Public knowledge of alien species: a case study on aquatic biodiversity in North Iberian rivers

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ABSTRACT

Biological invasions have increased in recent decades due to globalization and human activities. These invasions are currently one of the main threats to biodiversity, and their early detection is essential for a rapid and effective response. Here, we explored the use of citizen science strategies to create an early alert to detect invasive species. Our main objective was to evaluate the general knowledge of volunteer participants of invasive freshwater species in Asturias (north of the Iberian Peninsula) and compare it with both real data from electrofishing surveys and official data from the regional government. A total of 140 volunteer surveys were conducted in four different rivers in Asturias. The largest group of participants consisted of males older than 50 years. Four species were identified as native to the four rivers: *Anguilla anguilla; Mugil cephalus; Salmo salar*; and, *Salmo trutta*. More than 50% of the native species surveyed by electrofishing were recognized by the locals in each river region. A total of 22.86% of the volunteers were able to correctly name an exotic species, and a total of 7 were correctly identified: *Procambarus clarkii; Trachemys scripta; Cyprinus carpio; Esox lucius; Salvelinus fontinalis; Carassius auratus;* and, *Oncorhynchus mykiss*. However, compared to the list of actual exotic species surveyed, less than 40% were recognized in the four rivers. Despite the poor correlation between local knowledge and real exotic aquatic fauna, citizens were able to detect one exotic species not yet found in the wild in this region (*T. scripta*). Finally, more than 70% of the volunteers were in favor of fighting against invasive species, although only 22.86% were able to identify any specific exotic species found in the region. The positive attitude to exotic species control was correlated with both the level of native species knowledge and the concern about the ability of exotic species to impact native fauna in the region. Better training will improve public awareness, reduce the non-intentional release of non-native species, and increase the detection of non-indigenous species. The attitudes of the citizens make the region a promising candidate for education efforts to reduce alien species introductions and help preserve fauna biodiversity.

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1. Introduction

In the last several decades, the number of non-indigenous species (NIS) has increased due to globalization and human activities (Hulme, 2009). NIS (exotic, alien, non-native species) are species outside their native range that are often introduced by human activities (introduced species). In some cases, these NIS can proliferate, undergo exponential population increases and spread quickly to become invasive species (Occhipinti-Ambrogi & Galil, 2004). Invasive species cause numerous impacts to the community structure and environment (Chown et al., 2015). Eradication of these exotic species may allow for the recovery of the native fauna, but if they become invasive, eradication is nearly impossible; therefore, the main efforts should be performed before establishment. Early detection is essential for rapid response and prevention from further spread (Havel, Kovalenko, Thomaz, Amalfitano, & Kats, 2015).

During the last twenty years, the number of research articles based on citizen science has increased exponentially. There are many projects involving citizen science, including ones about climate change, conservation biology, ecological restoration, water quality, invasive species and many more topics (Silvertown, 2009). Technology has facilitated citizen science programs through new smartphone applications or on the Internet. Such applications can improve communication between scientists and citizens, as daily citizen observations can be easily uploaded online and made accessible to researchers, thereby generating thousands of data records (Newman et al., 2012). In citizen science programs, many volunteers can cover large regions with their observations and help identify migration patterns, the spread of infectious diseases and other ecological phenomena at a large scale (Devictor, Whittaker, & Beltrame, 2010; Dickinson, Zuckerberg, & Bonter, 2010). For example, many citizen science programs are the basis of large bird inventories (Tulloch, Possingham, Joseph, Szabo, & Martin, 2013), such as the eBird program in North America that collects five million bird observations per month (Sullivan et al., 2014). Another example is the study of hosts' natural resistance to virulent forest pests, which was carried out in the USA with the help of citizen science (Ingwell & Preisser, 2011). Citizen science programs have been increasingly used to collect data for monitoring invasive species in real time (Crall et al., 2010; Dickinson et al., 2012), especially for early alerts of new NIS. Citizens can reach locations that may not be accessible to scientists; for example, some areas in South Florida where Burmese pythons (*Python molurus bivittatus*) have been found (Falk, Snow, & Reed, 2016). Mapping crab invasions (*Carcinus maenas* and *Hemigrapsus sanguineus*) along US coasts would not be possible without citizen science (Delaney, Sperling, Adams, & Leung, 2008) due to the large size and extent of the invaded spaces.

Many of the established citizen science programs are aimed at invasive plants. After training, citizen scientists are able to distinguish invasive plants and collect robust data, as has been shown in Texas (Gallo & Waitt, 2011). Other examples include the monitoring of invasive plants in a natural reserve in Georgia, which was carried out by citizens with the help of smartphones and a geo-referencing application (Hawthorne et al., 2015); the Invasive Plant Atlas of New England (IPANE) that was created in 2001 (Bois, Silander, & Mehrhoff, 2011; Crall et al., 2011); the Invasive Plant Atlas of the Mid-South (IPAMS); and the Cactus Moth Detection and Monitoring Network (CMDMN) (Simpson et al., 2009). Plants are not the only species studied; successful programs are also running for the detection of invasive animals, as reported above for serpents and crabs. In Japan, 300,000 bumblebees were removed from the wild within the monitoring program of the invasive *Bombus terrestris* (Kobori et al., 2016). In

