NeoBiota 84: 211–229 (2023)
doi: 10.3897/neobiota.84.95177
https://neobiota.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

Citizen science at school increases awareness of biological invasions and contributes to the detection of exotic ambrosia beetles

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Academic editor: C. Orazio | Received 21 September 2022 | Accepted 6 March 2023 | Published 18 May 2023

Citation: Colombari F, Battisti A (2023) Citizen science at school increases awareness of biological invasions and contributes to the detection of exotic ambrosia beetles. In: Jactel H, Orazio C, Robinet C, Douma JC, Santini A, Battisti A, Branco M, Seehausen L, Kenis M (Eds) Conceptual and technical innovations to better manage invasions of alien pests and pathogens in forests. NeoBiota 84: 211–229. https://doi.org/10.3897/neobiota.84.95177

Abstract

The serious and growing threat posed by biological invasions to biodiversity and livelihoods means that public engagement in dealing with problems of invasive alien species is ever more urgent and necessary hence a citizen science experiment was carried out in north-eastern Italy. The study aimed *i*) to raise awareness of invasive alien species threatening trees and forests, and *ii*) to perform monitoring activities of a group of wood borers as an example, involving teachers and students (aged 11 to 18) of high schools. Students and teachers were given background knowledge and trained about the protocol for collecting data in schoolyards/grounds. Native (*Anisandrus dispar* (Fabricius, 1792), *Xyleborinus saxesenii* (Ratzeburg, 1837)) and exotic ambrosia beetles (*Anisandrus maiche* Kurentsov, *Cnestus mutilatus* (Blandford), *Xylosandrus crassiusculus* (Motschulsky, 1866), *Xylosandrus germanus* (Blandford, 1894)) were used as the target species, as they could be easily detected through accessible and low-cost traps requiring limited effort. The traps were exposed for 24 hours weekly between March and June 2021. The experiment also aimed to strengthen public involvement, connecting environmental education and experiential outdoor learning. The mutual collaboration resulted in a wider knowledge of the potential impact of exotic species. It also led to new geographical citizen-science records of two alien ambrosia beetles considered to be quarantine pests by the European Union: *C. mutilatus*, new for the European part of the EPPO (European and Mediterranean Plant Protection Organization) region, and *A. maiche*, which was previously found only in Eastern European EPPO member countries.

Keywords
Anisandrus maiche, *Cnestus mutilatus*, environmental education, first record, invasive alien species, knowledge, students, surveillance

Introduction

Humans have traded and transported alien species for decades, intentionally or unintentionally, but, over the last 50 years, the rates of Invasive Alien Species' (IAS) introductions have significantly grown and currently do not show, at a global scale, any sign of saturation (Hulme 2009). Instead, the trend is increasing, especially for insect species mainly introduced accidentally as stowaways or contaminants (Hulme et al. 2008; Seebens et al. 2017; Kenis et al. 2019; Turbelin et al. 2022). The introduction of IAS as contaminants may be predicted from their pathways, e.g., by plants, fruits, or wood (Kenis et al. 2007; Hulme et al. 2008; Pergl et al. 2020). Or stowaways can arrive independently of a specific commodity, as hitchhikers on ships, in containers, vehicles (car, train, airplane), packing material, and in the luggage of tourists (Hulme et al. 2008; Pergl et al. 2020; Turbelin et al. 2022). Identifying and managing the pathways through which IAS arrive and spread is an important component of any strategy aimed at reducing the threat of biological invasions but difficult to carry out (Roques 2015; Seebens et al. 2017; Pergl et al. 2020; Turbelin et al. 2022). Consequently, given sets of gaps that regulations cannot cover, the direct involvement of the wider public in the surveillance and management of IAS is crucial (Hulme et al. 2008; Faulkner et al. 2020; Turbelin et al. 2022).

Citizen science, which Pocock et al. (2019) defined as "the involvement of people in the scientific process, including participating in environmental recording and monitoring", represents an opportunity to raise awareness of common problems of biological invasions and to expand better monitoring efforts conducted by researchers and phytosanitary personnel in detecting IAS (Sagy et al. 2019). IAS exemplify an excellent case of citizen science application as they threaten the environment and society (García-Llorente et al. 2008; Novoa et al. 2017). Increasing the public's perception of IAS is essential (Jubase et al. 2021) and it has been shown that after educational and informative efforts the public was much more aware of IAS (García-Llorente et al. 2008). Actions aimed at increasing public knowledge and awareness, such as workshops, training programs, or media involvement, must be supported in policy decisions and by funding (García-Llorente et al. 2008; Novoa et al. 2017).

In particular, educating and training school students in IAS has become a commonly recognised innovative and holistic approach because students bring home the message and share it with relatives, in this way supporting intergenerational learning (Verbrugge et al. 2021). Among IAS affecting trees and forests, bark and ambrosia beetles (Coleoptera Curculionidae Scolytinae) represent an important group and have already been used in a citizen science initiative, called 'Backyard Bark Beetles' (Steininger et al. 2015). The purposes of our study were to implement a large-scale surveillance and increase high school students' awareness about two recently reported ambrosia beetle species (*Anisandrus maiche* Kurentsov, 1941 and *Cnestus mutilatus* (Blandford, 1894)). This paper aims to disseminate how environmental education can strengthen public engagement and contribute to IAS detection.

