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# A citizen science method to monitor a polyphagous shot hole borer infestation in Johannesburg's urban forest

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ABSTRACT

Citizen science has become a powerful tool for gathering data, and the validity of these data should be tested. The accuracy of a citizen science database used to monitor the polyphagous shothole borer (PSHB) (*Euwallacea fornicatus*) (Coleoptera: Curculionidae: Scolytinae) infestation in a suburb of the city of Johannesburg was assessed. Out of 785 trees surveyed by the citizen scientists, 157 trees (20%) were selected as a validation data set to confirm the tree identity, tree health status and level of PSHB infestation. A chi-square ($\chi^2$) test was performed to examine whether there was a significant agreement between the citizen scientists' and researcher's data used for the classification of the tree infestation, tree health status and PSHB infestation holes. A Cohen's kappa coefficient was calculated to determine the level of agreement between the two different sources of data, for the infested parts (trunk, main branches, and canopy branches) of the trees surveyed and PSHB infestation signs. The two surveys showed no significance difference for classifying tree health status and PSHB infestation holes. There was a high level of agreement between citizen scientists and the researcher ratings for measures of PSHB infestation (kappa values ranging between 0.71 and 0.89) and the level of agreement was significant. In conclusion, citizen science allowed us to obtain a large quantity of data at a low cost that correlated with the researchers' validation dataset. Citizen science is a useful method for monitoring PSHB in a diverse urban forest in trees that show obvious signs of infestation.

## 1. Introduction

Trees are an important component of urban ecosystems providing several ecosystem services such as an aesthetic beauty for urban dwellers. In cities, trees act as habitats for birds and insects, as well as a filter for atmospheric carbon (Zhao et al., 2010). On the other hand, urban forests can play a major role in the introduction and or establishment of non-native pests (Branco et al., 2019). In cities, invasive pest species can lead to economic loss and reduced quality of life if trees are infested and lost (Francis and Chadwick, 2015). However, the rate of detection of invasive forest pests decreases as one moves away from cities due to changes in vegetation diversity (Branco et al., 2019). According to Poland and Rassati (2019), urban trees are more prone to abiotic stress, rendering them more susceptible to insect attack. Despite the important contribution of urban forests, there are often challenges in maintaining them because of this threat from invasive exotic pests, thus, it is necessary to develop strategies to protect urban forests. These will, however, depend on effective tree surveys using various methods to determine the spatial and temporal distribution of trees hosting a pest or disease to prioritize intervention measures and curb any spread. One such widely used method to gather scientific data on invasive species is 'citizen science' (Weckel et al., 2010).

The Polyphagous shot hole borer (PSHB) (E*uwallacea fornicatus*) (Coleoptera: Curculionidae: Scolytinae) is an invasive beetle native to Southeast Asia. It affects both native and exotic trees across the world (Eskalen et al., 2013; Umeda et al., 2016). In South Africa, PSHB is threatening both native and exotic trees countrywide (Paap et al., 2018; Potgieter et al., 2024; Townsend et al., 2024). The PSHB shares a symbiotic relationship with a fungus called *Fusarium euwallacea*e, and this fungus is the source of food for the beetle larvae and adults (Umeda et al., 2016). Trees attacked by the PSHB are classified either as non-reproductive or reproductive hosts. Non-reproductive hosts are those trees attacked by the PSHB but in which it cannot complete its lifecycle, while reproductive hosts allow the beetle to complete its

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lifecycle (Eskalen et al., 2013). There are 130 identified host trees, with 48 being reproductive hosts and 82 being non-reproductive hosts in South Africa (Van Rooyen et al., 2021). Some of the known reproductive hosts include *Acer buergerianum*, *Acer negundo*, *Platanus x acerifolia*, *Quercus robur* and *Quercus palustris* (Paap et al., 2018; Van Rooyen et al., 2021). Once a PSHB attacks a host, it reduces the movement of water, which causes wilting, branch dieback and often eventual death of the infested branch or tree (Mendel et al., 2012). Some of the common symptoms of PSHB attack include stains at entrance holes, frass or white powdery substance on the tree trunk, and wilting (Eskalen et al., 2013). The size of the PSHB entrance hole is less than 1 mm in diameter. This is where the dispersing female beetle gnaws her way into the tree. It requires many actions to monitor spread of the beetle, but the first is to measure the extent and distribution of the infestation using the presence of the entrance hole as confirmation of PSHB presence. Currently, mapping of the beetle is done using traditional field methods, and the involvement of citizen scientists is crucial since most of the city trees attacked by PSHB are found in urban neighbourhoods. The spread of PSHB in urban environments is increasing, and its effects are likely to be detrimental.

Citizen science (CS) refers to the participation of public in data collection for scientific investigations (Silvertown, 2009; Hulbert et al., 2019; Miller-Rushing et al., 2012) and for finding scientific solutions to large-scale ecological problems (Horvath and Cameron, 2015). According to Bird et al. (2014) citizen science can be defined as an intentional participation of the public in scientific research. This practice can be considered as informal science since it involves both research and education. Usually, citizen science projects involve a collaboration between citizen scientists and professional scientists (Larson et al., 2020). Citizen science has gained wide popularity in many scientific and ecological field applications globally (Cohn, 2008; Crow et al., 2020; Falk et al., 2019; Hulbert et al., 2019). Traditional methods for urban vegetation monitoring are often constrained by insufficient time and resources to cover a wide geographical area (Malek et al., 2018). Some scholars have suggested citizen science as a potential source of data for detection of invasive species and mapping their current distribution (Silvertown, 2009; Larson et al., 2020; Werenkraut et al., 2020; Dickinson et al., 2010; Crow et al., 2020). The citizen science approach has been practised for at least the last two decades and since its inception has become a powerful tool for public engagement as well as for gathering useful data (Silvertown, 2009; Horvath and Cameron, 2015; Ryan, 2015; Pocock and Evans, 2014; Miller-Rushing et al., 2012). Thus, citizen science can function as a binding initiative to close the gap between scientists and members of a community.