North Italy and Switzerland, it was possible to map the stink bug *Halymorpha halys* and develop identification guides to help track this invasive species in other regions (Maistrello, Dioli, Bariselli, Mazzoli, & Giacalone-Forini, 2016). The use of citizen science to detect invasive aquatic species has also increased in recent years. In Alaska, citizen science was employed to control marine invasions, which are a threat to native marine resources (https://seagrant.uaf.edu/research/projects/summary.php?id=939). In Greece, 86 observations of 28 alien species reported in 2012 demonstrated the spread of more than 20 invasive species (Zenetos, Koutsogiannopoulos, Ovalis, & Poursanidis, 2013). Citizen scientists contributed to the detection of the invasive lionfish in the Caribbean Sea (Carballo-Cárdenas & Tobi, 2016). The first report of the sergeant major (*Abudefduf saxatilis*) in the Mediterranean Sea was collected through citizen science on the "Seawatchers" webpage (http://www.observadoresdelmar.es), where volunteers collect data and inform scientists about new invasive species (Azzurro, Broglio, Maynou, & Bariche, 2013).

Evaluating public knowledge of the specific taxa to be monitored is recommended before creating a citizen science program about NIS. García-Llorente, Martín-López, González, Alcorlo and Montes (2008) studied how different groups (tourists, conservation professionals, local users and others) perceived the impact caused by IAS (invasive alien species) in the Natural Reserve of Doñana (Southwest Spain) and their attitudes towards IAS eradication. As many as 97% of the people in all groups agreed that IAS eradication was necessary, but they were principally concerned with the recent invasions and the species that had been objects of particular campaigns and appeared in the news. The authors concluded that the general knowledge of citizens is crucial to generating public demand for actions against invasive species, and they emphasized the low concordance found between official data, real data and citizen perceptions.

The main objective of this study was to evaluate the public's knowledge about freshwater NIS in Asturias (north of the Iberian Peninsula) through a survey on species reports, and the survey results were compared with actual local fauna and official data from the regional and national environmental authorities. The results served to identify knowledge gaps that could be used to focus training efforts in future citizen science programs on aquatic biodiversity inventories.

2. Materials and Methods

2.1. Sampling sites and river biota

During 2016, four different rivers in Asturias (south-central Bay of Biscay) were selected for social and biodiversity surveys: Raíces; Piles; Negro; and, Nalón (Figure 1). Three of the rivers are short coastal streams (the Negro, Piles and Raíces rivers are 20, 16 and 15 km in length, respectively), and the Nalón River (140 km long) originates from the Nalón-Narcea basin, which is the largest freshwater system in the region. Sampling sites were set within river towns at the following coordinates: Luarca (43.544240N, 6.535308W) on the Negro River; Salinas (43.566852N, 5.962669W) on the Raíces River; Gijón (43.537846N, 5.639280W) on the Piles River; Las Caldas (43.330988N, 5.930960W) and, Rioseco (43.218977N, 5.454763W) on the Nalón River.

The most recent official inventory of the native fauna and NIS of the regional rivers was published by De la Hoz (2006).

2.2. Social survey

A total of 140 local participants were interviewed across the study region, including males and females older than 20 years. The samples represented 0.05% of the population inhabiting the study areas. Potential interviewees were approached along recreational promenades near the rivers, and eligible and willing participants were interviewed in Spanish, their native language. Interview sessions were no longer than 5 minutes per person to facilitate easy and spontaneous responses.

The questionnaire was inspired by García-Llorente et al. (2008). The interview was formulated as a conversation to help the volunteers feel more comfortable and answer without any pressure. The survey was divided into two sections (Supplementary file 1), as follows:

1) General knowledge of aquatic species in the region, where the volunteers listed the species they remembered from the local river by their common names and classified them as native or exotic using their knowledge. The translation from common name to scientific name for each species was performed by the researchers. There was no possibility of error since the common names are unique for each species in this region, and there are no local variants in different valleys;
2) Awareness and concerns about exotic species, which contained four questions (Supplementary file 1). A final open question about the perceived changes in the river ecosystem, if any, was posed.

Pictures of animals inhabiting Iberian rivers were available if needed for recognition of a species but were not offered beforehand. The survey was previously tested in a pilot sample (N=10) to refine the questions and ensure the content was clear and easy to understood.

The word "invasive" was avoided in the interview because it has a negative connotation, so the answers from the participants were not influenced. If needed to clarify a participant's understanding, exotic species were defined as "species that are not native to this place".

The participant's answers were recorded in writing. After finishing the interview, the participants were asked to check their answers and confirm they were correctly recorded.

2.3. Ethics statement

All volunteers agreed to participate in the study and signed the informed consent for the use of their answers in research. The study was approved by the Ethics Committee from the Principality of Asturias with the permit of reference number 99/16.

2.4. Electrofishing surveys

The actual local aquatic fauna occurring in the four rivers considered was surveyed in March 2017. The standard protocol approved by the Spanish Ministry of Agriculture, Fisheries and Environment for implementing the EU Water Framework Directive 2000/60/CE was employed. This protocol, ML-R-FI-2015 (NIPO: 280-15-122-6), is based on electrofishing. The survey was carried out by Taxus S.L., a company authorized for aquatic biodiversity surveys in the Principality of Asturias. Due to the different river sizes, electrofishing was carried out from one sampling site in each of the three small rivers and six sampling sites along the Nalón River.

