Towards a real-time tracking of an expanding alien bee species in Southeast Europe through citizen science and floral host monitoring

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Abstract

Citizen science, a practice of public participation in scientific projects, is popular in Western countries, however, it is still a relatively novel approach in Southeast Europe. In this region, citizen science can be a useful tool for increasing the understanding of alien species. One such species is the sculptured resin bee, Megachile sculpturalis, a putatively invasive alien pollinator native to East Asia. It was introduced to France in 2008, from where it quickly spread across West and Central Europe. However, our knowledge of its eastern distribution is scarce since it is based mostly on isolated findings. We combined citizen science and data extraction from online sources (e.g., naturalist’s databases and social media) covering 6 years, and 3 years of targeted floral resource monitoring in the search for M. sculpturalis across regions of southeastern Europe. We collected presence data and information on M. sculpturalis abundances across an urban–rural gradient from eight countries: Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Montenegro, Romania, Bulgaria, and the region of the Crimean Peninsula. We present the first country records for Romania, Bulgaria, and Montenegro, identify the dynamic expansion front in southern Serbia and provide new southernmost occurrences in Southeast Europe. We also collected data on species ecology (e.g., phenology, pollen/nectar sources, nest characteristics) and gathered evidence of reproducing populations of this species across the studied region. Citizen science data provided a five times larger spatial coverage, including recordings from remote locations, than the data collected by expert field surveys and provided critical additional data about the species biology, thanks to exceptionally engaged participants. We emphasize the importance of close collaboration between regional scientist teams and citizen participants and the benefits of this approach for monitoring a species with a continent-wide spread potential.

1. Introduction

Invasive alien species are recognized as one of the main drivers of global biodiversity decline [1–4], with numbers on the rise over the last 60 years [5]. Detections of early phases of incipient invasions are rare [6], likely due to initially low population densities and limited geographical extent [7–9], but are crucial for understanding invasion processes and successful management [10, 11]. In most cases, newly introduced species are only detected once the populations have become abundant; thus, reconstructing the invasion history becomes difficult [9]. Moreover, the feasibility of management depends on the particular stage of the invasion process [12], with eradication programs being more successful in the early stages [13, 14]. Consequently, there is a
pressing demand for surveillance and monitoring of invasive alien taxa to enable early detection, particularly at dynamic expansion fronts or trajectories [15].

Citizen science, a practice of including non-professional citizens in data collection and other aspects of research and conservation, can represent a valuable and effective tool as an early-warning system for invasive alien species [16] as well as for long-term monitoring of species spread [15, 17]. Citizen science approaches have the potential to cover large geographic and temporal scales and provide data collected on private property, which would otherwise be inaccessible to scientists [18]. Despite some limitations of citizen science, e.g., observer and sampling biases [18–20], this approach has gained popularity and momentum in many western countries [21], including assessment of pollinator status and pollination services [22]. However, citizen science is a rather unexploited approach within Southeast Europe [23–25], still novel for investigating regional biodiversity. Noteworthy, the region of Southeast Europe has documented several introductions of alien taxa [26, 27].

*Megachile sculpturalis* Smith, 1853 has been the focus of several research projects in western and central Europe, including citizen science initiatives (e.g., [28–30]). The sculptured resin bee is native to East Asia. In Europe, it was first found near Marseille (France) in 2008 [31] and soon after (2009–2010) in northwestern Italy and Southern Switzerland [32, 33]. In the following years, the species’ range extended almost continuously across several western and central European countries: from France to Spain, south-eastwards throughout Italy, and north-eastwards through Switzerland to Germany and Austria [28, 34–39]. Spreading in Central Europe continued as separate dispersal processes, from SE-Hungary southwards (since 2015) and W-Slovenia eastwards (since 2016) [40–43]. In the countries of southeastern Europe, *M. sculpturalis* was first detected in Serbia (2017), followed by Croatia (2018), Romania (2019), Bosnia and Herzegovina (2020), and most recently in Bulgaria (2021) [43–48]. The most remote eastern occurrence was detected in the Crimean Peninsula in 2018 [49]. Large distances of many hundred kilometers between the initially isolated occurrences indicate human-mediated long-distance dispersal [28, 45]. Furthermore, a recent population genetic study detected two genetically distinct groups of *M. sculpturalis*, a western and an eastern population, suggesting at least two introduction events in Europe [50].

*Megachile sculpturalis* is a protandrous (males emerge before females) wild bee species, active during the summer, from mid-June to mid-September [39, 51]. Females are cavity-nesters, using pre-existing cavities in dead wood, hollow stems, and other materials. A significant negative correlation was detected between the presence of the sculptured resin bee and native species using the same artificial nests [52]. Documented competitive behavior includes nest evictions [28, 53, 54], nest blocking [55], and direct aggressive behavior [56]. Previous studies have already considered the bee as an invasive alien species mostly due to its rapid range expansion and the observed competitive behavior [39, 57]. We prefer to abstain from using the term ‘invasive’ until effects on native pollinators, native flora, and pollination networks have been carefully evaluated. Regardless of terminological controversies in invasion biology [58, 59], this alien bee needs to be closely monitored, considering the widespread decline of wild pollinator species in Europe [4].

