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Game-based learning for engaging citizens in biopollution control

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Abstract

Citizens are essential for safeguarding ecosystems from biopollutants, but the communication of scientific discoveries about biological invasions in order to make the population aware of the problem is still a challenge. Here we have assayed an interdisciplinary game-based method of recognizing the invasive pygmy mussel *Xenosotrobus securis* in volunteers of different age groups, measured their learning gain and engagement, and compared it with that obtained from conventional talk-lecture training methodology. Highly significant positive correlation was found between knowledge gain and awareness, that were both greater in children than in adults. Similar engagement (measured as recruitment for volunteering in an eradication project) was achieved in the two age groups. The results suggest high efficacy of game-based training, especially in young age groups. One year after volunteers' action, environmental DNA surveys and visual inspections confirmed the control of the population in a defined area through time.

Keywords: biological invasions, biopollutants, marine conservation, citizen science, volunteers engagement, learning gains, awareness.

1. Introduction

Marine biopollution concentrated in ports and marinas and the subsequent biological invasions, are an increasing concern for biodiversity conservation worlwide (e.g. Molnar et al. 2008; Azzurro et al. 2019). However, while there is general public consciousness about the need of conserving the marine environment, most citizens have limited understanding of the real specific problems of marine settings (McKinley and Fletcher 2010). The public is generally unaware of the potential impacts of biological invasions. Find ways of communicating scientific discoveries in this field remains a challenge (Simberloff et al. 2013). Especially nowadays when the problem has become of such a magnitude that the help of citizens is needed for the detection and control of potential biopollutants in marine ecosystems. Scientists cannot be everywhere and citizen support can help to afford the research of bigger areas. Voluntary citizens can provide support in observation tasks, data collection and other much valuable actions, especially when the available resources for scientific research are limited (Costello et al. 2010). In fact, there are successful projects where citizens, scientists and managers work together to face coastal introductions of foreign species, for example the mapping of invasive crabs from US coasts (Delaney et al. 2008), the detection of the sergeant major in the Mediterranean Sea (Azzurro et al. 2013) and the lionfish in the Caribbean (Carballo-Cárdenas and Tobi 2016), to cite a few. Moreover, projects that involve citizens forge new relationships between the volunteers and the marine environment, raising awareness about conservation issues (Cigliano et al. 2015; Couvet and Prevot 2015).

A dangerous biopollutant is the Australian/New Zealand native brown pygmy mussel *Xenostrobus securis*. It has invaded many Asian and European estuaries and lagoons causing serious damages to the native ecosystems in the two last centuries (e.g. Zenetos et al. 2005, Pascual et al. 2010, Adarraga and Martinez 2012, Iwasaki and Yamamoto 2014; Lau et al. 2018). Stopping its expansion is crucial for preserving native biodiversity. Thus the collaboration of citizens is especially needed since much personal workforce is required to monitor and control the species. In the south Bay of Biscay (North Atlantic), the brown pygmy mussel was detected for the first time and at a very low density in the port of Avilés (North Spain) in 2015 (Pejovic et al. 2016). It spread out extremely fast on the neighboring areas and invaded the whole estuary (Devloo-Delva et al. 2016). For that reason the help of citizens was essential for an experimental eradication of this biopollutant from the estuary and scientific monitoring of the invasion. After manual removal done by trained volunteers the success of the experience was confirmed by both visual assessment and environmental (eDNA) assays from water samples (Miralles et al. 2016).