2.5. Data analysis

Participants were grouped by river (Nalón, Negro, Piles and Raíces), age (older or younger than 50 years) and gender. Some participants provided additional information about terrestrial species, but answers about only aquatic species were considered.

Knowledge was measured as the concordance between a participant's answer and the official list of native and exotic species in Asturias, which is available in De la Hoz (2006). Four measurements were obtained: the number of native species correctly identified (correct natives, C_N); the number of exotic species correctly identified (correct exotics, C_E); the number of exotic or absent species mistaken as native (incorrect natives, I_N); and, the number of native or absent species mistaken as exotics (incorrect exotics, I_E).

A knowledge index (Ki) was calculated as the mathematically averaged knowledge (scored as correct – incorrect species) of native and exotic species, using the following formula:

$$K_i = \frac{(C_N - I_N) + (C_E - I_E)}{2}$$

In the second section of the survey, the scores were 0 (I don't know), 1 (No), and 3 (Yes) for the questions with three answer choices; and 0 (I don't know), 1 (No), 2 (Sometimes, depending on the species), and 3 (Yes) for the questions with four answer choices. In question C (changes in the ecosystem), the answers were classified into four large groups: "Water quality", including changes in water quality (cleaner or more polluted water, more or less algae, increase of floods, more sediments, lower water flow…); "Fauna", including changes in aquatic fauna (for example, reduced trout spawning, changes in species abundance such as an increase of *Mugil cephalus* and a decrease of *Salmo trutta*); "Infrastructure", including new ponds, dams and promenades; "Environment", including cleaner or dirtier surrounding environment and changes in riverbank vegetation and excluding changes in the water considered in the above category.

2.6. Statistical analysis

The data were analyzed with the program Past 3.15 (Hammer, Harper, & Ryan, 2001). Normality was checked using Shapiro-Wilk W and Anderson-Darling A tests. Comparisons among groups (rivers, ages or gender) were conducted using ANOVA or Kruskal-Wallis to test for differences among the means or medians of the groups, respectively (the latter in case of significant deviation from normality). Pairwise correlations (between questions, or between knowledge and perception/opinion) were calculated using Spearman's rs. Statistical significance was set at $p<0.05$. Bonferroni correction of the significance level was applied for multiple comparisons.

3. Results

In total, 58 women (41.43%) and 82 men (58.57%) participated in the survey (Table 1). The largest age group (34.29% of the total sample) was older than 60 years.

The native species identified by participants were the European freshwater crayfish ("cangrejo de río" in Spanish) *Austropotamobius pallipes*, the European eel ("anguila") *Anguilla anguilla,* the sea lamprey ("lamprea") *Petromyzon marinus,* the European sea bass *Dicentrarchus labrax* ("lubina"), the flathead gray mullet *Mugil cephalus* ("muil", an Asturias linguistic variant, or "mújol" in standard Spanish), the Atlantic salmon *Salmo salar* ("salmón"), the brown trout *Salmo trutta* ("trucha") and the gilthead sea bream *Sparus aurata* ("dorada") (Supplementary file 2). More than 23 participants in each river recognized *S. trutta* as a native species. Several exotic species introduced from other Spanish regions were considered to be native by some participants: the cyprinid ("madrilla") *Parachondrostoma miegii*; the minnow ("piscardo") *Phoxinus* spp.; the Iberian barbel ("barbo") *Luciobarbus bocagei*; and, the Iberian chub ("cacho") *Squalius carolitertii*. Only one person interviewed in the Raíces River region reported a native species to be an exotic species (*Anguilla anguilla*) (Table S1).

A total of 32 participants (22.86% of the total) correctly identified at least one exotic species. Seven exotic species were identified: the American crayfish ("cangrejo americano") *Procambarus clarkii;* the pond slider ("tortuga de Florida") *Trachemys scripta;* the common carp ("carpa") *Cyprinus carpio;* the northern pike ("lucio") *Esox lucius*; the goldfish ("carpín") *Carassius auratus*; the brook trout ("salvelino") *Salvelinus fontinalis;* and, the rainbow trout ("trucha arco iris") *Oncorhynchus mykiss* (Table S1). *P. clarkii* was reported as an exotic species by 10, 2, 2 and 3 participants from the Piles, Nalón, Negro and Raíces river regions, respectively. In contrast, C. *carpio* was more frequently reported as an exotic species in the Nalón River (8 participants) than in the Negro River (1 participant) and the other two rivers (no participants).

A few participants (1 in Nalón, 1 in Negro and 3 in Piles) considered the Asian carp *C. carpio* as a native species, and two participants (1 in Nalón and 1 in Piles) regarded the American rainbow trout *O. mykiss* as being native (Table S1). The most frequently reported NIS was *P. clarkii*, which was cited in the four rivers by a total of 17 citizens, followed by *C. carpio* (14 participants in three rivers) and *T. scripta* (6 participants in two rivers). These three species were also the most cited in recent media releases (Table S2).