Materials and methods

Study organisms

Ambrosia beetles were used as target species in this project, as they can be easily detected through accessible traps activated with a freely available attractant and following a simple trapping protocol. Moreover, the phenology of species allowed their monitoring during an ideal season for outdoor activities compatible with school time. Ambrosia beetles include thousands of species worldwide and are currently one of the main issues of phytosanitary measures and controls. The specimens are usually identified using morphological features and diagnostic keys, as in the current study (Rabaglia et al. 2009; Gomez et al. 2018; Smith et al. 2020), although DNA barcoding is generally required to confirm the taxonomic identity of new records and/or cryptic species. For these purposes, DNA barcoding using primers LCO- 1490/HCO- 2198 as in Folmer et al. (1994) was used, whenever necessary, by comparing the sequences obtained with those already available for the target species.

Study area

The monitoring sites made available by participants (see Increase public awareness on IAS) numbered 15 in total, all located in the Veneto Region (NE part of Italy; Fig. 1). All the schools were in urban areas in temperate and warm-temperate climate, with mainly various species of broadleaf trees and shrubs, both native and exotic, and a lower percentage of conifers in their immediate surroundings. Landscape composition around schools (i.e., the percentages of the different land-cover classes) was highly heterogeneous with values spread out over a wide range (Table 1). The categories "areas devoid of vegetation" and "agricultural areas' were dominant, while "green urban areas" and "forest and semi-natural areas" occupied only a small percentage of the buffers despite a slight increase of their sum (from 10 to 20%) with increasing distance.

Increase public awareness on IAS

In 2019 and 2020, a total of 66 headmasters of high schools were asked to collaborate on the project. Sixteen schools accepted the proposal for a total of 30 classes, and about 500 students aged 11 to 18. The project workflow is shown in Fig. 2. Before and after the background lecture, students were asked to complete anonymous questionnaires to test their knowledge and awareness on IAS.

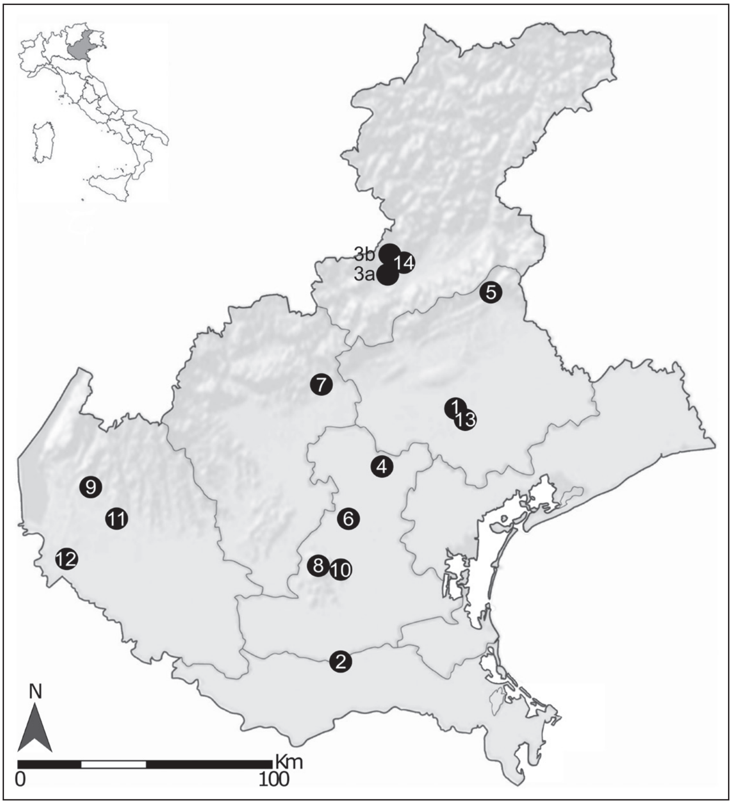

Figure 1. Map of the study area (the Veneto Region) indicating the high school locations.

Table 1. Landscape composition (mean % ± SE) within three different radii (0.5, 1 and 2 km) around schools.