Marine governance is undergoing a significant change, moving towards citizen-driven management and policy strategies (McKinley and Fletcher 2012). The active participation of citizens in research has resulted in the citizen science approach, a participatory research strategy where citizens and scientists work together on research projects and scientific monitoring (Irwin, 1995; Bonney et al. 2014), contributing substantially to the advance of basic and applied science (Theobald et al. 2015). Citizen science projects have broader societal impacts: an extensive collaboration between scientists and citizens (Couvet et al. 2008) generate cross-cultural and multi-generational learning outcomes (Phillips et al. 2012). However, the validity and reliability of the data collected by volunteers in citizen science activities are sometimes controversial (Goffredo et al. 2010; Lukyanenko et al. 2016). Most scientists agree that a good training significantly increases the quality of the data stemming from volunteers (Thiel et al. 2014). Guidelines for good practice in citizen science have been established progressively as long as new collaborations between scientists and citizens are being generated (e.g. Cohn 2008; Haklay 2015; Davies et al. 2016). They focus mainly on working methods and data collection in order to report accurate results (Silvertown 2009). However, it seems very important to involve citizens in marine exploration and conservation through a type of interdisciplinary training that increases not only their skills for a particular task but also their knowledge about marine environment. If volunteers taking part in research projects acquire an effective knowledge about the scientific principles that govern what they do, they can be more efficient and rigorous for marine exploration, promoting conservation efforts and awareness (Johnson et al. 2014).

The Society of Conservation Biology finds it urgent to find best methods and tools to engage citizens of different audiences in marine conservation (SCB 2016). Game-based training could be an option (Lean et al. 2006; Griggs et al. 2019). Didactic games are increasingly employed for teaching-learning in biological disciplines (Costa and Galembeck 2017), nevertheless, it has not been sufficiently explored yet. In this study, a game-based approach was followed in the real case of biopollution control of brown pygmy mussel (*X. securis*). Unambiguous accurate species recognition is required for not damaging the local native mussels *Mytilus galloprovincialis* and *M. edulis* that occur together with the invasive on the same mussel beds. We have evaluated the awareness increase from pretest-*posttest* methodology (Chen et al. 2016), and the engagement achieved following the game. The latter was compared with that obtained from a standard procedure based on public talks and lecture-like group training sessions. Different age groups were targeted to identify possible age-related differences in the efficacy of game learning for citizen engagement in biopollution control.

2 Material and Methods

2.1 The case study

The biological invasion of the brown pigmy mussel was located in the estuary of Avilés. (Asturias, northwestern Spain). The first individuals were discovered in 2014 (Pejovic et al. 2016) and in 2015 the species had invaded the estuary (Devloo-Delva et al. 2016). The mussel community in the estuary was composed by native *Mytilus* species (*M. edulis* and *M. galloprovincialis*), the cryptogenic *Mytilaster minimus* and the invasive *X. securis*.

With the interdisciplinary collaboration of biologists and educators, this study was carried out in three locations of Asturias: Avilés (invasion hotspot), Salinas (at 3 km from the invasion) and Oviedo (at 25 km from Avilés). A total of 135 participants were recruited from groups of different generations with different marine backgrounds, skills, educational level, experience and incentive (Table 1). For young groups, 37 children (ages 6-17) were contacted from Salinas surf school “El Pez Escorpión” (*The Scorpion Fish)*, and 42 children (ages 15-18) studying in Grades 10 and 11 (KS 4) from Salinas High School. Adults were recruited from two Lifelong Learning programs developed in two Asturian cities: one in Oviedo (with 36 adults aged 21-75) and the other in Aviles (with 20 adults aged 31-74).

Table 1. Participants in eradication of exotic mussels

Group	N	Age	Completed pretest-*posttest*	Recruitment

El Pez Escorpión	37	(6-17)	83.8%	18.9%
Salinas High School	42	(15-18)	100%	0%
LL-Oviedo	36	(21-75)	100%	19.4%
LL-Aviles	20	(31-74)	95%	20%

2.2 Questionnaire

We designed a single questionnaire to be used as both pretest and posttest, with 5 items arranged like a Likert-type scale (table 2).

Table 2: Questionnaire

being 1 the lowest level and 4 the maximum, point out	*1*	*2*	*3*	*4*
Number of known invasive species				
Management actions				
Perception of environmental nuisance caused by invasive species				
Sea frequentation				
Intention to collaborate in the citizen science project				

A pilot trial of the test was passed to 40 faculty colleagues. No inconsistencies were found, and the redaction of the questions was revised for better understanding. The test was validated for internal consistency in the sample based on Cronbach α-coefficient. Since there are no correct or incorrect answers, tests of item reliability were not done. The discrimination value of each item was estimated from the homogeneity index HI based on the correlation between the scores obtained by the participants in each element and in the total scale.