Significant differences in the knowledge about river species were not found between genders and age groups (data not shown) with the exception of the number of incorrect exotics (I_E). The mistakes about exotic species (I_E) were significantly different between age groups (Kruskal-Wallis Hc=3.97; 3 degrees of freedom (df); P=0.046), and there were clearly fewer mistakes by younger participants (I_E=0±0) than by older participants (I_E=0.06±0.24). The rest of the data were pooled and organized by river. Knowledge on native species (C_N) was significantly different among rivers (Kruskal-Wallis Hc=41.87; 3 df; P=4.27x10^{-9}) (Table 2), and the knowledge levels were clearly lower in the Raíces River region (C_N=0.86±0.60) than in the rest of the regions (Figure 2). The knowledge of exotic species (C_E) was significantly lower (Kruskal-Wallis Hc=14.13; 3 df; P=0.003) in Negro and Raíces than in the Nalón and Piles river regions (Figure 2). Mistakes about exotic and native species (I_E and I_N, respectively) were generally lower than those about correct species assigned to these categories, and significant differences among rivers were not found (Kruskal-Wallis of Hc=0.62; 3 df; P=0.892 and Hc=4.07; 3 df; P=0.254, respectively). The knowledge index, Ki, was significantly different among river regions (Kruskal-Wallis of Hc=32.97; 3 df; P=3.27x10^{-7}), and the Ki was lower in the Raíces River region than in the other river regions accordingly (Figure 2), as fewer native species were reported from the Raíces

River. Significant differences between genders were not found for any question regarding perception/opinion about NIS (data not shown). The two-way ANOVA that considered age and river as factors revealed significant differences between ages and among rivers for Question A, which was about the potential of NIS to adapt in the rivers of the region (F=4.33 with P=0.039 for age; F= 2.86 with P=0.039 for river; F= 0.317 with P=0.813 for interaction).

Participants in the Nalón area and younger participants perceived, on average, a higher capacity for the adaptation of NIS than other participant groups (Figure 3). For Question D (demanding NIS eradication from Asturias rivers), highly significant differences among rivers were found (F=0.034 with P=0.853 for age; F=8.922 with $P=2x10^{-5}$ for rivers; F=0.287 with P=0.835 for interaction). Participants interviewed in the Raíces River region were less supportive of the eradication of exotic species than those interviewed in other river regions (Figure 3). For the other two questions on how much exotics affect native species (Question B) and how intense the changes perceived in the river ecosystem are (Question C), significant differences were not found among rivers nor between ages (data not shown).

Table 3 presents pairwise Spearman's rs correlations in the dataset. The knowledge index, Ki, was positively correlated with the knowledge about native and exotic species (Table 3), as expected. Interestingly, after Bonferroni correction, the knowledge index was positively correlated with the demand for the control actions against exotic species, Question D ($P=3.21x10^{-4}$). The number of correctly identified native species (C_N) was also positively correlated with Question D (control of exotic species) ($P=3.08x10^{-5}$). The number of correctly identified exotic species (C_E) was consistently positively correlated with the perception of the adaptation ability of the exotic species, which was Question A ($P= 2.55x10^{-3}$). As also expected, Question B (opinion on how harmful NIS are to native species) was highly positively correlated with Question D, which was the demand for NIS control ($P= 5.71x10^{-8}$). The main changes detected in the ecosystem by participants (Figure 4) were changes in the river environment (59 participants). More participants from the Nalón River region (12) than from the other zones detected changes in water quality; 7 of them reported improved water quality. For river fauna, in the Negro River region, 11 participants noticed a decrease in the *S. trutta* population in the region. In the river environment category, more citizens in the Piles River region detected changes in the ecosystem, while in the river infrastructure category, many Raíces River participants (11) reported a new promenade near the riverbank.

Regarding the value of public knowledge used for early alerts of exotic species in river systems, in this case study, *Acipenser sturio*, *Esox lucius* and *Luciobarbus bocagei* were listed by different participants as occurring in the region although they have not yet been found in biodiversity surveys in Asturias rivers (Ministerio de Medio Ambiente 2007). On the other hand, the electrofishing survey detected the pond slider *Trachemys scripta* (Table S1) in the river where the participants reported it. The species is cataloged in the official list of exotic species, but until now it has been reported from only isolated artificial ponds in Gijón and La Granda (Pleguezuelos 2002). Thus, this is the first time the exotic pond slider was found in the wild in this region.

From the electrofishing survey, a total of 8 NIS were found in the region: *Chondrostoma duriense; Cobitis paludica; Gobio lozanoi*, *Phoxinus* spp.*; Squalius carolitertii; Carassius auratus; Procambarus clarkii;* and, *Trachemys scripta*. Seven native species were sampled: *Anguilla anguilla; Chelon labrosus; Dicentrarchus labrax; Mugil cephalus; Petromyzon marinus; Platichtys flesus;* and, *Salmo trutta* (Table S1). The brown trout *Salmo trutta* was the only species found in all four rivers.

The Nalón River contained more NIS (five species), and the Raíces River exhibited the highest proportion of NIS (three NIS out of a total of four species, 75%) (Table 4).