Among the key factors affecting the species’ establishment and colonization success, introduced bees are principally dependent on the availability of food and nesting resources, which may vary significantly between the main classes of habitats, landscapes, and/or land-use modes [60, 61]. In particular, the suitability and distribution of pollen-source plants might be essential for the spread of *M. sculpturalis*. In terms of foraging preferences, the species is widely referred to as polylectic [39, 62–64], although in Europe, females were documented to collect pollen of relatively few plants, principally *Styphnolobium japonicum, Wisteria sinensis, Lathyrus sp., Ligustrum sp.*, and *Tetradium daniellii* [33, 35, 36, 65, 66]. Since exotic ornamental plants are currently documented as dominant food sources throughout the species’ non-native range, many European records are associated with various human settlements, urban and rural. *Megachile sculpturalis* seems to thrive in urban areas [67], following the concentration of s foraging resources [42, 43], and abundant nesting opportunities [68]. The complicated interplay of these factors may also vary over time through the effects of temporal food variability and the early dynamics of local bee population build-up (cf [42, 43]). On the other hand, detections’ incidence and spatial pattern are expectedly biased towards more densely populated human settlements. Former citizen science approaches also report controversial results on spatial recording bias [17, 69, 70]. For the scope of this study, it is of great interest to explore how the frequency of *M. sculpturalis* detections varies along the urbanization gradients, particularly concerning the types and intensity of recording approaches (citizen science versus targeted key floral resource monitoring).

We aimed to improve our understanding of the current distribution of *M. sculpturalis* in Southeast Europe and to track its ongoing southeastern expansion. Considering its rapid spreading potential, we predicted that *M. sculpturalis* has spread and established broadly in Southeast Europe. To test this, we conducted researcher-led sampling on key floral resources combined with a citizen science program and data extraction from online sources. Previous studies showed that integrating data from various sources provided high spatial coverage and efficient resource management, especially when the public was asked to report (invasive) alien species [70–72].

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We predicted that citizen science data would reveal a much broader distribution than the floral host monitoring by a team of researchers.

2. Material and methods

2.1. Study area
The study region encompassed the eastern and southeastern expansion fronts of M. sculpturalis in Europe. This included most of the countries from the Balkan Peninsula (Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Albania, North Macedonia, Romania, Bulgaria, and Greece) and two adjacent Central European countries (Slovenia and Hungary). We referred to the study area as Southeast Europe for the simplicity of reporting while acknowledging the inconsistency in this term (topographical versus political versus biogeographical). We also report data from the Crimean Peninsula to cover the entire eastern extent of the M. sculpturalis distribution in Europe (supplementary figure S1 (available online at stacks.iop.org/ERC/4/085001/mmedia)).

2.2. Data collection
We collected data using two main approaches: 1) systematic/targeted fieldwork by researchers, and 2) opportunistic, mostly citizen science data (figure 1). Systematic/targeted fieldwork followed a protocol designed specifically for M. sculpturalis in a previous project [42]. Opportunistic data was collected within citizen science projects and did not follow standardized field protocols [73, 74]. Additionally, this data set included searching online data sources for M. sculpturalis records.

2.2.1. Opportunistic recording
Citizen science data was gathered via contributory citizen science approaches (after Miller-Rushing et al [75] and Shirk et al [76]), within two European citizen science projects established for this purpose (Central Europe: http://www.beeradar.info since 2018; Serbia: https://srbee.bio.bg.ac.rs/azijska-pcela-smolarica/azijska-pcela-projekat-ucesco since 2020). Two research teams published calls for reports on their homepages in late spring and summer before and during the known activity period of the species for three consecutive years (2019–2021). Calls were advertised in print, online web pages, on local and national TV and radio stations (data collection ‘CSP interaction (via conventional media)’, and on social media (data collection ‘CSP interaction (via social media)’, e.g., Facebook, Instagram, Twitter, various blog posts; figure 2; [77, 78]). Report calls were written in the language of the countries where they were published, but with the most important information available in English to enable participation beyond the initially targeted countries (e.g., Slovenia, Greece, Hungary).

Participants reported observations of the target species via social media, contact forms on project homepages, email, or mobile phones. Reports included a mandatory photo or video of the specimen,
observation date, and location (coordinates, ZIP code). We validated all photos by assigning species identifications to observations and provided feedback directly to the participants (figure 1). In addition to species record data, which was our primary focus [79], we asked participants to specify their observations to obtain additional information on biotic interactions and ecological preferences termed ‘secondary data’ (figure 1), following Callaghan et al [80] and Wang Wei et al [81]. We used submitted images to determine host plants, bee nesting activity, the number and sex of the individuals, and direct or indirect competing behavior. We also asked participants where they had heard about the project to improve our outreach ability in the future.

Web data extraction: We manually searched four public naturalists’ platforms (data collection ‘retrieval from naturalists’ databases’, see supplementary table S1c) for records of the sculptured resin bee, as well as various local social media groups (data collection ‘extraction from social media’) using keyword searches ‘sculpturalis’, ‘megachile sculpturalis’, ‘giant resin bee’, ‘sculptured resin bee’, and available common names for this species in local languages, ‘azijiska pčela smolarica’ (used so far in Serbia, Bosnia & Herzegovina and Croatia) and ‘őriás műveszméh’ (in Hungary); for a complete list of searched Facebook groups see supplementary table S1c) [74, 77]. We also searched for internet-based publications on web pages and blog posts for records (data collection ‘web data extraction - miscellaneous’).

2.2.2. Systematic/targeted research

Data was gathered by repeated (3–10) observations of blooming essential floral resources (supplementary table S1d) during the periods of M. sculpturalis activity (July and August), and under optimal weather conditions (sunny to partly cloudy days, with no rain or strong wind). The localities of the plants of interest were either recorded during previous fieldwork or by additional targeted fieldwork searches, often owing to information from citizen scientists. Floral monitoring was mostly conducted by experienced researchers (authors), except in one location in Greece, where citizen scientists were also engaged. If the study species was found, we recorded the number of individuals (timed counts in combination with snapshot counts - methodology described in [43]), collected specimens if possible, and documented the abundance and blooming status of plants following the protocol described by Bila Dubać et al [43]. This protocol also allowed us to gather data on ‘not detected’ records for study sites (figure 3): when necessary conditions were met (optimal weather conditions and the sufficient abundance of blooming key floral resources), but no records of M. sculpturalis were obtained [79, 82–85].