	Areas devoid of vegetation		Agricultural areas		Green urban areas		Forest and semi-natural areas		Discontinuous urban fabric		Water bodies	
Radius	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0.5 km	60.47	5.56	26.93	5.41	7.23	2.15	3.56	2.02	0.97	0.33	0.84	0.49
1 km	48.23	5.47	35.73	5.75	4.86	1.21	7.71	3.10	1.25	0.24	2.23	1.03
2 km	36.03	5.30	42.49	5.80	3.67	0.80	14.82	5.61	1.64	0.23	1.35	0.45

A simple pre-lecture questionnaire had to be filled out based only on the IAS definition (FAO 2007), provided at the beginning of the test. It contained 10 questions (Suppl. material 1) relating to knowledge of IAS definition and IAS species, perception of the possible impact of an introduced alien species in the country, and propensity to get information about IAS. A one-hour lecture entitled ‘Monitoring of insect species harmful to trees and forests’ (Suppl. material 2) was delivered in the classes, both face-to-face and online. This activity was launched in Spring 2020, interrupted due the COVID-19 pandemic, and resumed in March and April 2021. In addition, a short video lecture (length of about 17 minutes) was provided (Suppl. material 2).

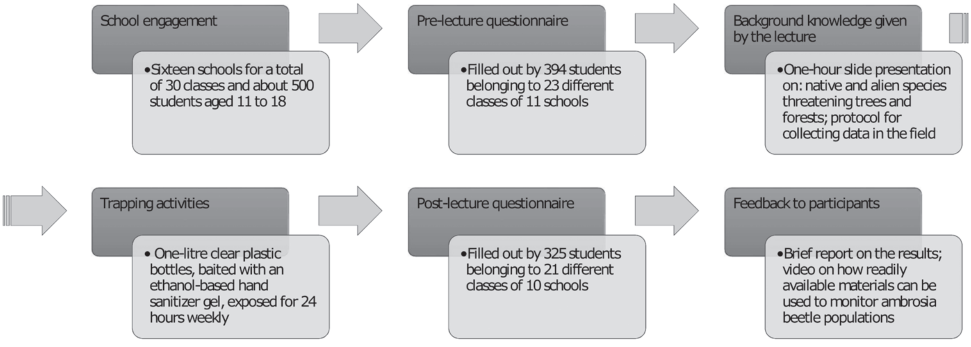

Figure 2. Flowchart of the citizen science project on ambrosia beetles.

A further simple post-lecture questionnaire aimed at testing students on the new knowledge they had acquired about the subject. It contained 10 questions, all closed-ended, with 4 of them having the possibility to provide a brief opinion or explanation (Suppl. material 1). The questionnaire was addressing the increase of awareness and knowledge of IAS, the understanding of their impacts, and the role of information campaigns, such as the one developed with the schools. A brief report on the main results of the experiment and a video on how readily available materials can be used to monitor ambrosia beetle populations (Suppl. material 2) were sent in 2022 to all headmasters and teachers to be shared with the students who had actively participated in the project.

IAS monitoring activity

The traps were prepared using one-litre clear plastic bottles baited with Septaman Gel (Nuova Farmec® S.r.l., Settimo di Pescantina, Italy), a 70% ethanol unscented hand sanitizer gel (Steininger et al. 2015). Traps were tested at the university campus and shown to be efficient in trapping the target ambrosia beetles (see Study organisms). Starting from late March 2021, 3 traps were deployed at each school (Fig. 3), placed within the understory and hung at a height of about 1.5 m above the ground on a branch of trees or shrubs, depending on the vegetation available around each school. The distance from one trap to another varied with the area available, but usually was not less than 8 m. Traps were filled with gel on a day of the week chosen by the school and checked after 24 hours. The short duration of trap exposure prevented complete ethanol evaporation, which would lead to the formation of a crust on the gel surface. Trapped insects were collected by a spoon, then put in a small, labelled plastic bag that was stored in a fridge until delivery to the laboratory for identification (see Study organisms). In one school (school n. 1; Fig. 1) the survey was repeated from the second half of July 2021 until October, to get one more confirmation of the occurrence of new IAS species (for Italy and the EPPO region) detected during the spring trapping (Colombari et al. 2022).