Comparing the aquatic fauna found from the electrofishing survey with the knowledge of the local citizens (Table 4) revealed that the percentage of native species recognized by locals in the four river regions was higher than the percentage of NIS. In the Negro River region, where no NIS and only two native species were found from electrofishing (Table 1S), participants recognized all species surveyed. In the Piles River region, citizens were able to recognize 80% of the surveyed native species. In the Raíces River region, participants recognized the native species but only one of three exotic species. In the Nalón River region, citizens recognized 50% of the native species sampled from the river (the same percentage of the official records).

4. Discussion

This case study illustrates the importance of considering the knowledge of citizens and their opinions on treating biodiversity issues. Despite the relatively limited knowledge about NIS, citizens were generally aware of their potential risks. Although only 22.9% of the participants correctly recognized any NIS, as many as 73.6% were of the opinion it is necessary to act against exotic species, and 67.9% believed that NIS could affect native species. Accordingly, there was a positive attitude towards the eradication of the NIS that affect native aquatic fauna. The results were similar to those found in Scotland where 87% of the respondents supported the control and eradication of invasive species (Bremner & Park, 2007).

In our particular case, the correspondence between real data, government reports and citizen data was not accurate in relation to NIS; but, citizens recognized more than 50% of the native species surveyed by electrofishing in each river (Table 4), and they were able to detect one exotic species in running waters in the wild, *Trachemys scripta,* which was previously believed to only occur in artificial ponds (Pleguezuelos 2002) (Table S1). The occurrence of species in the Raíces River was confirmed by electrofishing in our study. This is a case where citizens reported a NIS that was overlooked in official reports, and, as emphasized by many other authors working with invasive species (Gallo & Waitt, 2011; Zenetos et al., 2013; Hawthorne et al., 2015; Kobori et al., 2016; Maistrello et al., 2016), this result reinforces the importance of counting on citizen scientists.

The local knowledge about native species was much greater than that about NIS. More than 80% of the participants listed brown trout as a native species. Brown trout is actually the dominant freshwater species in the region (e.g., Lobón-Cerviá, 2009) and was the only species found from all four rivers considered in this study (Table S1). Interestingly, such knowledge about the native fauna was highly and positively correlated with the demand for NIS eradication (Table 3). Positive correlations between local knowledge and awareness about biodiversity have been found by other authors in Scotland, Chile and the Pyrenees (Bremner & Park, 2007; Loyau & Schmeller, 2017; Zorondo-Rodríguez, Reyes-García, & Simonetti, 2014), and the results of this study are along the same lines.

In the Raíces River region, the knowledge of the native and exotic species was significantly lower than in the rest of river regions, as was the support of actions against NIS. This could be explained by the lower quality environmental conditions in this river. The Raíces River is a small narrow coastal stream (<2 meters wide), with very reduced water flow. The local people may believe that there is not aquatic fauna in the river and conservation efforts are not worthy there. The electrofishing survey revealed a population of the native species *S. trutta*. It also revealed that the Raíces River is invaded by NIS, since 75% of the species surveyed were exotics, including *Phoxinus* spp., *P. clarkii* and *T. scripta*.

Better environmental education will improve the public awareness of NIS and reduce the intentional release of some aquatic species (Zenetos et al., 2013). For instance, *Carassius auratus*, which was found in Gijón, can be purchased in any pet shop and is likely one of the cases of releases from pet owners (Elvira & Almodóvar, 2001; Maceda-Veiga, Domínguez-Domínguez, Escribano-Alacid, & Lyons, 2016), as reported in the Pacific Northwest (Strecker, Campbell, & Olden, 2011), Iberian Peninsula (Maceda-Veiga, Escribano-Alacid, de Sostoa, & García-Berthou, 2013), and Czech Republic (Lusková, Lusk, Halačka, & Vetešník, 2010). The importance of good environmental education is undeniable. Jordan, Gray, Howe, Brooks, and Ehrenfeld (2011) showed a substantial change in behavior regarding invasive plants after citizens acquired new knowledge about them. Environmental education would reduce the misclassification of species and likely increase the reports of non-native species. In our study, the species officially cataloged as exotics in Spain were considered NIS by the participants, except for two fishes that were misidentified as native species by some respondents: *Cyprinus carpio;* and, *Oncorhynchus mykiss*. These species are old introductions since *C. carpio* was introduced to Spain in the 17th century (Elvira & Almodóvar, 2001) and *O. mykiss* has been farmed in the region for more than 50 years (Stanković, Crivelli, Snoj, Stankovi, & Snoj, 2015). People tend to be more aware of recent introductions (García-Llorente et al., 2008). The most cited exotic in our study was the American crayfish *P. clarkii,* which was identified in all four river regions. In Gijón (Piles River), 10 participants out of the 35 identified *P. clarkii* as an invasive species, compared with two participants in the Nalón and Negro river regions and three in the Raíces River region. This is consistent with the higher awareness about recent introductions (García-Llorente et al., 2008) because this species was found in an artificial pond in downtown Gijón in June 2016, and the discovery was highly publicized in the local newspapers (Table S2).