In South Africa there are several successful ongoing citizen science projects (Hulbert et al., 2019). Among these are the Iimbovane Outreach Project (collection and identification of ants) and the rePhotoSA (collection of historical landscape photographs) (Hulbert et al., 2019). The biggest citizen science project in Southern Africa is the Bird Atlas Project (SABAP) for monitoring bird distribution (Barnard et al., 2017). Other examples of citizen science projects from the rest of the world that provide useful information for monitoring pests and diseases include the LIFE ARTEMIS in Slovenia and Observatree in the UK (Crow et al., 2020). In Canada, a citizen science initiative known as Forest Health Ambassador Program in Oakville-Ontario provides records for early detection of invasive pests in urban forests (Emerald ash borer, Gypsy moth and Asian longhorned beetle) (Barker et al., 2018). Similarly, the citizen science project by the Lower Houghton Residents Association (LHRA) in Johannesburg has recorded PSHB infested trees in their neighbourhood and provided relevant authorities with georeferenced data on the PSHB infestation in one suburb of Johannesburg.

Citizen science initiative gives more time to investigators to gather more data through engagement with volunteers compared to individual surveys (Horvath and Cameron, 2015). The incorporation of technological platforms such as the internet and smartphones, allows citizen science to become an inexpensive, large data gathering technique (Steininger et al., 2015). Although, there are different approaches to citizen science, the key is to provide valuable quality data for scientific research and or monitoring (Roman et al., 2017). Often, residents are more or less 'custodians' of their local green spaces through participation in tree planting as well as maintaining street trees (Ryan, 2015).

The major drawback of citizen science is, however, lack of adequate skills of participants compared to professional biologists and scientists (Dickinson et al., 2010). Citizen scientists differ in experience and type of training and such inadequacies can contribute to error or bias (Dickinson et al., 2010; Baker et al., 2019). Most common identification errors from citizen science projects are attributed to lack of adequate experience among participants, complex sampling procedures and training effectiveness (Gardiner et al., 2012). In most cases citizens involved in the scientific data collection are not rewarded financially (Cohn, 2008), but rather are simply interested in the topic under investigation.

The citizen science approach has been successfully applied in invasive species identification, mapping distribution and abundance estimation (Crall et al., 2011). Through participation in citizen science, it has been noted that experts identified tree species more accurately than citizen scientists (Crall et al., 2011). Conversely, genus and tree species identification by citizen scientists was reported to be highly consistent with experts (Roman et al., 2017). Other studies have also reported a high level of agreement between citizen scientists and experts for species identification (De Felici et al., 2021; Kosmala et al., 2016). Usually different experience levels contribute to species misidentification (Crall et al., 2011). A study by Crow et al. (2020) showed that volunteers in the UK and the Slovenia successfully identified pests and diseases from their observations; however, ambrosia beetles of *Xylosandrus* spp. were not easily identified, and for further identification were sent to experts. Citizen science data can have some bias; species may exhibit different detection probabilities based on their abundance and behaviours (Redolfi De Zan et al., 2023). For example, in Italy, *Osmoderma* spp. beetle was deemed less suitable for monitoring by citizen science because of its low probability of detection by non-qualified entomologists (Redolfi De Zan et al., 2023). Thus, citizen science data, once validated by experts and researchers can contribute to increased knowledge of tree pests or disease identification and broader management actions.

This research marks the first attempt to test the efficacy of a citizen science-based approach for monitoring PSHB in the City of Johannesburg's urban forest in South Africa. Here, we asked a question; can citizen science aid in mapping and monitoring the PSHB infestation in an urban forest? The aim of this research was to assess the value of an existing citizen science database to monitor the PSHB infestation in the City of Johannesburg by validating citizen scientists *vs.* researcher data. If sufficiently accurate, then the method can be used for broad-scale monitoring of the extent and impact of the beetle on the city's urban trees.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in the Houghton Estate residential suburb (26.1649° S, 28.0625° E) (Fig. 1) of the city of Johannesburg (CoJ) in Gauteng Province, South Africa. This suburb was selected based on the presence of trees showing evidence of beetle attack and interest from the residents in participating in a citizen science initiative. The City of Johannesburg is known to have one of the largest urban forests in the world, with approximately 10 million trees (Hardy and Nel, 2015). Johannesburg's urban forest is diverse and constitutes exotic trees like *Jacaranda*, London Planes, Oaks and *Eucalyptus* (Turton et al., 2006). Most of the trees in the CoJ are found on pavements, public parks and private gardens (Schäffler and Swilling, 2013).

