meter sections will encompass optimal, suboptimal and possibly uninhabitable locations, reducing the overall average abundance. Other factors that could influence the data are tidal height, wave exposure, and seasonality but these were minimized by consistently sampling at dead low tide and randomly moving to different geographic areas of the transect throughout the 4 months of the spring and summer (May–August), instead of sampling from north–south.

Sampling intensity and behavior of the organism could have been important factors in explaining the observed pattern of crab distribution. It is imperative to note that even during this study, some of the sampled sites in northern Maine may have been invaded by *H. sanguineus* unbeknownst to the research team and volunteers who monitored the coasts, because the introduced crab was at very low densities and therefore might have gone undetected. Another challenge to consider is that *H. sanguineus* can migrate to the subtidal zone during the winter months to avoid challenges of the colder temperatures (Ledesma and O'Connor 2001). This organism could possibly be utilizing this behavior year-round in northern Maine. This adaptation could initiate a slew of unknown interactions, as well as decrease the probability of detection. There is a 60-km range expansion between the newly detected northernmost limit of *H. sanguineus* at Schoodic Peninsula, and the previous northern record at Moores Harbor, Isle au Haut, Maine (Fig. 3). The monitoring network did not detect *H. sanguineus* at any of the five sites between these two locations or at the four additional sites further northeast. The citizen scientist that detected the gravid *H. sanguineus* female at Schoodic Peninsula did so during a manual search and not in a randomly placed quadrat. Thus, further analysis should experiment with different sampling techniques and variations in sampling intensity to determine how to optimally allocate effort and determine the probability a species is present, if not detected (i.e. false-negatives).

These aforementioned issues raise the question of whether Schoodic Peninsula will be the final extent of *H. sanguineus*' migration north. The Asian shore crab found at Schoodic Point was a gravid female, demonstrating that even at this northern extent of the invasive range, *H. sanguineus* is reproducing. The unresolved matter is whether the population is sustainable. The colder water temperatures of Maine increase the obligate minimum time that larvae of *H. sanguineus* spend as plankton and therefore the crab may not be able to recruit due to increased advection and a mean southwestward flow (Byers and Pringle 2006). The ultimate explanations for the patterns of distribution and abundance could be due to abiotic tolerances, advection, competition, propagule pressure, or a time lag in the expansion of the *H. sanguineus* in the northeastern region. It is more likely the synergy of a few of these factors. Arguably, large systematic databases generated by citizen scientists will be vital for testing which factors and interactions are important. The final extent of its range can only be determined by joint models that incorporate invasibility, propagule pressure and climate change models. These complex models will need large-scale standardized datasets, such as the one created by citizen scientists in this study, to validate these models.

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