Although few people recognized any alien species in this study, 77.9% of the participants were able to notice changes in the river ecosystem. Increasing the local knowledge could help control non-native species. In general, citizen science programs are cheaper and more affordable than research programs where scientists obtain the data (Delaney et al., 2008). In our case, the cost would make the monitoring of the rivers and the aquatic fauna at every moment throughout the region impossible without the help of citizen science. As an example, in the Netherlands, Nunes and Van den Bergh (2004) calculated that the benefits of a marine protection program far exceeded the costs with the help of citizen science. Therefore, citizen science programs will help make research cheaper and profitable, especially in this era when mobile phones and applications are continuously renewed throughout the world (Newman et al., 2012). A strategy to develop better responses to invasive species is publicly sharing the information collected (Simpson et al., 2009), as is the case for the open-source atlas of invasive plants of New England created in 2001, which offers presence/absence data and contributes to many studies (Bois et al., 2011). However, it is necessary to create good cyber infrastructure to manage the vast amounts of data from the citizen science programs (Dickinson et al., 2012; Kobori et al., 2016).

On the other hand, molecular methods, such as environmental DNA (eDNA), have been recently developed for the early detection of exotic species (Clusa et al., 2016; Ficetola, Miaud, Pompanon, & Taberlet, 2008; Thomsen & Willerslev, 2015). Together, eDNA and citizen science could be a promising tool to monitor and avoid the spread of non-native species. For example, researchers trained 20 volunteers to differentiate between the invasive pygmy mussel (*Xenostrobus securis*) and native mussels in Asturias. In one day, volunteers were able to clean the affected area. The eDNA tool made it possible to monitor the population in the region after the cleaning, and the results demonstrated the success of the eradication process (Miralles, Dopico, Devlo-Delva, & Garcia-Vazquez, 2016). Also, in the United Kingdom, the use of volunteers to collect eDNA samples across the country helped to monitor the status of the crested newt (*Triturus cristatus*) (Biggs et al., 2015).

Finally, efforts should focus on explaining the problems caused by NIS to the local population and collaborating with the media to quickly divulge this knowledge to the citizens, both of which could help detect new alien species that may come to the region. Sharing research results with managers will help provide a better understanding of the real fauna and the potential invaders, allowing for the design of better management programs. In addition, the involvement of the general public through citizen science, perhaps coupled with eDNA surveys, would be very helpful to prevent the future spread of present and upcoming NIS in the region.

5. Conclusion

In this work, we detected how local citizens could be the first to detect significant changes in the ecological environment of rivers and the introduction of any exotic species. Early alert networks will contribute to transferring knowledge of any changes detected to researchers and authorities for a rapid response. There is evidence that action by citizens at an ecosystem level could keep the presence of non-native species under control. For this reason, developing citizen science programs will increase public interest in NIS intervention and may keep citizens in contact with scientific knowledge. With better education about NIS, intentional releases may decrease, and people will be more vigilant about their environment. Moreover, taking advantage of their enthusiasm and motivation to participate in scientific research is also a strong incentive to share scientific knowledge. In the case of Asturias, the local knowledge about non-indigenous species is not accurate; but, the attitude towards these species makes the region a promising candidate for focused education efforts to help preserve the fauna biodiversity and protect against exotic species.

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7. Data Accessibility

- Questionnaire is available in "Supplementary material_1".
- Data obtained from the 140 surveys are available in "Supplementary material_2".

- List of aquatic species and their status in Asturias together with the results from the official inventory, electrofishing results and social survey in the 4 rivers are available in "Supplementary material_3_Table S1"
- Compilation of data from official inventory, electrofishing results, social survey and releases in public media regarding non indigenous species is available in "Supplementary material_4_Table S2".
- All the supplementary material is available in the online repository figshare: https://figshare.com/s/cb7524b36edc574de412 doi: 10.6084/m9.figshare.5357671

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9. Tables

Table 1. **Sample for social survey**. Number of citizens classified by gender and age in each river is shown.

	Nalón		**Negro**		**Piles**		**Raíces**		
	Men	**Women**	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**	**Total by age**
20-30	0	2	0	0	3	2	0	2	9
30-40	5	5	2	2	1	2	3	3	23
40-50	6	3	4	2	2	4	3	5	29
50-60	5	1	4	4	5	3	6	3	31
>60	8	0	11	6	7	6	7	3	48
Total by river	35		35		35		35		140

Table 2. **Kruskal-Wallis tests of the results analyzed by basin, age or gender.** Results are based on averages across the different sample groups. Significant *P* values for differences among or between sample medians are in bold. C_N and C_E are correct native and correct exotic species identified. I_N and I_E are incorrect native and incorrect exotic species identified.

	C_N	I_N	C_E	I_E	Knowledge index (Ki)	A- Exotic adaptation	B- Harm to natives	C- Ecosystem changes	D-Exotics's removal
Basin	**<0.001**	0.254	**0.003**	0.892	**<0.001**	**0.041**	0.238	0.061	**<0.001**
Age (<50 and >50)	0.625	0.942	0.262	**0.046**	0.660	**0.041**	0.557	0.308	0.784
Gender	0.490	0.283	0.297	0.947	0.385	0.310	0.269	0.634	0.780

Table 3. **Spearman's rs correlation results of the 140 surveys**. The rs and p values are below and above the diagonal, respectively. Significant correlations (after Bonferroni correction) are indicated in bold and significant p-values are highlighted in grey. C_N and C_E are correct native and correct exotic species identified. I_N and I_E are incorrect native and incorrect exotic species identified. Ki = knowledge index. A-Exotic adaptation is the answer to the ability of exotic species to adapt in Asturian rivers; B- harm to natives is the answer to the ability of exotic species to affect native fauna; C- Ecosystem changes is the answer to detection of changes in the ecosystem by the citizens and D- Exotic's removal is the answer to the necessity of taking action against exotic species.