2.3 Training approach

A two-step training program was followed. The total duration of the training was a maximum of 2 hours. Before starting the training an anonymous questionnaire was passed to each participant. In the first step we explained briefly (in 15 minutes) the problem of invasive species in the region, presenting the main species with supporting visual presentation (PowerPoint) containing pictures and key messages. The recently discovered problem of mussel invasion in Aviles estuary was explained more in detail. Photographs of exotic *Xenostrobus securis* and native *Mytilus galloprovincialis* individuals were shown and the differences between the two species were explained.

The next step was the training for recognizing the invader species in practice. It was based on a cooperative game (Kyriazi et al. 2017). Participants were asked to form a line. A mixture of shells of *Xenostrobus securis* and *Mytilus galloprovincialis* was presented. Each participant picked one shell (in blind) and examined it for two minutes. Then, they were asked to move themselves to the group of "Exotics" (*Xenostrobus*) or "Natives" (*Mytilus*). Then, the researchers disclosed the actual species by only said how many misidentifications were done. Participants who were wrongly self-assigned to any of the two groups were asked to move to the other group helped by the rest of participants. Through cooperative learning (Tran et al. 2019), all participants worked together to identified the intruder. The game was repeated until all the participants identified correctly the species.

When ending the training, the post-test questionnaire was passed, again anonymously. Identification of pre- and post-test matches was done based on birth dates and sex. Contact data (name, telephone and email) of participants interested in the activity of the control of *Xenostrobus securis* population of Aviles estuary were taken at the end of the training activity.

As a complementary activity, in the field a brief additional training was carried out for refreshing the acquired knowledge, and learning basic safety measures. Detailed instructions about how to remove *Xenostrobus securis* individuals were given, with a practical demonstration by the researchers.

2.4 Statistical analysis

Pre- and post-tests were analyzed from the score difference for the items 1, 2 and 3. Scores were compared among groups using single-factor analysis of variance, for each question separately. The factor considered was the group age (levels young and adult). Levene´s test for homogeneity of variance was done, and when the variances were significantly unequal a Welch F test was employed instead of classic F-test for the analysis of variance. Correlation between the variables considered was tested employing Pearson-r values. The statistics was performed using the software PAST version 2.17c (Hammer et al. 2001).

2.5 Ethics statement

This study adheres to the European Code of Conduct for Research Integrity. Informed consent, in writing, was obtained from all the participants to use the collected data for research publication. Parental permit was required for children under legal age (18 in Spain).

Before starting the activity all participants signed an informed consent and committed to follow the instructions given by the researchers, including to not to keep or transport out of the sampling area any living or dead *X. securis*. All participant children were always accompanied by their parent/s or tutor/s. Safety measures were explained before starting the eradication trial. First-aid kits and cell phones with connectivity for emergency calls were available for each participant group. Aviles Port Authority and its Environmental Department were informed and were given permission for the activity. The land accessed is not privately owned nor protected.

All removed individuals of *X. securis* were destroyed as biological waste by the regional service in charge (Consortium of Management of Solid Residues of Asturias, COGERSA; http://www.cogersa.es/metaspace/ portal/14498/18718). All materials employed for manual removal were carried to the closest Clean Point and disposed there together with the plastic containers. Protected species and the rest of native species were not sampled, disturbed or damaged in any case.

3. Results

Although the exotic and native mussel species are relatively similar to each other (Figure 1), after the game-based training all the participants were able to recognize them correctly.

Figure 1: Shells of *Xenostrobus securis* (left) and *Mytilus galloprovincialis* (right)

A maximum of 3 trials were needed for the correct classification of both species by all the participants (Table 3).