2.3. Data exploration

Reported sites less than 250 m apart were merged into a single location. To characterize the recording locations for the urban-rural-natural gradient, we used the degree of urbanization approach based on the human population distribution grid 'JRC-GEOSTAT 2018' [86] and two additional grids from DG AGRI and DG REGIO [87–89]. Each location is assigned to one of the three main categories based on 1 × 1 km resolution grid cells and their clustering pattern [89]: (a) ‘high-density clusters’ (contiguous grid cells with ≥1,500 inhabitants each and a total population of ≥50,000, corresponding to urban centers), (b) ‘urban clusters’ (contiguous grid
cells with \( \geq 300 \) inhabitants each, and a total population of \( \geq 5,000 \), or (c) ‘rural grid cells’ (cells outside urban clusters: cells with less than 300 inhabitants each, or cells with higher density but not contiguous with urban clusters). This analytical scale is suitable for capturing both the variability of effective human presence (and respective activity) and the foraging activity pattern of a large, highly mobile bee species. To enable a more meaningful resolution among various landscape types within the broad category ‘rural grid cells’, we divided it into convenient sub-categories: ‘rural/moderate density’ (cells having \( \geq 25 \) inhabitants each), and ‘rural/low density’ (cells having < 25 inhabitants each). For a straightforward reference to the simplified landscape ecology context, hereafter, we use the terms: urban/high density, urban/intermediate density, rural/moderate density, and rural/low density landscapes.

To process georeferenced data and produce maps we used ArcGIS Pro 2.8.3 [90]. We used the Minimum Bounding Geometry tool in ArcGIS to calculate minimum convex polygons; and in RStudio [91] alpha hulls with relaxed assumptions of connectivity of data points allowing for disconnected hulls and convex angles of the hulls using the packages ‘alphahull’ [92], ‘sf’ and ‘sp’ [93] with alpha = 2 according to IUCN recommendations [94] to compare the hull sizes, separately for two main data sources - opportunistic recordings and systematic/targeted research (figure 3; supplementary figure 4). However, we excluded isolated records from Bulgaria and Romania from the hulls since they might represent long-distance dispersal events (cf [43]) similar to those found on the Crimean Peninsula, i.e., not yet a continual distribution.

3. Results

In total, we compiled 270 records of the sculptured resin bee from 178 locations in seven countries of the Southeast European region and the Crimean Peninsula (figure 3, table 1; supplementary table S1a). Opportunistic recording provided 133 records from 114 locations, two of which are the first country records: Romania (2019) and Bulgaria (2021) (records #074 and #008; see supplementary table S1a for respective data sources). Our systematic/targeted field research resulted in 137 records from 64 locations, including the first country record for Montenegro in 2021 (published herewith). We also tentatively documented the species’ absence from Greece and parts of Montenegro based on a targeted field search at three localities (figure 3; supplementary table S1b). The study area of documented bee presence based on opportunistic recordings was estimated as five times bigger than the area of our systematic/targeted research coverage (minimum convex
3.1. Opportunistic data recording
In total, 71 records of *Megachile sculpturalis* (26% of total records) originated from our citizen science projects: 46 from interaction via social media, seven from interaction via conventional media, and 18 from miscellaneous types of interactions (documented and reported by colleagues, by self-initiated internet research, or by family members of the authors). Intensive searches on social media platforms yielded 38 records, including the first record for Romania (data collection ’extraction from social media’), while ‘retrieval from naturalists’ databases’ delivered 17 records. Further, seven records were from miscellaneous source types. Opportunistic observations displayed 49 bee-plant interactions, including 17 plant taxa (supplementary table S1d).

Data sources were unevenly distributed across the urban-rural gradient, as citizen science provided mostly data from urbanized areas (figure 4). The greatest share of recording locations are in the category of urban/high density — 96 (55%); 38 are in urban/intermediate density (22%); 44 are in rural/moderate density (16%), and 16 in rural/low density landscape types (9%) (supplementary figure 3). The altitudes of the recorded locations ranged from 0 to 1,060 m (supplementary table S1a). There was one exceedingly late record in Hungary, a live female observed on 1st October.

Out of all reported records, 41% were verified as our target species, and the remaining observations were misidentifications, most commonly of *Bombus pascuorum* (23%) and *Apis mellifera* (20%). Few other insects were also reported (1–6 times): other Anthophila (*Amegilla* sp., *Andrena* sp., *Bombus* sp., *Halictus* sp., *Lithurgus*...
Megachile sp., Xylocopa sp.), Scoliidae (Scola sp., Megascolia maculata), Vespidae (Polistes sp., Eumeninae nest); Sphecidae; Syrphidae and other Diptera.

One particularly engaged citizen scientist family in Serbia provided information on life history traits (and participated in collecting specimens). They provided data on bee numbers for two nests, using emergence cages they constructed to enable observations (figure 4). During the 9 days in the early summer of 2021 (supplementary table S2; figure 5), 19 individuals (15 females and four males) emerged from a completed nest (figure 5(a): the rectangular cage on the right side). The nest consisted of a tunnel 16.5 cm deep and 14 mm in

Figure 5. Details of a citizen-scientist conducted study of M. sculpturalis nesting during 2020–2021: (a) ‘emergence cages’ set after the season of 2020 for trapping the individuals emerging in 2021; (b) freshly emerged male and female of M. sculpturalis (c) the first bee hatched in 2021, managed to bite through the modeling balsa wood lid, and escaped (d) a female closed the nest with resin and plant material; (e) a female built its nest inside a hollow plastic syringe, inserted into the cavity in wood; All photographs are taken by R. Samurović, CC by 4.0.
diameter. Four specimens emerged from the incomplete nest (figure 5(a): the rounded cage on the left side) during the same period, with two females, one male, and one specimen of unknown sex (supplementary table S2).