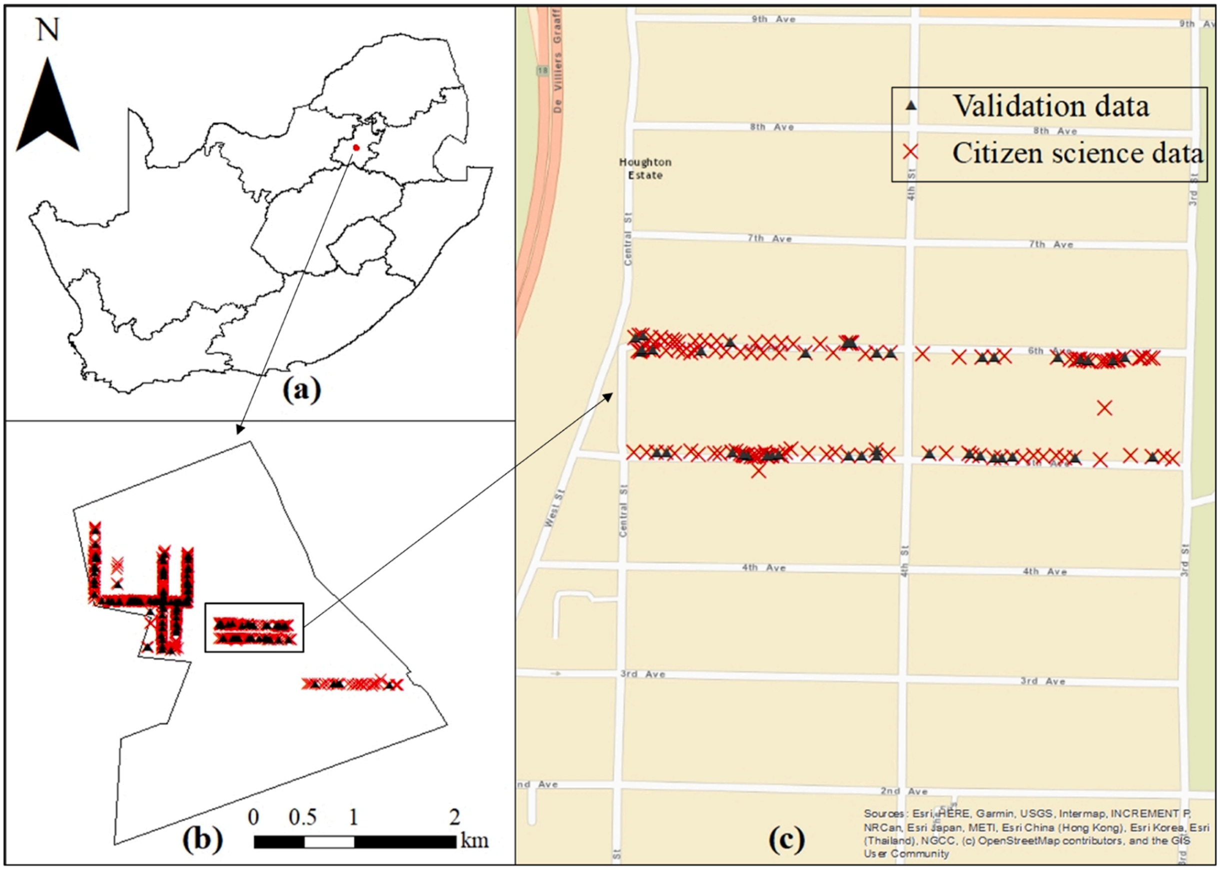


**Fig. 1.** Map of South Africa showing Gauteng Province and location of Houghton estate (red dot) **(a)**, A map of Houghton Estate showing locality of trees surveyed by citizen scientists (red X) and black triangles representing ground truthing points of trees used as validation points **(b)**, A map of part of Houghton Estate showing the roads (5th and 6th avenues) along which trees were surveyed for PSHB **(c)**.

### *2.2. Citizen scientists*

Adult volunteers (10) participated in the PSHB infestation field data collection. The level of knowledge of the citizen scientists who participated in the tree survey varied widely and was not quantified in this study. An expert entomologist trained two citizen scientists, and these two citizen scientists further trained the other eight citizen scientists. Citizen scientists were trained how to identify trees, classify PSHB infestation holes and assess tree health status. Citizen scientists were also trained on how to record data on PSHB scars which are obvious as distinctive brown oozing stains on the trunks of trees with smooth bark. These stains are more difficult to discover on rough-barked species. Before, becoming involved in monitoring the PSHB beetle, Houghton residents wanted to understand the extent of the problem and to take some sort of action to prevent the loss of their street trees. Volunteers included people living in the Houghton Estate who were interested in monitoring trees infested by PSHB beetles. Most volunteers who participated in data collection belonged to the Lower Houghton Residents Association (LHRA). Data recorded are detailed in Section 2.3 below. No reward in the form of financial benefit was provided to the volunteers who participated in data collection. The participants recorded data on foot using handheld global positioning system (GPS) devices and smartphones to collect GPS positions for each tree surveyed. Citizen science data (CSD) was collected between September 2019 to September 2020 covering an area of 6.94 km$^2$.

### *2.3. Field data collection*

Tree species, circumference, tree height, GPS location and status of PSHB attack (infested or non-infested) were recorded for each tree surveyed. However, some of the tree species were not identified correctly to their species level by the citizen scientists. In such a case both the trees local name and scientific name were recorded with a question mark (?). Those species not correctly identified to species level, were recorded based on their genus name. A tree was defined as a perennial woody plant with many secondary branches supported by a single main trunk with clear apical dominance (Richardson and Rejmánek, 2011). The researcher had prior knowledge of the area and the streets surveyed by the citizen scientists through visualising them on Google Earth Pro and Google Street View. This was done primarily to plan the routes for the survey. Furthermore, the researcher possessed knowledge of PSHB and the trees found in the area from training done with an expert plant pathologist conducted in nearby suburbs, where PSHB infested trees were surveyed. However, the researcher did not know the tree identity or health status assigned to a tree by the citizen scientists.

To validate the accuracy of citizen science data in this study, the researcher adopted the method of Hallet and Hallet (2018) by selecting 20% (n = 157) of the 785 original trees surveyed by the citizen scientists. These validation trees were randomly selected by random number generation in Microsoft Excel. The GPS points were then loaded into a Garmin etrex 10 device and a Vivo y12 smartphone. Using Google Maps on mobile, the selected trees were surveyed in Houghton Estate in September 2022. The validation points were loaded into the free software Google Earth Pro (http://www.google.com/earth/download/gep/agree.html) for visualisation.

During data collection by citizen scientists, trees were assessed for evidence of PSHB attack, and recorded as infested or non-infested. Within the infested class, dead trees were also noted, and these were defined as having dry canopy branches and with PSHB entrance holes.

The researcher was trained by Dr Trudy Paap to recognise PSHB. An entry hole with a diameter of 0.85 mm, comparable to that of the tip of a toothpick; along with other signs such as frass and oozing, confirmed the evidence of the PSHB. Entry holes caused by other pests were noted and recorded as "others". The infested class was further divided into three levels based on the parts of the tree attacked, trunk, main branches and or canopy branches. All trees were also scored into tree health classes (Table 1).

Oozing and frass were classified using three ratings: major, minor and none. Oozing is identified by watery-like jelly on entrance holes (Fig. 2; photo A). Frass was identified as a powdery residue or sawdust, or noodle-like excreta or on tree bark (Van Rooyen et al., 2021). The three classes were distinguished based on a visual assessment of the quantity of frass or oozing on the trunk, the main branches or the canopy branches. Examples of signs of frass are shown in Fig. 2 (Photos B and C). Severity of PSHB attack on trees was recorded by counting the number of holes on tree trunks in an A5 sized quadrat (315 $cm^2$) at 1.3 m (breast height) above ground level on the side of the tree facing the road. Counts of PSHB holes were classified into one of five classes (Table 2). If there were no obvious signs of PSHB entrance holes on a tree, such tree was recorded in class 1 as zero holes (not visible).