	C_N	I_N	C_E	I_E	A- Exotic adaptation	B- Harm to natives	C- Ecosystem changes	D- Exotics's removal	Knowledge index (Ki)
C_N		0.439	0.150	0.143	0.466	0.083	0.032	$3.08x10^{-5}$	$1.42x10^{-37}$
I_N	0.066		0.012	0.452	0.468	0.116	0.442	0.084	0.023
C_E	0.122	0.213		0.391	$2.55x10^{-3}$	0.149	0.343	0.212	$2.14x10^{-8}$
I_E	0.125	-0.064	0.073		0.223	0.675	0.228	0.724	0.857
A- Exotic adaptation	-0.062	-0.062	**0.253**	0.104		0.022	0.715	0.021	0.347
B- Harm to natives	0.147	0.134	0.123	0.036	0.193		0.959	$5.71x10^{-8}$	0.087
C- Ecosystem changes	0.182	0.065	0.081	0.103	0.031	0.004		0.243	0.135
D- Exotics's removal	**0.344**	0.146	0.106	0.030	0.194	**0.439**	0.099		$3.21x10^{-4}$
Knowledge index (Ki)	**0.835**	-0.192	**0.452**	-0.015	0.080	0.145	0.127	**0.300**	

Table 4. **Comparison between real aquatic fauna, official records and local citizens' data**. Two results are considered per river, the number of correct species (native, exotic and total species) listed by volunteers over the total number of species in the region based on official records (over region), and the number of correct species listed by volunteers over the number of species found in the electrofishing survey (over survey). In parenthesis percentage of species recognized by locals over region and over survey is shown.

		Nalón			**Negro**			**Piles**			**Raíces**		
		Electrofishing Survey	Recognized by locals		Electrofishing Survey	Recognized by locals		Electrofishing Survey	Recognized by locals		Electrofishing Survey	Recognized by locals	
	Region (N)		Over region	Over survey		Over region	Over survey		Over region	Over survey		Over region	Over survey
Native	12	4	6 (50%)	2 (50%)	2	5 (41.7%)	2 (100%)	5	6 (50%)	4 (80%)	1	4 (33.3%)	1 (100%)
Exotic	16	5	6 (37.5%)	2 (40%)	0	6 (37.5%)	0 (0%)	2	4 (25%)	0 (0%)	3	2 (12.5%)	1 (33.3%)
Total	28	9	12 (42.9%)	4 (44.4%)	2	11 (39.3%)	2 (100%)	7	10 (35.7%)	4 (57.1%)	4	6 (21.4%)	2 (50%)

10. Figures

Figure 1. **Map showing the sampling sites of the four rivers**: Nalón, Negro, Piles and Raíces

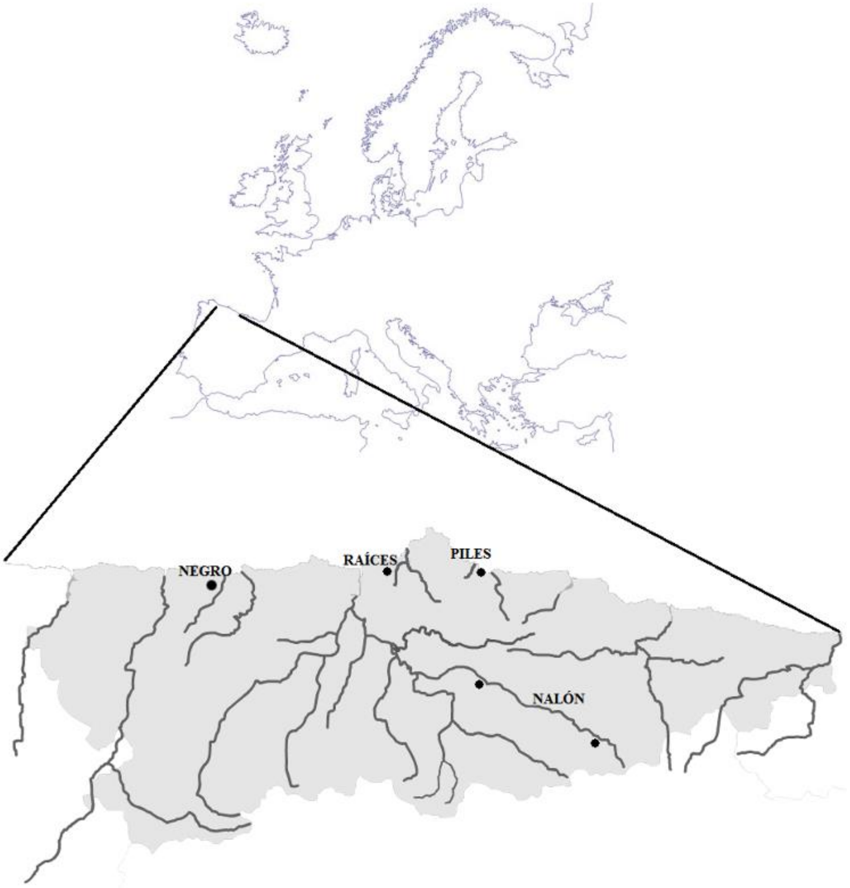

Figure 2. **Mean and standard deviation of public knowledge per basin**. Correct natives (C_N), incorrect natives (I_N), correct exotics (C_E), incorrect exotics (I_E) and knowledge index (K_i) are shown.