3.2. Systematic/targeted data recording

The floral resource monitoring approach conducted in 2019, 2020, and 2021 resulted in 136 presence records from 63 locations: 54 in Serbia (2019–2021), five in Bosnia and Herzegovina (2020), and four in Montenegro (2021) representing the first record of _M. sculpturalis_ for this country (figure 3). In Montenegro, observed population densities ranged from five individuals to aggregations containing more than 30 bees. In total, 129 bee-plant interactions were recorded at ten plant taxa (supplementary table S1d).

During seven independent 15-minute observations (five by an engaged citizen scientist, two by researchers) of two floral resources (_Strychnolidium japonicum_ sp and _Vitex agnus-castus_) in Greece across five locations (supplementary table 1b), no individuals of _M. sculpturalis_ were spotted.

Recordings gathered by systematic/targeted research are mostly located in highly urbanized areas - urban/high density (51%), and urban/intermediate density (30%). Rural locations are much less represented in this data set (11% for both sub-categories (figure 4); most of these rural locations were first reported by citizen scientists, and then re-visited by experts.

4. Discussion

We report the range expansion of _M. sculpturalis_, across countries of Southeast Europe. Citizen science data provided about five times larger geographical coverage than fieldwork by researchers, as well as a longer time period of records (dating back to 2017). Before extended focused research was initiated after 2019 (cf [42, 43]), only scattered evidence was formally published in the scientific literature [40, 41, 44, 49] or made available via well-known international platforms [95, 96] for this region. Web data extraction from social media and local naturalists’ sources provided essential information for the reconstruction of the early colonization history in the region. In contrast, repeated visitation of the same localities and use of standardized sampling provided data about population dynamics, especially useful in the case of (potentially) invasive species. To obtain observations of the target species from least populated areas (rural/moderate density and rural/low density), it is advised to use different methods. We show that different collecting approaches complement each other and provide comprehensive information on the distribution and ecology of the target species.

4.1. Range expansion in southeast/east europe

Records presented in this study confirm the successful spread of _Megachile sculpturalis_ in Southeast European countries (figure 3; supplementary figures S1–S2). Previously published findings for most countries were generally sporadic [40–43, 49], except for Serbia and Hungary [42, 43]. We compiled numerous further findings, particularly from 2021, with the most remarkable growth of recording incidence in Croatia. Our data on reproducing populations over several years confirm that _M. sculpturalis_ is now naturalized and widespread in the region, presumably fully established several seasons ago. The two southeasternmost records from Serbia (Niš and Vlasotince) and one easternmost (Negotin) are interesting as they represent the ‘apparent’ range expansion of about 140–150 km in the period 2020–2021 (supplementary figure S6). Remarkably, the intensive field search during the season of 2020 in Niš [43] yielded no records, indicating a recent colonization of this area. However, even the intensive and detailed field search for such a large and distinctive bee may not result in successful detection during the early phases of local colonization due to initially low population abundance [43]. Accordingly, we may regard the area of southeastern to eastern Serbia as a tentative but very widely defined southeastern expansion front. This does not imply that the bee could spread effectively and continually with such a speed (150 km/year). Rather, our focused and tedious floral resource monitoring, combined with citizen engagement, may closely approach the ideal of real-time expansion tracking by reducing the usual time lag between the spreading dynamics and detection within/along well-defined fronts and trajectories.

We documented the presence of _M. sculpturalis_ in several coastal locations in Montenegro, representing the new country record and the southernmost occurrence in Southeast Europe known so far. The Montenegro population also represents the most southeastern location on the Adriatic coast, most likely resulting from the continuous eastward spread along the coastline of Croatia (Supplementary figure S2).

In contrast with the surrounding countries (Croatia and Serbia), where we confirmed the widespread presence of _M. sculpturalis_, there are still very few findings in Bosnia and Herzegovina, as well as most of Montenegro and SW-Serbia. The Dinaric Mountains range stretching across this area probably represents a dispersal barrier for coastal populations. On the other hand, Bosnia’s mostly lowland peri-Pannonian zone was presumably already colonized from the north—more widely than currently documented [42].
Our data (supplementary table S1) indicates the existence of two main expansion trajectories in Southeast Europe: from the E-Pannonian core (2015) southward-southwestward and from N-Italy (2014–2015) through Slovenia (2016–2018) eastward-southeastward, along the Adriatic coast of the western Balkans (Supplementary figure S2). The spreading trajectory along the Adriatic coast was probably not yet merged with the Pannonian-central-Balkans expansion axis through Serbia. However, the two sections of the eastern range were most likely merged within Croatia and/or Slovenia before 2021. We have no indication if it has reached the southern Balkans (North Macedonia, Albania, and Greece), but this is expected in the near future. A similar spatial pattern of spreading and detection within Southeast Europe was documented for a few introduced species of apoid Hymenoptera [27, 97, 98]. The ongoing studies on the genetic structure of the Balkan populations should provide a clearer image of colonization routes and dynamics in this region.

The first records of *M. sculpturalis* for Romania (from 2019) and Bulgaria (from 2021) are both remote from other Southeast European records. The Romanian record is positioned about 450 km linear distance from the closest contemporary record in Serbia (reduced to 290 km in 2021) and 630 km from the records in the Crimean Peninsula. The Bulgarian record is positioned 300 km away from the closest records in southern Serbia, 740 km from the Crimean Peninsula, and 230 km to the Romanian record. These two records in the eastern Balkans might indicate further cases of long-distance dispersal events, similar to the ones in Hungary [28, 40] and the Crimean Peninsula (figure 3; [49]). The lack of further records probably indicates insufficient investigations, but the species establishment needs yet to be confirmed in both countries, Romania and Bulgaria. The addition of two more and repeated records over four years in the Crimean Peninsula (now spanning about 65 km) and first findings of nesting females outside the Peninsula in Odessa, Ukraine [99] in 2022 clearly confirm that *M. sculpturalis* is fully established in that region.