### 2.4. Data analyses

A chi-square ($\chi^2$) test of independence was performed to evaluate whether there was a significant association between citizen scientists' data (n = 157) and researcher data (n = 157) for classifying tree infestation, tree health status and PSHB infestation holes. We examined the level of agreement between the citizen scientists and researcher's data to evaluate whether citizen science data is reliable for monitoring a PSHB infestation based on infested parts of the tree (trunk, main branches, and canopy branches) and infestation sign (oozing and frass). A confusion matrix was produced, with producer accuracy, user accuracy, and overall accuracy using Microsoft excel software. Overall accuracy was calculated as the diagonal total of all correctly classified trees divided by size of the sample (n = 157). This overall or percent agreement can also be called recorder success (Falk et al., 2019). Butt et al. (2013) and De Felici et al. (2021) suggest treating expert (researcher) observations or data as correct. The Cohen's kappa coefficient of agreement was then calculated to determine the level of agreement between citizen scientists and researcher scoring for PSHB infestation. The kappa coefficient is a mathematical measure that gives the level of agreement between two datasets (Cohen, 1960). The Cohen kappa was used because it is a measure of agreement that considers chance agreement between two raters as a result of uncertainty (Cohen, 1960). When interpreting the kappa coefficient, kappa rating standards proposed by Landis and Koch (1977) (Table 3) were used. Statistical analysis for the $\chi^2$ test and Cohen's kappa were performed using SPSS version 28, at 5% level of significance.

## 3. Results

A total of 785 trees were surveyed by citizen scientists in Houghton Estate. Of these, 157 trees (20%) were randomly selected for validation to confirm the level of PSHB infestation signs, PSHB holes, tree health assessment and tree identity. There was a total of 33 tree species in the citizen scientists' and the validation data (n = 157). *Platanus x acerifolia* and *Celtis africana* were the commonest species with 23.4% and 9.5% respectively as recorded by citizen scientists. Species identification by citizen scientists was consistent with the researcher and the level of agreement was high (Table 4). Three species namely *Harpephyllum caffrum*, *Ficus natalensis* and *Brachychiton acerifolius* had been labelled by the citizen scientists as unknown. There was no significance difference between the two surveys for classifying tree health ($\chi^2 = 2.6$; p = 0.5) (Fig. 3).

Citizen scientists found that 113 of the 157 trees (72%) surveyed were non-infested, and 44 (28%) trees were infested, while the researcher reported 109 trees (69%) as non-infested, and 48 trees (31%) as infested by the PSHB. Results of the $\chi^2$ test showed that there was no significant difference between the citizen scientists and researcher identification of tree infestation ($\chi^2 = 0.246$; p = 0.620). The trees recorded were also assessed for the level and location of the infestation by recording signs of PSHB on the trunk, the main branches, and the canopy branches. For the citizen scientists' data, 44 trees (28%) and 27 trees (17.2%) exhibited signs of PSHB on the trunk and main branches respectively. Whereas the researcher data showed that 48 trees (30.6%) were infested on the trunk, 36 trees (22.9%) on the main branches and 2 trees (1.3%) on the canopy branches. Three dominant species namely *Platanus x acerifolia*, *Betula pendula* and *Quercus robur* were attacked by PSHB on trunks and main branches as noted by citizen scientists and the researcher. Furthermore, *Platanus x acerifolia* was the only species showing signs of PSHB attack on the canopy branches from the researcher data.

The citizen scientists' classification of tree infestation on the trunk showed a strong agreement with the researcher's validation data ($p < 0.001$) (Table 5). Again, citizen scientists and researcher data for infestation rating on the main branches showed a substantial agreement between the two surveys ($p < 0.001$) (Table 5). When classifying trees infested on the canopy branches, the kappa coefficient showed no agreement and p value was insignificant ($p > 0.05$) because no trees were recorded as infested by citizen scientists. When classifying a PSHB infestation sign as oozing and frass the citizen scientists and researcher level of agreement was significant (Table 6). The overall accuracies were close to 100% meaning that the citizen scientists' rating was highly consistent with that of the researcher (Table 6). Results of the $\chi^2$ test showed that there was no significance difference between citizen scientists' and researcher ratings' for PSHB infestation holes ($\chi^2 = 4.9$; p = 0.3) (Fig. 4).

## 4. Discussion

This study explored how citizen science derived data can be of significance in mapping and monitoring a PSHB infestation with the underlying assumption that the citizen science can yield sufficient information to help urban forest managers to develop a better understanding and management plans. The results revealed a high level of agreement between the two different sources of survey data for species identification and provided equally accurate observations of PSHB infestation levels. Citizen scientists were given training in tree identification before surveying the street trees for PSHB monitoring, which could have contributed to the high accuracies of matching identifications. In addition, the PSHB has been well publicised, therefore there are many online resources available to assist with identification (www.fabinet.up.ac.za/pshb). Similarly, Berland et al. (2019) found a high level of agreement between volunteers and expert for species identification of *Oak*, *Platanus*, *Acer* and *Liquidambar,* although they compared level of agreement between 16 volunteers and experts, intermediate, and novice analyst groups as opposed to the comparison made between citizen scientists and a researcher in this study. Fuccillo et al. (2015) showed that citizen scientist observations were consistent with expert observations with an overall accuracy of 91% for identifying 19 tree

**Table 1**
Tree health assessment and rating used for surveying PSHB infestation on trees in Houghton estate by citizen scientists and the researcher.

| Class | Definition |
|---|---|
| 1 | Vigorous/ healthy |
| 2 | Ailing |
| 3 | Visible dieback |
| 4 | Dead |