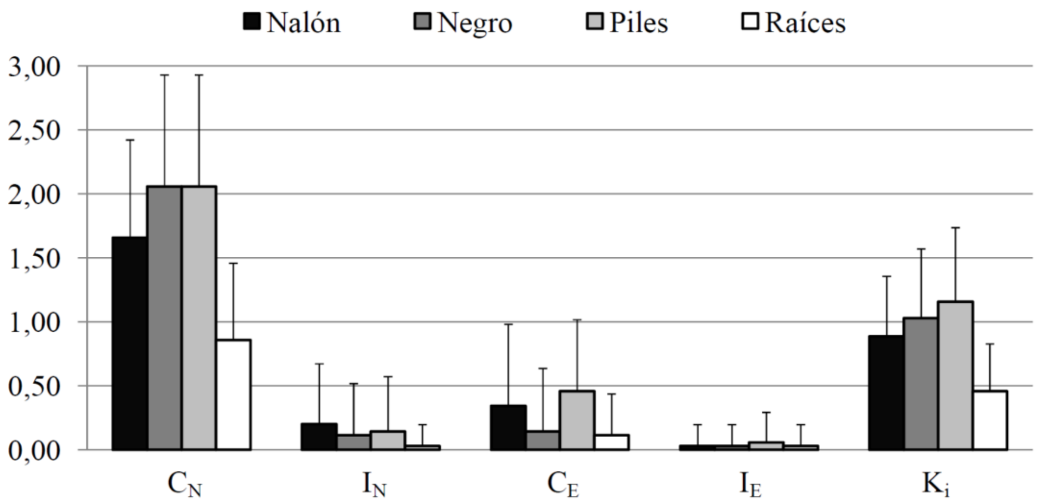

Figure 3. **Mean and standard deviation of perception issues about exotic species per basin and age**. A-"Exotic adaptation" is the answer to the ability of exotic species to adapt in Asturian rivers; B- "harm to natives" is the answer to the ability of exotic species to affect native fauna; C- "Ecosystem changes" is the answer to detection of changes in the ecosystem by the citizens and D- "Exotic's removal" is the answer to the necessity of taking action against exotic species.

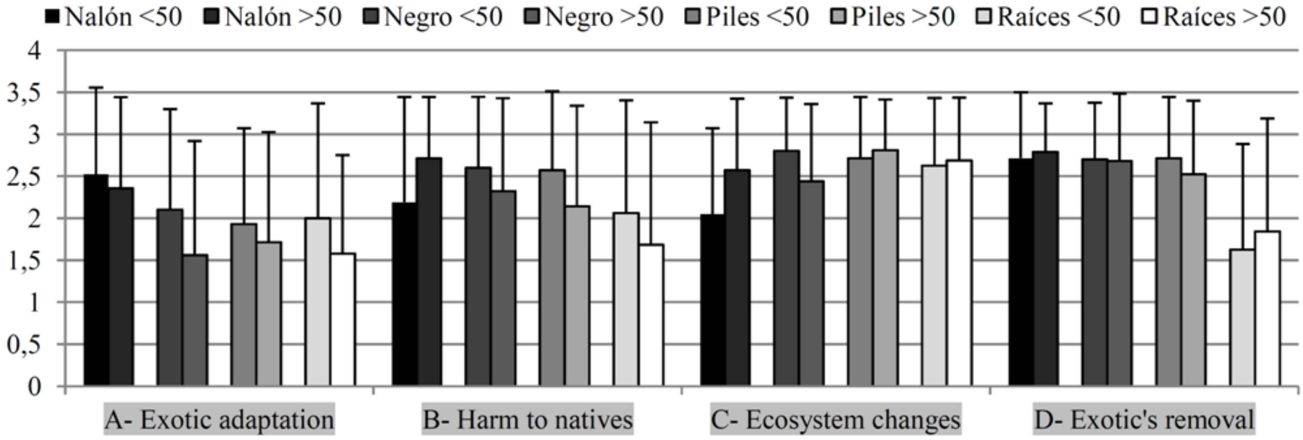

Figure 4. **Changes in the environment reported by the citizens in the four rivers surveyed**. Four groups of changes were considered: changes water quality (including water flow, algae, or sediments), changes regarding river fauna (less *S. trutta*, more *Mugil cephalus*); infrastructure (new ponds, dams, promenade); and environment (cleaner environment, more pollution, more vegetation). Number of citizens in each place expressing each kind of change is shown.