### 4.2. Functional biotic interactions revealed by participants

Aside from occurrence records, citizen scientists documented important aspects of the ecology of *M. sculpturalis*, such as interactions with host plants. Two formerly unknown host plant species for *M. sculpturalis* were documented (*Dipsacus* sp. and *Jacobaea maritima*), which contribute to still inadequate understanding of the diet breadth of this species. Although the targeted searches on floral resources counted higher numbers of discrete bee-plant interactions, the opportunistic recordings documented more plant taxa, including several nectar sources. However, both approaches resulted in frequent documentation of *S. japonicum* (supplementary table S1a, d), supporting previous hypotheses on the importance of this pollen provisioner for the successful establishment of this pollinator [33, 43]. In the future, the foraging behavior of the bee and various other aspects of functional biotic interactions should be examined (e.g., interactions with other pollinators) for a better understanding of the invasiveness potential of this alien species and to test keystone hypotheses in invasion ecology [100, 101].

### 4.3. Limitations of citizen science in southeast europe

Data gathered by citizen science approaches can differ in quality. It can be influenced by major biases: uneven spatial coverage, recording density, sampling efforts, and species detectability across space and time [19, 102]. In an attempt to overcome these issues, we integrated data from various approaches by combining structured data gathered by a floral host protocol and unstructured data derived by opportunistically obtained observations of participants. Despite our efforts to integrate data from various sources, we can not rule out that our data set, especially the systematic/targeted search, reflects a sample bias towards urban areas. Rural recordings were largely provided by citizen scientists (89%), some from very remote, inaccessible locations, thereby providing valuable information about this species’ spread, dispersal ability, and behavior. Thus, complementary monitoring regimes conducted by field ecologists and citizen scientists provided reliable presence and absence data - both important for following the expansion of *M. sculpturalis*.

### 4.4. Social media and public outreach

The large size and unique appearance of the sculptured resin bee enables species recognition by a broader public. Distinctive features of *M. sculpturalis* can be used in public outreach to communicate more efficiently about global species homogenization and draw attention to the project [78, 95, 96, 103]. The educational aspects of citizen science programs dealing with (invasive) alien species are especially relevant for preventing future introductions [78, 104, 105].

Calls for (invasive) alien species monitoring on different social platforms can reach widespread and heterogeneous audiences resulting in numerous reports [106]. Naturalist forums on social networks store rich biodiversity data sets and are too valuable not to be considered or included in monitoring efforts [107], while the role of the users and data collectors as citizen scientists should be acknowledged. Hence, social media is an...
efficient tool for science communication, advertising, and disseminating calls for participation, and is a source for data extraction of biological information, as we demonstrated [74, 78, 108, 109]. Language can be a barrier when working on cross-country and multilateral cultural scales [110]. For example, data extraction on social media comes with challenges, as misspellings and misidentification are common. Hence, a simple keyword search (e.g., ‘sculpturalis’) is usually not enough. Also, considering that many people on social media national groups use common names in their official language for M. sculpturalis, it is critical to have a native speaker in the network.

5. Conclusion

We demonstrated the effectiveness of citizen science as a research approach and social media as an efficient tool in data collection for an insufficiently studied region of Southeast Europe. The citizen science approach enabled collecting data from otherwise inaccessible areas, such as private properties, sparsely populated rural areas, and a much larger geographical range than sampled through the targeted fieldwork. Our study also highlights how individual citizen scientists can show enormous dedication, self-initiative, and provide valuable information.

Furthermore, we demonstrated that combining citizen science and research-led targeted fieldwork is an effective approach for investigating the distribution and expansion fronts of highly mobile and fast-spreading potentially invasive alien species, such as M. sculpturalis. While citizen science provided broader geographic coverage, targeted field work provided new insights into the current southeastern range expansion.

We see an urgent need to broaden the search efforts and further investigate the ecology of the sculptured resin bee. We propose that citizen science projects should be launched in other European countries within the species’ known and potential future range. Collaborations between research groups, researchers, and volunteers in the framework of citizen science projects and the exchange of experience among involved parties can result in mutually beneficial knowledge. Citizen science projects could be further improved by developing multidisciplinary cooperation of biologists and computer scientists (e.g., for automated data mining or/and managing highly heterogeneous data sources, machine learning approaches). We conclude that citizen science studies are an efficient tool for biodiversity surveys and public outreach, especially in low-income regions such as Southeast Europe.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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References