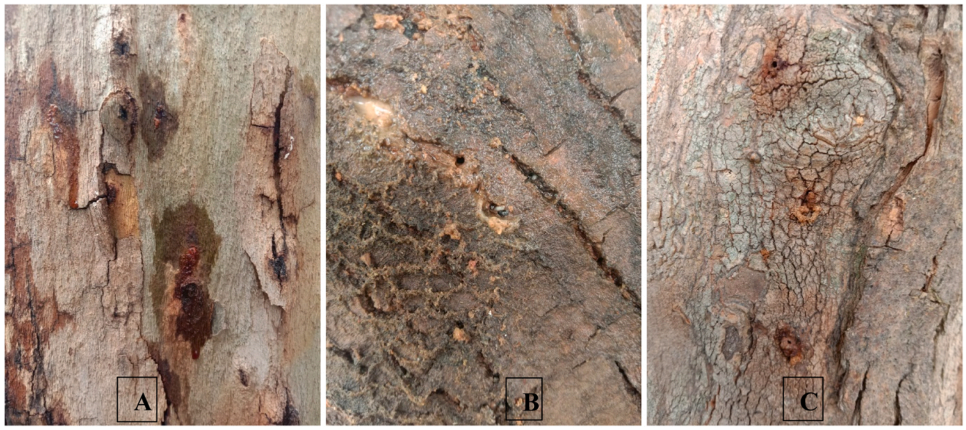


**Fig. 2.** Bark of *Platanus x acerifolia* (A), *Acer negundo* (B) and *Acer buergerianum* (C) infested by the PSHB showing entrance holes, signs of oozing and frass.

**Table 2**
PSHB entrance holes rating classes used for surveying trees in Houghton estate by citizen scientists and the researcher.

| Class | Number of holes/ 315 $cm^2$ quadrat |
|---|---|
| 1 | 0 holes (not visible) |
| 2 | 1–10 holes |
| 3 | 11–20 holes |
| 4 | 21–50 holes |
| 5 | >50 holes |

**Table 3**
Description of kappa values according to Landis and Koch (1977).

| Kappa coefficient value | Level of agreement |
|---|---|
| ≤ 0.00 | poor or no agreement |
| 0.01–0.20 | slight |
| 0.21–0.40 | fair |
| 0.41–0.60 | moderate |
| 0.61–0.80 | substantial |
| 0.81–1.00 | almost perfect |

**Table 4**
Trees species surveyed by citizen scientists that were re-examined by the researcher (n =157) to validate their identity and % level of agreement.

| Species | Citizen scientists | researcher | % agreement |
|---|---|---|---|
| *Acacia mearnsii* | 3 | 3 | 100 |
| *Acacia sieberiana* | 1 | 1 | 100 |
| *Acer buergerianum* | 2 | 2 | 100 |
| *Ailanthus altissima* | 1 | 1 | 100 |
| *Betula pendula* | 7 | 7 | 100 |
| *Harpephyllum caffrum* | 0 | 1 | 0 |
| *Buddleja saligna.* | 2 | 2 | 100 |
| *Butia capitata* | 7 | 7 | 100 |
| *Cedrus deodara* | 1 | 1 | 100 |
| *Celtis africana* | 15 | 15 | 100 |
| *Combretum erythrophyllum* | 1 | 1 | 100 |
| *Cupressus spp.* | 10 | 10 | 100 |
| *Coprosma repens* | 1 | 1 | 100 |
| *Cussonia spicata* | 2 | 2 | 100 |
| *Eugenia spp.* | 2 | 2 | 100 |
| *Ficus natalensis* | 0 | 1 | 0 |
| *Brachychiton acerifolius* | 0 | 1 | 0 |
| *Jacaranda mimosifolia* | 9 | 9 | 100 |
| *Ligustrum vulgare* | 1 | 1 | 100 |
| *Liquidambar styraciflua* | 7 | 7 | 100 |
| *Liriodendron tulipifera* | 7 | 7 | 100 |
| *Melaleuca bracteata* | 4 | 4 | 100 |
| *Melia azedarach* | 2 | 2 | 100 |
| *Morus alba* | 1 | 1 | 100 |
| *Ocotea bullata* | 3 | 3 | 100 |
| *Pinus patula* | 15 | 15 | 100 |
| *Platanus x acerifolia* | 37 | 37 | 100 |
| *Populus nigra* | 1 | 1 | 100 |
| *Quercus palustris* | 1 | 1 | 100 |
| *Quercus robur* | 3 | 3 | 100 |
| *Styphnolobium japonicum* | 1 | 1 | 100 |
| *Viburnum sinensis* | 4 | 4 | 100 |
| *Ulmus parvifolia* | 3 | 3 | 100 |
| Total | 154 | 157 | |

species. Our findings concur with a study by De Felici et al. (2021) on assessment of butterfly species identifications and geographic location based on Italian Forums of Natural Science in Italy and found a high level of agreement (96.9%) between citizen scientists and expert taxonomist ratings. Citizen scientists were supposed to identify 248 species of which they misidentified three species, and two species couldn't be validated by experts. This is because butterflies are easy to differentiate using colour, and specialised parts like wings and legs. A different study by Kosmala et al. (2016) showed 98% level of agreement between citizen scientists and experts for 4000 images classifications obtained from photographic traps placed in the Serengeti National Park. Plane trees have distinctive bark, leaves and fruit, and constituted the majority of trees in Houghton, which may be why the researcher and citizen scientists agreed in their identification.

The findings from this study showed that citizen scientists provided high-quality data, largely in agreement with the researcher dataset in identifying trees with PSHB. A study by Roman et al. (2017), showed a citizen science data set was consistent with that of an expert for rating tree dieback in urban street trees in Sweden. Also, PSHB is a pest that people can see because the holes are easy to identify on infested trees, especially on *Platanus x acerifolia* which has smooth bark. The citizen scientists reported no PSHB infestation on the canopy branches which might be attributed to their failure to distinguish between the main branches and the canopy branches. However, there was a low proportion (1.27%) of trees infested on the canopy branches and this could be a result of an increase in PSHB infestations since the citizen scientists' data was collected in 2020 suggesting that the beetle is spreading within the attacked trees. Fuccillo et al. (2015) suggested that citizens scientists and experts should collect data on the same day to reduce bias of different sampling times. This study also revealed *Platanus x acerifolia* as one of the major trees targeted by the PSHB and this conforms with an earlier study by Paap et al. (2018) that reported the first incidence of PSHB in South Africa on the same tree.