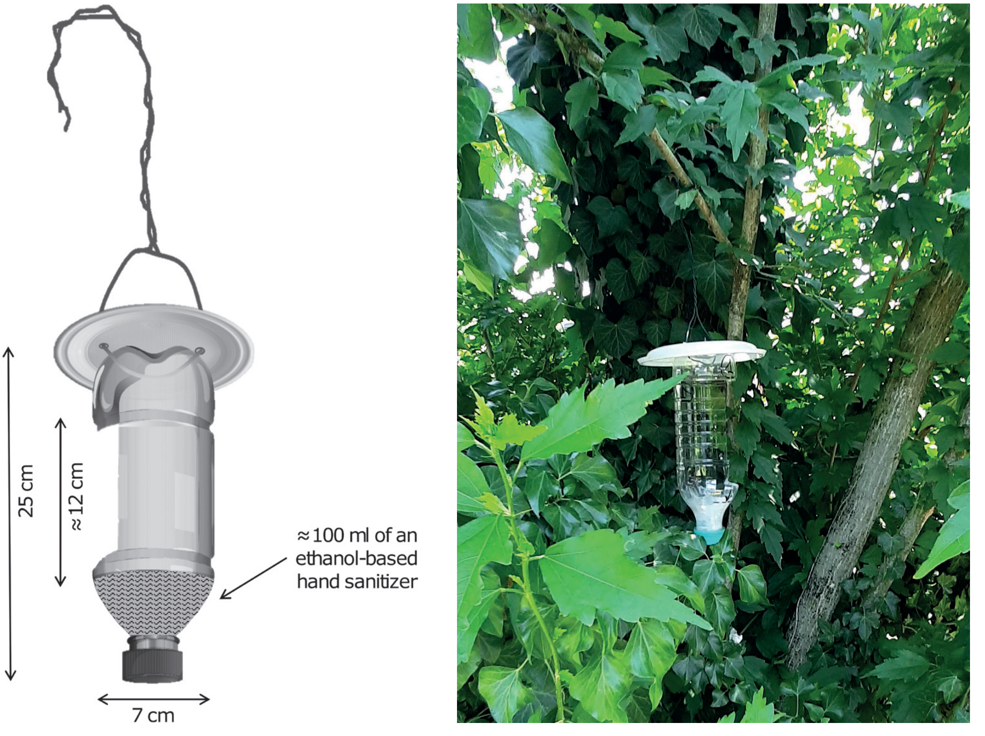

Figure 3. Schematic and photographic representation of a plastic bottle trap filled with hand-sanitizer as attractant.

Data analyses

To compare the trapping data collected by the schools that differed in the duration of the monitoring period and in the number of trapping rounds, the number of captured individuals was standardised by dividing it by the number of trapping rounds. The standardised number of native, alien species, and individuals was considered as dependent variable; while elevation, land cover class, and the number of samples were independent variables.

Landscape composition within three different circles (radius of 0.5, 1 and 2 km) around each school was assessed to determine the impact of habitat variability on data. In QGIS 3.22 (QGIS.org 2022), from the regional land cover map (Regione del Veneto, Sezione Pianificazione Territoriale Strategica e Cartografia – https://idt2.regione.veneto.it/) the percentage (in hectares) of six land cover class of interest was quantified. CORINE land cover nomenclature was followed: (1) discontinuous urban fabric, (2) green urban areas, (3) forest and semi-natural areas, (4) agricultural areas, (5) areas devoid of vegetation, and (6) water bodies. Percentages obtained in QGIS were eventually adjusted after examining high-resolution satellite images in Google Earth Pro (version 7.3.4; © 2022, Google LLC, Mountain View, CA).

A correlation matrix and the Pearson correlation coefficient were used through the 'Tidyverse' and 'Reshape2' packages in the software R (R Core Team 2022) before testing with linear regression the possible relationships. Trap catch data were log-transformed for the analysis.

Results

Increasing public awareness on IAS: Questionnaires

A total of 394 students, belonging to 23 different classes of 11 schools, participated in the pre-lecture questionnaire (Fig. 2). Thirty percent of respondents did not know what an IAS was, and 42% were unsure. Among the "aware" students (28%) the most mentioned insect species were the brown marmorated stink bug, *Halyomorpha halys* (Stål, 1855), and the Asian tiger mosquito (*Aedes albopictus* (Skuse, 1894)). Coypu, *Myocastor coypus* Molina, 1782, was the species cited most among mammals, whereas, among fishes, *Silurus glanis* Linnaeus, 1758 commonly named wels catfish, was very popular. When answered about the main source of information, "aware" respondents indicated "School" followed by "TV" (28% and 21%, respectively), whereas "Social media'"and "Family/Friends'" achieved almost the same percentages (12% and 11%, respectively). "Radio", instead, was sorely neglected (1%). Only 23% of the students perceived alien species to be invasive, i.e., causing damage.

Awareness of the possible occurrence of alien and invasive alien species in Italy was quite high, 87% and 81%, respectively, but the real number of invasive alien species was underestimated by 70% of total respondents. However, 60% considered native Italian species as a possible threat for ecosystems of other countries when introduced. Regarding their motivation for having interest in IAS, on a scale of 1 to 5 respondents rated almost a five (4.8) "if it causes harm to human or animal health", followed by "if it is present in the area where I live" (3.8), "if it causes harm to the environment" (2.9), and "if it can limit my hobbies or activities" (2.4). The motivation "if the species causes harm to the economy" had the lowest score (1.4). When answering the question "How would you prefer to receive information on invasive alien species"? students rated as most favourite source of information "School" (4.8), followed by "TV", "Family/Friends" and "Social media "(3.3, 3.2 and 3, respectively), whereas "Radio" had the lowest score (1.2).