[1] Potts S G, Biesmeijer J C, Kremen C, Neumann P, Schweiger O and Kunin W E 2010 Global pollinator declines: trends, impacts and drivers Trends Ecol Evol 25 345–53
[2] Bellard C, Cassey P and Blackburn T M 2016 Alien species as a driver of recent extinctions Biol Lett 12 20150623
[3] Sánchez-Bayo F and Wyckhuys K A G 2019 Worldwide decline of the entomofauna: A review of its drivers Biol Conserv 232 8–27
[4] IPBES 2019 Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services ed E S Brondizio, J Settele, S Díaz and H T Ngo (Bonn, Germany: IPBES secretariat) https://ipbes.net/global-assessment
[5] Seebens H et al 2017 No saturation in the accumulation of alien species worldwide Nat Commun 8 14435
[6] Puth L M and Post D M 2005 Studying invasion: have we missed the boat! Ecol Lett 8 715–21
[7] Crooks J A 2005 Lag times and exotic species: The ecology and management of biological invasions in slow-motion Écoscience 12 316–29
[8] Lockwood J, Hoopes M and Marchetti M 2006 Invasions Ecology (Carlton, Australia: Blackwell Publishing)
[9] Hui C and Richardson D M 2017 Invasion dynamics (Oxford: Oxford University Press)
[10] Myers J H, Simberloff D, Kuris A M and Carey J R 2000 Eradication revisited: dealing with exotic species Trends Ecol Evol 15 316–20
[11] Simberloff D 2008 We can eliminate invasions or live with them. Successful management projects Biol Invasions 11 149–57
[12] Blackburn T M, Pysek P, Bacher S, Carlton J T, Duncan R P, Jarosik V, Wilson J R and Richardson D M 2011 A proposed unified framework for biological invasions Trends Ecol Evol 26 333–9
[13] Genovesi P, Scalera R, Brunel S, Roy D B and Solarz W 2010 Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe European Environment Agency 52
[14] Perrings C, Mooney H and Williamson M 2010 Biodiversification and globalization: ecology, economics, management, and policy BioScience 60 651–2
[15] Roy H E, Rorke S L, Beckmann B, Booy O, Botham M S, Brown P M J, Harrower C, Noble D, Sewell J and Walker K 2015 The contribution of volunteer recorders to our understanding of biological invasions Biol J Linn Soc 115 678–89
[16] Geoghegan H, Dyke A, Pateman R, West S and Everett G 2016 Understanding motivations for citizen science. Final report on behalf of UK ECOF 124 University of Reading, Stockholm Environment Institute (University of York) and the West of England, on behalf of the UK Environmental Observation Framework 1–120 (https://ukecof.org.uk/resources/citizen-science-resources/MotivationsforCSREPORTFINALMay2016.pdf)
[17] Silvertown J 2009 A new dawn for citizen science Trends Ecol Evol 24 467–71
[18] Dickinson J L, Zuckerberg B and Bonter D N 2010 Citizen science as an ecological research tool: challenges and benefits Annu Rev Ecol Evol Syst 41 149–72
[19] Isaac N J B, van Strien A J, August T A, de Zeeuw M P, Roy D B and Anderson B 2014 Statistics for citizen science: extracting signals of change from noisy ecological data Methods Ecol Evol 5 1052–60
[20] Ward D F 2014 Understanding sampling and taxonomic biases recorded by citizen scientists J Insect Conserv 18 753–6
[21] Requier F, Andersson G K S, Oddé F J and Gariibaldi L A 2020 Citizen science in developing countries: how to improve volunteer participation Front Ecol Environ 18 101–8
[22] Bartomeus I and Dicks L V 2019 The need for coordinated transdisciplinary research infrastructures for pollinator conservation and crop pollination resilience Environ Res Lett 14 045017
[23] Golubovic A, Tomovic L, Nikolic M, Nikolic S, Andjeljkovic M, Arsovski D, Ikovic V, Gvozdenovic S and Popovic M 2019 Distribution of hermann’s tortoise across Serbia with implications for conservation Arch Biol Sci 71 509–16
[24] Bâllâceanou F et al 2021 Corthyucha arcuata (say, 1832) (Hemiptera, Tingidae) in its invasive range in Europe: perception, knowledge and willingness to act in foresters and citizens NeoBiota 69 133–53
[25] Pateman R, Dyke A and West S 2021 The diversity of participants in environmental citizen science Citz Sci 6 9
[26] Schneider K, Makowski D and van der Werf W 2021 Predicting hotspots for invasive species introduction in Europe Environ Res Lett 16 114026
[27] Četković A, Radović I and Dorović L 2004 Further evidence of the Asian mud-daubing wasps in Europe (Hymenoptera: Sphecidae) Entomol Sci 7 225–29
[28] Lanner J, Huchler K, Pachinger B, Sedivy C and Meinberg H 2020 Dispersal patterns of an introduced wild bee, Megachile sculpturalis Smith, 1853 (Hymenoptera: Megachilidae) in European alpine countries PLoS One 15 e0236042
[29] Le Fèon V, Aubert M, Genoud D, Andrieu-Pond V, Westrich P and Geslin B 2018 Range expansion of the Asian native giant resin bee Megachile sculpturalis (Hymenoptera, Apsidea, Megachilidae) in France Ecol Evol 8 1534–42
Environ. Res. Commun. 4 (2022) 085001
J Bila Dubači et al

[30] Flaminio S, Ranalli R, Zavatta L, Galloni M and Bortolotti L 2021 Beewatching: a project for monitoring bees through photos Insects 12 841

[31] Vereucken J and Barbier E 2009 Premières données sur la présence de l’abeille asiatique Megachile (Callomegachile) sculpturalis Smith (Hymenoptera, Megachilidae) en Europe Osmia 34–6

[32] Amiet F 2012 Kurzbeitrag die Blattschneiderbiene Megachile sculpturalis Smith, 1853 (Hymenoptera, Apidae) nun auch in der Schweiz Entomo Helv 5 157–9

[33] Quaranta M, Sommaruga A, Balzarini P and Felicioli A 2014 A new species for the bee fauna of Italy: Megachile sculpturalis continues its colonization of Europe Bull Insectol 67 287–93

[34] Westrich P, Knapp A and Berney I 2015 Megachile sculpturalis Smith 1853 (Hymenoptera, Apidae), a new species for the bee fauna of Germany, now northern of the Alps Eucera 3 9–10

[35] Diller F-X 2016 Eingeschleppte Asiatische Mörthbiene Megachile sculpturalis Smith, 1853 (Hymenoptera, Apidae) erstmals nördlich der Alpen gesichtet Entomo Helv 9 153–6