Validating observations from citizen scientists is difficult since in most cases there is no feasible way of accounting for errors because of sampling bias. Additionally, misidentification of tree species can be difficult to account for when data is collected by many citizen scientists. The findings from this study showed that three trees namely *Harpephyllum caffrum*, *Ficus natalensis* and *Brachychiton acerifolius* were not

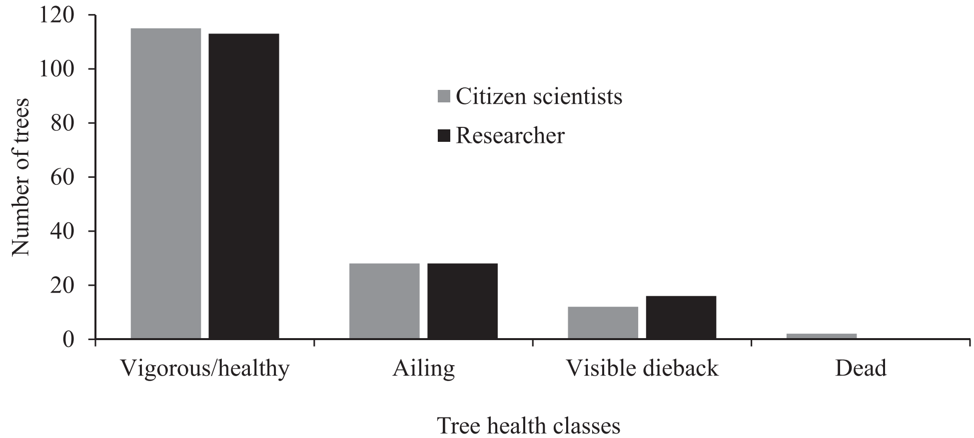


**Fig. 3.** Total number of trees classified by the citizen scientists' (n =157) and the researcher's validation (n = 157) surveyed for tree health status.

**Table 5**
Cross tabulation comparison of the level of agreement between the citizen scientists and researcher's rating for PSHB signs of infestation on tree trunk, main branches, and canopy branches; OA- overall accuracy.

| | | Class | Researcher | | | | |
|---|---|---|---|---|---|---|---|
| | | | Non-infested | Infested | Total | Producer's accuracy (%) | User's accuracy (%) |
| Citizen scientists | Trunk | Non-infested | 104 | 9 | 113 | 95.41 | 92.04 |
| | | Infested | 5 | 39 | 44 | 81.25 | 86.64 |
| | | Total | 109 | 48 | 157 | OA = 91% kappa = 0.89, $p < 0.001$ | |
| | Main branches | Non-infested | 120 | 10 | 130 | 99.17 | 92.31 |
| | | Infested | 1 | 26 | 27 | 72.22 | 96.30 |
| | | Total | 121 | 36 | 157 | OA = 93% kappa = 0.78, $p < 0.001$ | |
| | Canopy branches | Non-infested | 155 | 2 | 157 | 100 | 98.73 |
| | | Infested | 0 | 0 | 0 | 0 | 0 |
| | | Total | 155 | 2 | 157 | OA = 99% kappa = 0.00, $p = 1.00$ | |

**Table 6**
Cross tabulation comparison of level of agreement between citizen scientists and researcher's rating for PSHB infestation signs (oozing and frass); OA- overall accuracy.

| | | Class | Researcher | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Major | Minor | None | Total | Producer's accuracy (%) | User's accuracy (%) |
| Citizen scientists | Oozing | Major | 19 | 0 | 0 | 19 | 76 | 100 |
| | | Minor | 3 | 14 | 2 | 19 | 87.50 | 73.68 |
| | | None | 3 | 2 | 114 | 119 | 98.28 | 95.80 |
| | | Total | 25 | 16 | 116 | 157 | OA = 94% kappa = 0.84, $p < 0.001$ | |
| | Frass | Major | 2 | 0 | 0 | 2 | 50 | 100 |
| | | Minor | 0 | 6 | 1 | 7 | 66.67 | 85.71 |
| | | None | 2 | 3 | 143 | 148 | 99.31 | 96.62 |
| | | Total | 4 | 9 | 144 | 157 | OA = 96% kappa = 0.71, $p < 0.001$ | |

correctly identified to species level by the citizen scientists. With researcher resampling of the citizen science data the error was corrected, and this highlighted the importance of citizen science data validation. A study by Gardiner et al. (2012) revealed lack of training and sampling protocol complexity as contributing factors to identification errors. The PSHB beetle in the city of Johannesburg is spreading, therefore citizen science remains a useful method for providing high quality data for monitoring and management purposes. Additionally, the utilization of other free available platforms like iNaturalist will aid in monitoring and management of PSHB spread of in urban forests (Potgieter et al., 2024).

## 5. Conclusions

In conclusion, engaging the public in science is becoming a key aspect of obtaining scientific data, yet the validity of the data remains debatable. This citizen science project in the Houghton Estate residential area marks the first initiative dealing with the public in monitoring the PSHB beetle in Johannesburg. It allowed us to obtain a large quantity of data at a low cost that correlated well with a researchers' validation dataset. Findings from the citizen science approach will aid in management of the Johannesburg city's urban forest and further research. Overall, our study showed that a citizen science approach is a useful method for monitoring a PSHB beetle attack in a diverse urban forest.

## CRediT authorship contribution statement

**Marcus J. Byrne:** Conceptualization, Supervision, Writing – review & editing. **Solomon W. Newete:** Methodology, Supervision, Writing – review & editing. **Khaled Abutaleb:** Methodology, Supervision, Writing – review & editing. **Marko F. Mudede:** Conceptualization, Investigation, Methodology, Writing – original draft.