Table 3: Number of specimen misidentifications in consecutive game rounds, in %

Group	1st Round	2nd Round	3rd Round
El Pez Escorpión	10.8%	2.7%	None
Salinas High School	11.9%	4.8%	None
LL Oviedo	8.3%	2.8%	None
LL Aviles	10%	None	None

Most questionnaires (pre- and post-tests) were successfully completed (see Table 1). The test provided Cronbach α values of 0.95 or higher in the four samples analyzed, being therefore internally consistent for the groups analyzed. The HI was >0.20 for the five items considered.

The knowledge about biological invasions in the region increased after the training sessions in all the groups (Figure 2), with the greatest change in ‘El Pez Escorpión’ and the lowest in the Lifelong learners of Aviles.

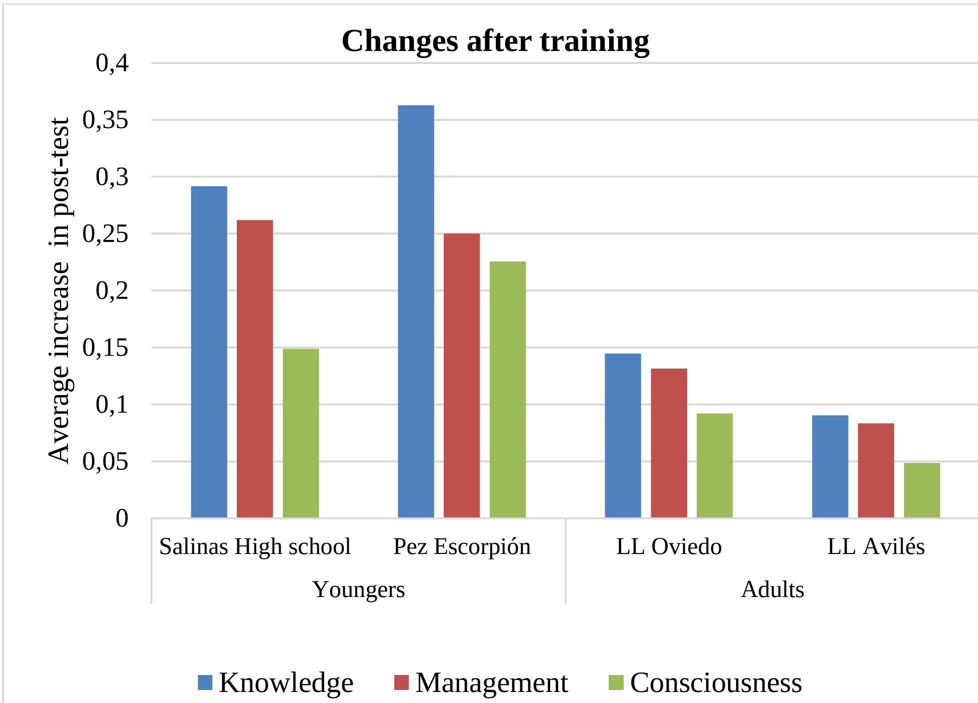

Figure 2: Learning gains between groups

There were significant differences between age groups (Levene’s test for homogeneity of variances with P= 1.098E-29, Welch F=21.9, d.f.=1.872, p=0.048), the youngers increasing more their knowledge than the Lifelong learners. The changes about management actions considered suitable for fighting invasive species were also significantly greater for young students than for Lifelong learners, with F=35.72 and P=0.027 in the ANOVA. On the other hand significant differences were not found when considering age as a factor for consciousness about the danger of biological invasions, sea frequentation and declared intention to volunteering

For the correlation between the different variables considered in this study, three of them were statistically significant (Table 4). The intention to volunteering and the real recruitment for eradication of invasive mussels were highly and positively correlated (r=0.998, d.f.=2, P=0.0016), which is coherent and demonstrates the results of this study are reliable. Significant positive correlations were also found between increase of knowledge about biological invasions and, on one hand, increase of more radical management choices (r=0.958, P=0.041), and on the other hand increase of consciousness about the danger posed by biological invasions (r=0.979, P=0.021).