[36] Ortiz-Sánchez FJ, Navarro JF and Taeger U 2018 Megachile (Callomegachile) sculpturalis Smith, 1853, nueva especie para la fauna ibérica (Hymenoptera, Megachilidae) Boletín de la SE 63 259–61

[37] Aguado O, Hernández-Castellano C, Bassols E, Miralles M, Navarro D, Stefanescu C and Vicens N 2018 Megachile (Callomegachile) sculpturalis Smith, 1853 (Apoidae: Megachilidae): a new exotic species in the Iberian Peninsula, and some notes about its biology Bull Inst Catalana Hist Nat 82 157–62

[38] Guariento E, Lanner J, Stagg M A and Kranebitter P 2019 Megachile sculpturalis (Smith, 1853) (Hymenoptera: Megachilidae), the giant resin bee new to South Tyrol with a newly described plant species interaction Gredlertiana 19 209–15

[39] Ruzzier E, Menchetti M, Bortolotti L, Selis M, Monterastelli E and Forbicioni L 2020 Updated distribution of the invasive Megachile sculpturalis (Hymenoptera: Megachilidae) in Italy and its first record on a Mediterranean island Biodivers Data J 8 e57783

[40] Kovács T 2015 Megachile sculpturalis Smith, 1853 in Hungary (Hymenoptera, Apidae) Fol Hist-Nat Mus Muraesinis 39 73–6

[41] Gogala A and Zadravec B 2018 First record of Megachile sculpturalis Smith in Slovenia (Hymenoptera: Megachilidae) Acta Entomol Slov 26 79–81

[42] Bila Dubači J, Račič J, Plečaš M, Lanner J, Nikolić P, Žižek V, Stanisavljević L and Četković A 2021 Further range expansion of the sculptured resin bee Megachile sculpturalis Smith in Serbia and Bosnia (Hymenoptera: Apidae) Entomol Serb 36 27–32

[43] Bila Dubači J, Plečaš M, Račič J, Lanner J and Četković A 2022 Early-phase colonization by introduced sculptured resin bee Megachile sculpturalis (Hymenoptera, Megachilidae, Megachile sculpturalis) revealed by local floral resource variability Neobiota 73 57–85

[44] Četković A and Plečaš M 2017 Dalje širenje ablohtone azijiske pčele u Evropi: prvni nalaz Megachile sculpturalis (n. v.) na Balkanu In Proc. of the XI Simpozijum entomologiške Srbije 2017, Goč, Zbornik režime pp 82–93 September 17–21, 2017 (https://edrs.org/SES/2017/SES_2017_Zbornik.pdf)

[45] Reš FI 2018 In: Scarabaeidae: Aktivitv: Zajamvaje objekv. Megachile (Callomegachile) sculpturalis Smith, 1853 (accessed in January 2021) (http://scarabaeidae.cz/products/megachile-callomegachile-sculpturalis-smith-1853/) (http://files.listerzori.webnode.cz/ 200000105-50b451f64/Megachilida%20mojo.pdf)

[46] Stefan-Fotin A 2019 Megachile sculpturalis [det. by Verecken N. 2019]. Observed in Bucharest, Romania, on July 16, 2019 (accessed in December 2021) (https://facebook.com/photo/?fbid=2295375623879014&set=pcb.1627477290719458)

[47] Nikolić P 2020 Sculptured Resin Bee Megachile (Bee) sculpturalis. Observed in Banja Luka, Bosnia and Herzegovina, on August 3, 2020 (accessed in August 2020) (https://inaturalist.org/observations/5526652.)

[48] Valcheva K K 2021 Sculptured Resin Bee Megachile (Bee) sculpturalis. Observed in Star Zagora Centre, Bulgaria, on August 7, 2021 (accessed in February 2022) (https://inaturalist.org/observations/90306992)

[49] Ivanov SP and Fateryga AV 2019 First record of the invasive giant resin bee Megachile (Callomegachile) sculpturalis Smith, 1853 (Hymenoptera: Megachilidae) in the Crimean Far East Entomol 395 7–13

[50] Lanner J, Gstottennayer F, Curto M, Geslin B, Huchler K, Orr M C, Pachinger B, Sedivy C and Meimberg H 2021 Evidence for multiple introductions of an invasive wild bee species currently under rapid range expansion in Europe BMC Ecol Evol 21 17

[51] Sasaki Y and Maeta Y 1994 Occurrence of fresh adults of Chalcidoma sculpturalis (Smith) in autumn (Hymenoptera: Megachilidae). [In Japanese, English abstract] Chugoku Kontyu 5 38–47

[52] Geslin B et al 2020 Bee hotels host a high abundance of exotic bees in an urban context Acta Oecol 105 103556

[53] Laport RG and Minckley RL 2012 Occupation of active Xylocopa virginica nests by the recently invasive Megachile sculpturalis in upstate New York J Kansas Entomol Soc 85 384–6

[54] Roulston T and Malfi R 2012 Aggressive eviction of the eastern carpenter bee (Xylocopa virginica (Linnaeus)) from its nest by the giant resin bee Megachile sculpturalis Smith J Kansas Entomol Soc 85 387–8

[55] Straffon-Diaz S, Carisio L, Manino A, Biella P and Porporato M 2021 Nesting, sex ratio and natural enemies of the giant resin bee in relation to native species in europe 12 545

[56] Lanner J, Meyer P, Hartetzky F, Meimberg H and Pachinger B 2020 Die Asiatische Mörthbiene (Hymenoptera: Megachile sculpturalis Smith, 1853)—eine neue Bienenart für Österreich Beitr Entomofaunist 21 87–95