## Declaration of Competing Interest

The authors declare that they have no known competing financial

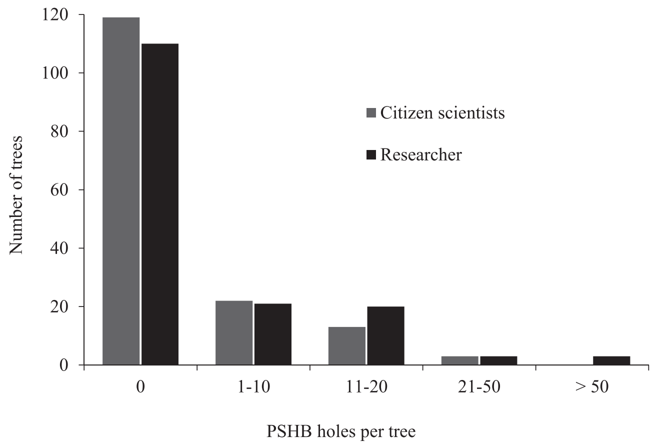


**Fig. 4.** Total number of trees from the citizen scientists' survey (n = 157) and researcher's validation survey (n =157) showing evidence of PSHB holes.

interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Baker, E., Jeger, M., Mumford, J.D., Brown, N., 2019. Enhancing plant biosecurity with citizen science monitoring: comparing methodologies using reports of acute oak decline. J. Geogr. Syst. 21, 111–131.
Barker, E.J., Craig, A., Winmill, A., Meating, J., Karandiuk, C., 2018. Volunteering for forest health: A public-private partnership in Oakville, Ontario, Canada. Arboric. Urban For. 44, 283–290.
Barnard, P., Altwegg, R., Ebrahim, I., Underhill, L.G., 2017. Early warning systems for biodiversity in southern Africa–How much can citizen science mitigate imperfect data? Biol. Conserv. 208, 183–188.
Berland, A., Roman, L.A., Vogt, J., 2019. Can Field Crews Telecommute? Varied Data Quality from Citizen Science Tree Inventories Conducted Using Street-Level Imagery. Forests 10, 349. https://doi.org/10.3390/f10040349.
Bird, T.J., Bates, A.E., Lefcheck, J.S., Hill, N.A., Thomson, R.J., Edgar, G.J., Stuart-Smith, R.D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J.F., 2014. Statistical solutions for error and bias in global citizen science datasets. Biol. Conserv. 173, 144–154.
Branco, M., Nunes, P., Roques, A., Fernandes, M.R., Orazio, C., Jactel, H., 2019. Urban trees facilitate the establishment of non-native forest insects. NB 52, 25–46. https://doi.org/10.3897/neobiota.52.36358.
Butt, N., Slade, E., Thompson, J., Malhi, Y., Riutta, T., 2013. Quantifying the sampling error in tree census measurements by volunteers and its effect on carbon stock estimates. Ecol. Appl. 23, 936–943.
Cohen, J., 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20, 37–46.
Cohn, J.P., 2008. Citizen Science: Can Volunteers Do Real Research? BioScience 58, 192–197. https://doi.org/10.1641/B580303.
Crall, A.W., Newman, G.J., Stohlgren, T.J., Holfelder, K.A., Graham, J., Waller, D.M., 2011. Assessing citizen science data quality: an invasive species case study. Conserv. Lett. 4, 433–442. https://doi.org/10.1111/j.1755-263X.2011.00196.x.
Crow, P., Perez-Sierra, A., Kavčič, A., Lewthwaite, K., Kolšek, M., Ogris, N., Piškur, B., Veenvliet, J.K., Zidar, S., Sancisi-Frey, S., 2020. Using Citizen Science to monitor the spread of tree pests and diseases: outcomes of two projects in Slovenia and the UK. Manag. Biol. Invasions 11, 703.
De Felici, S., Mazzei, P., Sbordoni, V., Cesaroni, D., 2021. Scientists by chance: Reliability of non-structured primary biodiversity data. Insights from Italian Forums of Natural Sciences. Biogeogr. – J. Integr. Biogeogr. 36.
Dickinson, J.L., Zuckerberg, B., Bonter, D.N., 2010. Citizen science as an ecological research tool: challenges and benefits. Annu. Rev. Ecol., Evol., Syst. 149–172.
Eskalen, A., Stouthamer, R., Lynch, S.C., Rugman-Jones, P.F., Twizeyimana, M., Gonzalez, A., Thibault, T., 2013. Host Range of Fusarium Dieback and Its Ambrosia Beetle (Coleoptera: Scolytinae) Vector in Southern California. Plant Dis. 97, 938–951. https://doi.org/10.1094/PDIS-11-12-1026-RE.
Falk, S., Foster, G., Comont, R., Conroy, J., Bostock, H., Salisbury, A., Kilbey, D., Bennett, J., Smith, B., 2019. Evaluating the ability of citizen scientists to identify bumblebee 396 (Bombus) species. PLoS One 14, e0218614.
Francis, R.A., Chadwick, M.A., 2015. Urban invasions: non-native and invasive species in cities. Geography 100, 144–151.
Fuccillo, K.K., Crimmins, T.M., De Rivera, C.E., Elder, T.S., 2015. Assessing accuracy in citizen science-based plant phenology monitoring. Int J. Biometeorol. 59, 917–926. https://doi.org/10.1007/s00484-014-0892-7.
Gardiner, M.M., Allee, L.L., Brown, P.M., Losey, J.E., Roy, H.E., Smyth, R.R., 2012. Lessons 403 from lady beetles: accuracy of monitoring data from US and UK citizen-science 404 programs. Front. Ecol. Environ. 10, 471–476.
Hardy, C.H., Nel, A.L., 2015. Data and techniques for studying the urban heat island effect in Johannesburg. Int. Arch. Photogramm., Remote Sens. Spat. Inf. Sci. 40, 203–206.
Horvath, J., Cameron, R., 2015. Citizen Science and Open Source Labs. The New Shop Class. Springer, pp. 73–83.
Hulbert, J.M., Turner, S.C., Scott, S.L., 2019. Challenges and solutions to establishing and sustaining citizen science projects in South Africa. South Afr. J. Sci. 115, 1–4.
Kosmala, M., Wiggins, A., Swanson, A., Simmons, B., 2016. Assessing data quality in citizen science. Front. Ecol. Environ. 14, 551–560. https://doi.org/10.1002/fee.1436.
Landis, J.R., Koch, G.G., 1977. An Application of Hierarchical Kappa-type Statistics in the Assessment of Majority Agreement among Multiple Observers. Biometrics 33, 363. https://doi.org/10.2307/2529786.