Subsequently, the post-lecture questionnaire was completed (except by two entire classes of two schools and by some absentees from the other classes). Thus, in total, the survey involved 325 students belonging to 21 different classes of 10 schools (Fig. 2). The percentage of correct answers to the two questions present in the pre-lecture questionnaire and repeated in this questionnaire increased from 23% to 89% ("is an alien species always invasive"?) and from 60% to 75% ("could a species native to Italy be defined as invasive when introduced into ecosystems/areas of other countries"?). The five questions related to the new pieces of information given during the lecture got 87%

of correct answers. Many students demonstrated an understanding of environmental issues, with 45% of them providing an adequate explanation of the risks associated with the introduction of an alien species, although beneficial such as an organism that can be used in a classical biological control programme. Ninety percent of respondents believed the role of information is crucial for the proper management of IAS, and 86% that citizen science can be a very useful tool for the management of these harmful species. For almost all students (94%) the lecture was helpful to raise awareness and better understand the threat caused by IAS and the difficulties in managing them. Eighty percent commented that the lecture was fully comprehensive (20% did not comment) and more than half of them (55%) were really intrigued and wanted to gain a better insight into different points (e.g., pathways of introduction, degree of damage, ID, impact on environment and economies, control methods, etc.).

Large-scale surveillance of ambrosia beetles

Fifteen schools out of 16 provided insects caught in traps. The length of the monitoring period varied from one month to two-and-a-half months, whereas the interval between two consecutive samplings was one week with only one exception (2 weeks). Overall, 621 bark and ambrosia beetles, belonging to 9 genera and 11 species, were obtained across the whole monitoring period (Suppl. material 3).

Ambrosia beetles were the large majority (606 individuals) and four out of six species detected were non-native: *A. maiche*, *C. mutilatus*, *Xylosandrus crassiusculus* (Motschulsky, 1866), *Xylosandrus germanus* (Blandford, 1894) (Fig. 4). Native species were *Anisandrus dispar* (Fabricius, 1792) and *Xyleborinus saxesenii* (Ratzeburg, 1837). When assessing the respective percentage of captured individuals, the proportion of non-native was 34.8%, while the native *X. saxesenii* accounted for 62.2% of total insects caught.

Among alien ambrosia beetles, the two congeneric *Xylosandrus germanus* and *X. crassiusculus* constituted 33.0% and 1.3% of the overall catches, respectively. The remaining 0.5% was represented by three females of two new introduced alien species, *C. mutilatus* and *A. maiche*, as already reported by Colombari et al. (2022). Trapping conducted from July to October at the same school of the first records (school n. 1; Fig. 1), revealed the non-occasional occurrence of both the new species, as another 8 *C. mutilatus* (7.3%) and 5 *A. maiche* (4.6%) were captured (Fig. 5). Moreover, in this second monitoring period, total alien ambrosia species accounted for 54.1% given the large percentage of *X. germanus* (42.2%) that was the most common species found in the traps (Fig. 5).

There were strong differences in trap catch among schools (Fig. 6). The number of species and individuals showed a quite strong positive relationship with the sampling frequency, with correlation coefficients' (*r*) values ranging from 0.65 to 0.82. In particular, using regression analyses, it was found that sampling frequency significantly predicted the total numbers of both species and individuals ($R^2 = 0.52$, $F_{(1, 12)} = 13.28$, $P = 0.0034$ and $R^2 = 0.45$, $F_{(1, 12)} = 9.73$, $P = 0.0089$, respectively). That is, the higher

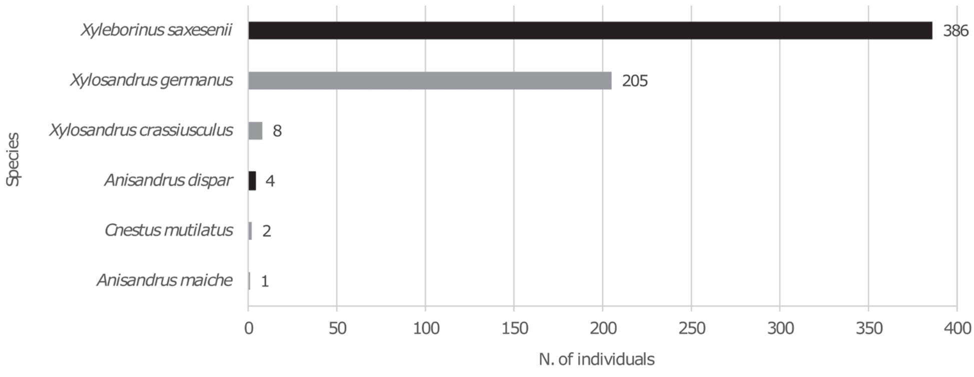

Figure 4. Overall species and abundance of ambrosia beetles (606 specimens). Black and grey bars indicate native and alien species, respectively).