Table 4. Pairwise correlation between constructs obtained in this activity of environmental education. Pearson’s r-value and P-value of each test are below and above the diagonal, respectively. Significant values are marked in bold.

	Knowledge	Management	Consciousness	Sea frequentation	Volunteering intention	Recruitment
Knowledge		**0.041866**	**0.020697**	0.17466	0.64177	0.60432
Management	**0.95813**		0.11248	0.35226	0.40511	0.36983
Consciousness	**0.9793**	0.88752		0.12877	0.83577	0.79466
Sea frequentation	0.82534	0.64774	0.87123		0.93938	0.96036
Volunteering intention	-0.35823	-0.59489	-0.16423	0.060618		**0.0015747**
Recruitment	-0.39568	-0.63017	-0.20534	0.039643	**0.99843**	

In total 18 participants were effectively recruited for the field activities (see Table 1), which represented 12.5% of the total sample. The final recruitment was different in the four groups, being 0 in the high school and around 19-20% in the other three collectives. By ages, 19.6% and 8.9% adults and youngsters were recruited, respectively.

The eradication of *Xenostrobus securis* from Aviles estuary was described in detail in Miralles et al. (2016). The removed mussels (N=774) were all checked from the researchers and mistakes with native mussels were not found. From water samples, the eDNA tool was consistent in all the cases including the samples obtained after *Xenostrobus securis* eradication and positive PCR amplification was found in all sites where the species was visually detected, and not for the sites where it was not. The posterior visual surveys revealed that only scarce and small individuals recolonized the area one year after the eradication.

4. Discussion and conclusion

The outcomes of this marine citizen science experience revealed that an interdisciplinary game based training is an efficient tool to promote awareness about biopollutant invasive species. The importance of the two-step training program was based on two pillars: to improve knowledge about marine invasive species, since citizens may have limited understanding of marine environment; and to avoid any damage to the native species during field work, because native biodiversity may protect against settlement of exotic species. Playing this specifically developed game based in different morphological characters of the native and the invasive mussels improved species identification on field, likely because they have seen, played and touched the mussels before field actions. The success of the training was plausible since the knowledge about biological invasions increased in all groups and, especially, because volunteers made no species mistakes in the field.

This study also revealed a correlation between knowledge gain during the training activities and environmental conscious attitudes. The participation in a citizen science training program resulted in content learning gains, an increase in skills and an increase in reported intention to engage in environmental activities (Crall et al. 2013). Although the declared intention to volunteer while training and the final recruitment of volunteers was well correlated, the fact is that recruitment is one of the hardest components of any citizen science project (Council and Horvath 2016). Research activities driven by similar approach used to involve mainly retired people and lifelong learners (Hughes et al., 2014). In our case, a greater recruitment (and intention to volunteering) was found in adults than in younger audiences. Actually, children that participate in the training during academic time (in High School) did not engage in volunteering, while children participating in their spare time (Surf School) did. Without belittling their ability to actively participate in citizen science initiatives, it should be noted that safety and liability issues of marine-based data collection could be tough when involving children (e.g. Cigliano et al. 2015).

Finally, the successful of this citizen science program were verified with two independent mechanisms: de visu expert observations and negative results obtained from eDNA. All together they indicated that, if any, the abundance of *Xenostrobus securis* was almost negligible just after eradication, since eDNA monitoring is highly sensitive (Miralles et al. 2016b). Moreover, one year later, the recolonization at different tidal levels in a control area was low, almost null. It means that making once a year an eradication activity with citizen scientists could control the invasion of *Xenostrobus. securis* in Aviles estuary by the same time that raising marine environment awareness. Probably, it could be also possible to apply that approach in other estuaries with similar conditions. In any case, it can be confirmed that in the case study studied here, citizen science is an effective approach to marine and coastal conservation.

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Declaration of competing interest

The authors declare no conflict of interest.

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Figure captions:

Figure 1: Shells of *Xenostrobus securis* (left) and *Mytilus galloprovincialis* (right)

Figure 2: Learning gains between groups