Larson, E.R., Graham, B.M., Achury, R., Coon, J.J., Daniels, M.K., Gambrell, D.K., Jonasen, K.L., King, G.D., LaRacuente, N., Perrin-Stowe, T.I., Reed, E.M., Rice, C.J., Ruzi, S.A., Thairu, M.W., Wilson, J.C., Suarez, A.V., 2020. From eDNA to citizen science: emerging tools for the early detection of invasive species. Front Ecol. Environ. 18, 194–202. https://doi.org/10.1002/fee.2162.
Malek, R., Tattoni, C., Ciolli, M., Corradini, S., Andreis, D., Ibrahim, A., Mazzoni, V., Eriksson, A., Anfora, G., 2018. Coupling traditional monitoring and citizen science to disentangle the invasion of *Halyomorpha halys*. ISPRS Int. J. Geo-Inf. 7, 171.
Mendel, Z., Protasov, A., Sharon, M., Zveibil, A., 2012. An Asian ambrosia beetle Euwallacea fornicatus and its novel symbiotic fungus Fusarium sp. pose a serious threat to the Israeli avocado industry. Phytoparasitica 40, 235–238. https://doi.org/10.1007/s12600-012-0223-7.
Miller-Rushing, A., Primack, R., Bonney, R., 2012. The history of public participation in ecological research. Front. Ecol. Environ. 10, 285–290.
Paap, T., De Beer, Z.W., Migliorini, D., Nel, W.J., Wingfield, M.J., 2018. The polyphagous shot hole borer (PSHB) and its fungal symbiont *Fusarium euwallaceae*: a new invasion in South Africa. Australas. Plant Pathol. 47, 231–237. https://doi.org/10.1007/s13313-018-0545-0.
Pocock, M.J., Evans, D.M., 2014. The success of the horse-chestnut leaf-miner, *Cameraria ohridella*, in the UK revealed with hypothesis-led citizen science. PloS One 9, e86226.
Roman, L.A., Scharenbroch, B.C., Östberg, J.P., Mueller, L.S., Henning, J.G., Koeser, A.K., Sanders, J.R., Betz, D.R., Jordan, R.C., 2017. Data quality in citizen science urban tree inventories. Urban For. Urban Green. 22, 124–135.
Poland, T.M., Rassati, D., 2019. Improved biosecurity surveillance of non-native forest insects: a review of current methods. J. Pest Sci. *92* (1), 37–49.
Potgieter, L.J., Cadotte, M.W., Roets, F., Richardson, D.M., 2024. Monitoring urban biological invasions using citizen science: the polyphagous shot hole borer (Euwallacea fornicatus). J. Pest Sci. 1–13.
Redolfi De Zan, L., Rossi De Gasperis, S., Andriani, V., Bardiani, M., Campanaro, A., Gisondi, S., Hardersen, S., Maurizi, E., Mosconi, F., Nardi, G., Zapponi, L., Rombolà, P., Romiti, F., 2023. The Big Five: Species Distribution Models from Citizen Science Data as Tool for Preserving the Largest Protected Saproxylic Beetles in Italy. Diversity 15, 96. https://doi.org/10.3390/d15010096.
Richardson, D.M., Rejmánek, M., 2011. Trees and shrubs as invasive alien species – a global review. Divers. Distrib. 17, 788–809. https://doi.org/10.1111/j.1472-4642.2011.00782.x.
Ryan, R.L., 2015. The transformative power of engaging in urban greening projects. Cities Environ. (CATE) 8, 6.
Schäffler, A., Swilling, M., 2013. Valuing green infrastructure in an urban environment under pressure—The Johannesburg case. Ecol. Econ. *86*, 246–257.
Silvertown, J., 2009. A new dawn for citizen science. Trends Ecol. Evol. 24, 467–471.
Steininger, M.S., Hulcr, J., Šigut, M., Lucky, A., 2015. Simple and Efficient Trap for Bark and Ambrosia Beetles (Coleoptera: Curculionidae) to Facilitate Invasive Species Monitoring and Citizen Involvement. J. Econ. Entomol. 108, 1115–1123. https://doi.org/10.1093/jee/tov014.
Townsend, G., van Rooyen, E., Hill, M., De Beer, W., Roets, F., 2024. Invasion of an Afrotemperate forest complex by the polyphagous shot hole borer beetle. Entomol. Exp. Et. Appl.
Turton, A., Schultz, C., Buckle, H., Kgomongoe, M., Malungani, T., Drackner, M., 2006. Gold, scorched earth and water: the hydropolitics of Johannesburg. Water Resour. Dev. 22, 313–335.
Umeda, C., Eskalen, A., Paine, T.D., 2016. Polyphagous Shot Hole Borer and Fusarium Dieback in California. In: Paine, T.D., Lieutier, F. (Eds.), Insects and Diseases of Mediterranean Forest Systems. Springer International Publishing, Cham, pp. 757–767. https://doi.org/10.1007/978-3-319-24744-1_26.
Van Rooyen, E., Paap, T., Beer, W., de, Townsend, G., Fell, S., Nel, W.J., Morgan, S., Hill, M., Gonzalez, A., Roets, F., 2021. The polyphagous shot hole borer beetle: Current status of a perfect invader in South Africa. South Afr. J. Sci. 117, 1–10.

Weckel, M.E., Mack, D., Nagy, C., Christie, R., Wincorn, A., 2010. Using citizen science to map human- Coyote interaction in suburban New York, USA. J. Wildl. Manag. 74, 1163–1171.

Werenkraut, V., Baudino, F., Roy, H.E., 2020. Citizen science reveals the distribution of the invasive harlequin ladybird (*Harmonia axyridis Pallas*) in Argentina. Biol. Invasions 22, 2915–2921.

Zhao, M., Kong, Z., Escobedo, F.J., Gao, J., 2010. Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. J. Environ. Manag. 91, 807–813.