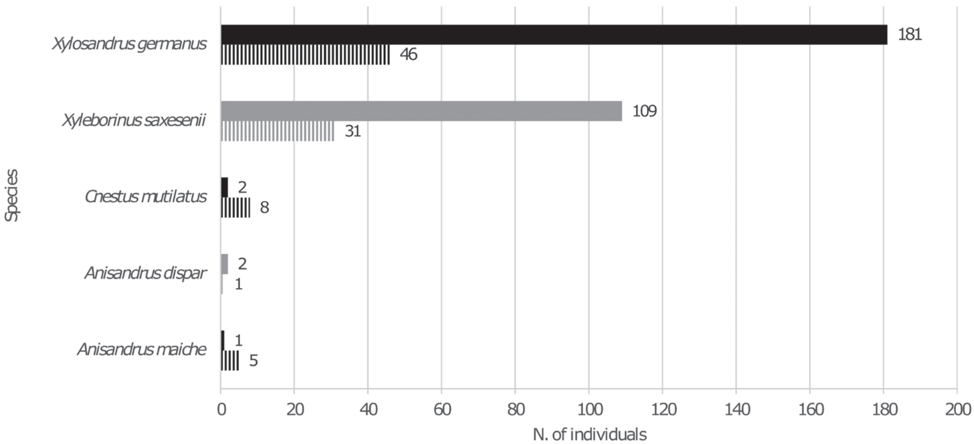

Figure 5. Overall species and abundance of ambrosia beetles at the site of first records of the two new alien species (school n. 1; see Fig. 1 – Map indicating the high school locations). Black and grey bars indicate native and alien species, respectively. Plain colour bars and striped bars indicate the first (from March to June) and the second (from July to October) 2021 monitoring periods, respectively.

the number of samples, the larger the number of species and individuals caught. The same was observed when the number of species and individuals of alien ambrosia beetles were considered alone ($R^2 = 0.43$, $F_{(1, 12)} = 9.11$, $P = 0.0107$ and $R^2 = 0.52$, $F_{(1, 12)} = 12.96$, $P = 0.0036$, respectively). The trap catch was not explained by any of the explanatory variables considered.

Bark beetles accounted for a very small percentage of the total (2.4%), as only fifteen specimens were found in traps, and were represented by five species: *Hypothenemus eruditus* (Westwood, 1834), *Phloeotribus scarabaeoides* (Bernard, 1788), *Hypoborus ficus* Erichson, 1836, *Trypophloeus asperatus* (Gyllenhal, 1813), and *Phloeosinus* spp.

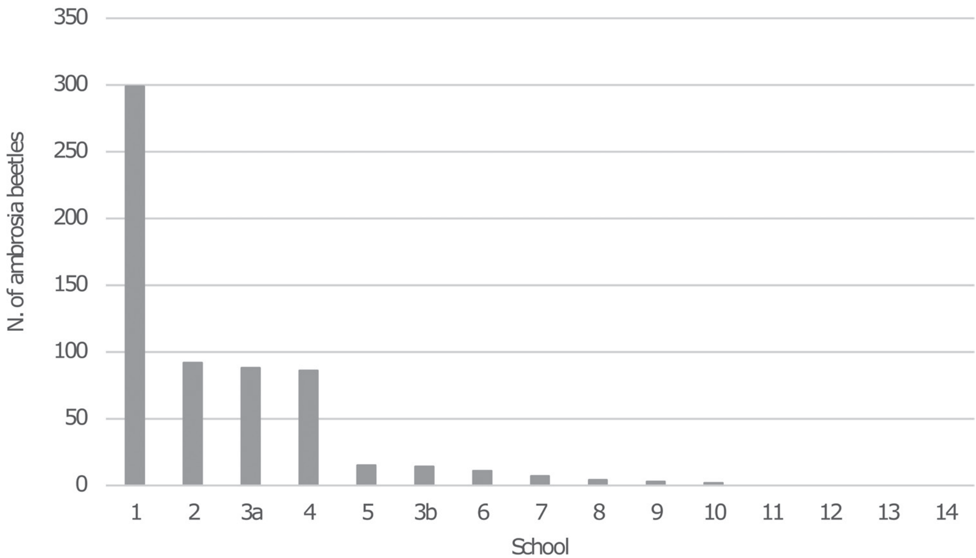

Figure 6. Total number of ambrosia beetles caught at different schools identified by number along the × axis (see Fig. 1 – Map indicating the high school locations).

Discussion

Our study aimed to both educate students and collect scientific data at sites such as schools where surveillance for potentially invasive ambrosia beetles is not usually conducted, or where it is sometimes misunderstood. Student involvement and curiosity were aroused during a pre-survey lecture where we stressed the importance of their role in assessing the unknown species and abundance of ambrosia beetles in their school yards/grounds, and the potential occurrence of undetected invasive species that could pose a serious threat to trees and forests in the surrounding environments. The results obtained provide strong evidence covering all prior expectations.

The citizen science approach contributed important goals for monitoring and alien species detection. Six different species of ambrosia beetles were recorded during the present study, two native species, *A. dispar* and *X. saxesenii*, and four alien species (35% of the total catch). *Xylosandrus germanus* and *X. crassiusculus* were accidentally introduced into Italy in 1992 and 2003, respectively, and are present in some deciduous temperate forests of the Veneto region (EPPO 2010; Rassati et al. 2016), whereas *C. mutilatus* and *A. maiche* were both first records in Italy and first and third records, respectively, in the European part of the EPPO region (Colombari et al. 2022; EPPO 2022).

Among ambrosia beetles, *X. saxesenii*, *X. germanus*, and *X. crassiusculus* were the most represented and our results are consistent with previous research using bottles and ethanol-based lures (Miller and Rabaglia 2009; Reding et al. 2011; Werle et al. 2012; Steininger at al. 2015; Tarno et al. 2021). In particular, ethanol has been demonstrated to have a significant effect on *X. saxesenii*, which usually accounted for the greater percentage of the overall catches (Oliver and Mannion 2001; Miller and Rabaglia 2009;

Galko et al. 2014; Steininger at al. 2015; Chen et al. 2021; Cavaletto et al. 2022) as our data confirm (62.2% of the total number of individuals collected). By contrast, the only other native species, *A. dispar*, was scarce even though it is lured to ethanol-baited traps, and it often represents alongside *X. saxesenii* one of the most trapped ambrosia beetles (Galko et al. 2014; Holuša et al. 2021). The two new species found and confirmed as successfully established, *C. mutilatus* and *A. maiche*, are known instead to respond almost exclusively to baits containing ethanol alone (Sweeney et al. 2016; EPPO 2020) and are significantly more attracted to bottle than to funnel traps (Klingeman et al. 2017; Miller et al. 2018; Tobin and Ginzel 2022).

Different catches indeed can be interpreted as the complex result of many variable factors that can affect trapping rates such as, among others, the aggressiveness of the species and their preferred host condition for attack and/or breeding (Oliver and Mannion 2001; Chen et al. 2021). Anyway, none of the overall species recorded were aggressive, able to attack healthy trees, but were instead associated with stressed (*X. saxesenii* and *X. germanus*), weakened (*X. crassiusculus* and *Hypothenemus* spp.) or dying hosts (*A. dispar*) (Chen et al. 2021; Holuša et al. 2021). Although *C. mutilatus* and *A. maiche* are classified as non-aggressive because of their preference for unhealthy (stressed and weakened) or recently dead small diameter materials, their low host specificity may raise concerns for forest ecosystems and particularly for nurseries, plantations, ornamentals, and fruit trees (Klingeman et al. 2017; EPPO 2020; Chen et al. 2021; Tobin and Ginzel 2022).

Diversity in species richness and abundance among sites was best predicted by sampling effects as more individual, and thus more species were caught where the monitoring effort was more prolonged (McCabe 2011; Brown et al. 2016). Thus, we cannot exclude that more species could be present at those sites where a low number of individuals was sampled and well aware of a bias in our analyses due to method we used, i.e., the ethanol-based lure known to be less attractive to host-specific bark and ambrosia beetles (Miller and Rabaglia 2009; Steininger at al. 2015). The time dimension in a sampling program is of great importance, as it considers temporal dynamics and phenological maturation of populations (Binns and Nyrop 1992). At the site where the monitoring period lasted more than two months, species richness and abundance were the highest, but considering the sites that collected no beetles at all, only in one case out of three a likely explanation was the methodological limitation. In the other two cases, sampling effort was not so different from that of other schools.

Undoubtedly, at the small scale, abundance and species richness are sensitive to sample size, but they also vary naturally, being affected by many geographic, abiotic and biotic factors such as resource availability, environmental heterogeneity, and ability to disperse (McIntyre et al. 2001; Brown et al. 2016). This is particularly true for dynamic and vulnerable urban ecosystems, where free movements of goods linked to population density can act as another driver influencing the occurrence of beetles (McIntyre et al. 2001; Branco et al. 2019; Meurisse et al. 2019; EPPO 2020). The complex interactions among all these local and landscape factors must be studied further for a better explanation of our results.

Questionnaire results showed that students acquired a greater knowledge and increased their awareness and interest by on average +57%, +40% and +55%, respectively, changing their attitude about IAS. At the beginning of the project, less than one third of the students were "aware" of biological invasions and their impact and were able to list some IAS, whereas a large majority of respondents were "unsure", a result in line with the research of Waliczek et al. (2017). It must be considered, however, that there is a great deal of confusion surrounding some terms and concepts relevant to biological invasion as they are open to subjective interpretation, such as the term 'invasive' on which a consensus has not been reached (Colautti and Mc Isaac 2004). If ambiguous, or very technical terminology is used by scientists, for example, invasive and alien species erroneously generate synonyms, which can be expected to create confusion for a lay audience that require a basic understanding of the terms (Verbrugge et al. 2021).

To improve clarity and avoid such unwanted discrepancies that emerged from the results of the pre-lecture questionnaire, during the lecture we devoted time to state key complex terms and concepts in a concise and simple manner. A better understanding of IAS, and a greater awareness of the serious threats they pose, does not always translate into a change in behaviour regarding invasive species (Jordan et al. 2011). Nonetheless, in our case, those students with more positive attitudes towards control and eradication were those "aware" of IAS, as found by Waliczek et al. (2017). These students, being children or grandchildren of farmers, experienced in some way negative/economic impact of IAS and were very knowledgeable about names and number of IAS occurring regionally, in Italy or neighbours' countries. Family was indeed selected as a reliable source of information, and this is a very important fact on which recent literature focused (Halmatov and Ekin 2017; Masykuroh et al. 2022). Quoting van Noordwijk et al. (2021) "people are more often inspired to change their behaviour if they are influenced by their own social contacts, including friends, family, colleagues, and neighbours". But the majority of the "aware" students said they learned about IAS mainly from school, as part of biology curricula. However, they amounted to half of total respondents showing that education on IAS at the high school level must improve to gain support for control and management (Waliczek et al. 2017).

After the lecture and once monitoring activities began, almost all students (87%) gave correct answers to questions related to the new topics explained. If we consider that in the pre-test half of respondents answered correctly, the increase in knowledge is 34%, but if we exclude students "aware" of alien species who had probably a greater basic knowledge, then the increase rises to 57%. Waliczek et al. (2018) has demonstrated that delivering comprehensive lectures and laboratory work on invasive species to students led them to perform better in a post-test than students who only attended lectures. The higher content knowledge was likely attributable to the active learning activity, which is known to have a positive influence on further outcomes more than a simple learning method (Verbrugge et al. 2021), and a combination of the two experiences could achieve even better results.

Another very satisfying feedback was that almost all the students enjoyed the lecture and found it an appropriate awareness-raising initiative for gaining new knowledge and greater awareness of the topic. Remarkably, more than half of them would like to learn more, especially about the multiple negative effects related to the introduction of IAS and practices to manage them (limit their spread).

Citizen science empowers school interest when students had to choose their preferred sources of information. Here school was the most favourite, whereas social media were placed only second, which was unexpected given the age of the respondents. Cerri et al. (2022) analysed whether European Union blacklists of IAS with media coverage increased the curiosity of laypersons seeking further information online, and concluded that there were not more visits than expected after the lists were posted. Considering that Wikipedia is the most famous online encyclopaedia largely used by students as a first (and often unique) approach to various issues, this is a noteworthy result highlighting the need for specific education programmes or public awareness campaigns from school level onwards (Hulme et al. 2010; Butkevičienė et al. 2021). Furthermore, the author's analysis took into consideration invasive alien mammals (such as the raccoon, *Procyon lotor* (Linnaeus, 1758) and the Eastern gray squirrel, *Sciurus carolinensis* Gmelin, 1788) that generally arouse interest and are held in higher affection by people, so making eradication and control difficult (Novoa et al. 2017), unlike insects that rarely pose ethical problems. But sensational news or viral videos may greatly affect interest (Cerri et al. 2022) and indeed, after school, TV and social media were selected as second preferred sources of info.

Our results confirm the primary role of education, which has been recognized as a major driver of change in dealing with sustainability challenges (Leicht et al. 2018). For this reason, teachers and environmental educators are expected to reach the knowledge and skills' objectives required to promote sustainable development (Leicht et al. 2018; Sosa et al. 2021). However, a study of a representative sample of teachers/educators found that half of them had never heard about IAS, or were unsure of the issues, stressing the need for well-trained teachers able to bridge the gap between scientists and students (Sosa et al. 2021; Verbrugge et al. 2021).

Concluding thoughts on citizen science

Despite many global measures implemented to limit the risk of IAS introduction, current tools are ineffective at slowing down the ever-increasing arrivals into new regions at unprecedented rates. An effective early detection of invasive forest pests should involve citizens, as most first records occur in cities or suburban areas. People are often unaware of the role they have in the entire invasive process. Therefore, promoting interest and receiving public collaboration and support through educational activities and information campaigns should be seen as a good long-term investment to counter biological invasions. We show here that citizen science can successfully involve school students, giving them an opportunity to participate and contribute in detection of ambrosia beetle species, a group associated with a number of pathways in international trade. Citizens can significantly help with the collection of scientific data to improve the management of natural and cultivated ecosystems.

Acknowledgements

The authors would like to thank all the headmasters, teachers and students who accepted the collaboration and collected the data. Special thanks go to headmaster Mario Dalle Carbonare, Professor Michele Zanata and their students (III H and IV H classes, SY 2020–2021; high secondary school "Leonardo da Vinci" – Treviso, Italy) for their enthusiastic participation in the project. Finally, the authors thank the reviewers and editors for all their useful and helpful comments on the manuscript. The monitoring programme was conducted in the context of the European project HOMED (Holistic management of emerging forest pests and diseases), which receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 771271.

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Supplementary material 1

Lecture questionnaires

Authors: Fernanda Colombari, Andrea Battisti

Data type: PDF file

Link: https://doi.org/10.3897/neobiota.84.95177.suppl1

Supplementary material 2

Slides of the lecture on 'Monitoring of insect species harmful to trees and forests' and link to educational videos

Authors: Fernanda Colombari, Andrea Battisti

Data type: PDF file

Link: https://doi.org/10.3897/neobiota.84.95177.suppl2

Supplementary material 3

Number of individuals of each species captured at each school

Authors: Fernanda Colombari, Andrea Battisti

Data type: table (PDF file)

Link: https://doi.org/10.3897/neobiota.84.95177.suppl3