[57] Ribas-Maquís E and Díaz-Calafat J 2021 The asian giant resin bee Megachile sculpturalis Smith 1853 (Hymenoptera: Apoidea: Megachilidae), a new exotic species for the bee fauna of Mallorca (Balearic Islands, Spain) J Apic Res 60 506–511

[58] Hoffmann BD and Courchamp F 2016 Biological invasions and natural colonizations: are they different? Neobiota 29 1–14

[59] Courchamp F, Fournier A, Bellard C, Bertelmeier C, Bonnaua E, Jeschke J M and Russell JC 2017 Invasion biology: specific problems and possible solutions Trends Ecol Evol 32 13–22

[60] Fitch G, Wilson JC, Glum P, Vaidya C, Simao M C and Jamieson M A 2019 Does urbanization favour exotic bee species? Implications for the conservation of native bees in cities Biol Lett 15 20190574

[61] Sivakoff F, Pfajrner S and Gardiner M 2018 Unique bee communities within vacant lots and urban farms result from variation in surrounding urbanization intensity Sustainability 10 1926

[62] Mangum W A and Brooks W R 1997 First records of Megachile (Callomegachile) sculpturalis Smith (Hymenoptera: Megachilidae) in the continental United States J Kansas Entomol Soc 70 140–2 (https://www.istor.org/stable/2508576)

[63] Maeta Y, Kitamura K, Kagino Y and Iekami G 2008 In-nest behaviors and labor economy of Megachile (Callomegachile) sculpturalis Smith (Hymenoptera, Megachilidae) Chugoku Kontyu 221 1–22

[64] Parsy K, Tripodi A D and Sampson B J 2015 The giant resin bee, Megachile sculpturalis Smith: New distributional records for the mid- and gulf-south USA Biodivers Data J 3 e6733

[65] Westrich P 2017 Ersatznachweis der Asiatischen Mörthbiene (Megachile sculpturalis) in Österreich [Projekte Megachile sculpturalis] 7 (accessed in August 2019) (https://wildbienen.info/forschung/projekte_37.php)
Ivanov S P, Faterya A V, Zhidkov V Y and Pivovarenko N A 2021 Giant resin bee Megachile (Callomegachile) sculpturalis Smith, 1853 (Hymenoptera, Apoidea, Megachilidae), an invasive species in the Crimea (notes on its biology) Ecosistema 28 122–8

Lanner J et al 2022 On the road: Anthropogenic factors drive the invasion risk of a wild solitary bee species Sci Total Environ 827 154246

Fortel L, Henry M, Guilbaud L, Guirao A L, Kuhlmann M, Mouret H, Rollin O and Vaisière B E 2014 Decreasing abundance, increasing diversity and changing structure of the wild bee community (Hymenoptera: Anthophila) along an urbanization gradient PLoS One 9 e94679

Suzuki-Ohno Y, Yokoyama J, Nakashizuka T and Kawata M 2017 Utilization of photographs taken by citizens for estimating bumblebee distributions Sci Rep 7 11215

Pernat N, Kampen H, Jeschke J M, Wernert D and Wiersma Y 2020 Citizen science versus professional data collection: comparison of approaches to mosquito monitoring in Germany J Appl Ecol 58 214–23

Roy-Dufresne E, Salte F, Cooke B D, Mellin C, Mutze G, Cox T and Fordham D A 2019 Modeling the distribution of a wide-ranging invasive species using the sampling efforts of expert citizen and professional ecologists Ecol Evol 9 11053–63

Boersch-Supan P H and Robinson R A 2021 Integrating structured and unstructured citizen science data to improve wildlife population monitoring bioRxiv (https://biorxiv.org/content/10.1101/2021.03.03.431294v1)

Vercayie D and Herremans M 2015 Citizen science and smartphones take roadkill monitoring to the next level Nat Conserv 11 29–40

Duane S and Galaz V 2016 ‘Anyone know what species this is?’ – twitter conversations as embryonic citizen science communities PLoS One 11 e0153137

Miller-Rushing A, Primack R and Bonney R 2012 The history of public participation in ecological research Front Ecol Environ 10 285–90

Shirk J L et al 2012 Public participation in scientific research: a framework for deliberate design Ecol Soc 17 29

Kaplan A M and Haenlein M 2010 Users of the world, unite! The challenges and opportunities of Social Media Bus Horiz 53 59–68

Chamberlain J 2018 Using social media for biomonitoring: how Facebook, Twitter, Flickr and other social networking platforms can provide large-scale biodiversity data Adv Ecol Res 59 133–68

Howard L, van Rees C B, Dahlquist Z, Luikart G and Hand B K 2022 A review of invasive species reporting apps for citizen science and opportunities for innovation NeoBota 71 165–85

Callaghan C T, Poore A G B, Moles A T, Nakagawa S, Roberts C, Rowley J J L, Vergé A, Wilshire J H and Cornell W K 2020 Three frontiers for the future of biodiversity research using citizen science data BioScience 71 55–63

Wang Wei J, Lee B P Y-H and Bing Wen L 2016 Citizen science and the urban ecology of birds and butterflies — a systematic review PLoS One 11 e0156425

Gu W and Swihart RK 2004 Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models Biol Conserv 116 195–203

Mackenzie I D 2005 What are the issues with the presence–absence data for wildlife managers? J Wildl Manage 63 849–60

Miller D, Nichols J, Mcclintock B, Grant E, Bailey L and Weir L 2011 Improving occupancy estimation when two types of observational error occur: non-detection and species misidentification Ecology 92 1422–8

Wallace R D, Bargeron C T, Moorhead D J and LaForest J H 2016 IvecGot1: reporting and tracking invasive species in Florida Southeast Nat 15 51–62

European Commission 2018 JRC-GEOSTAT (accessed on May 2022) (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat#geostat11)

European Commission 2011 Urban clusters (accessed on May 2022) (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/clustersurban11)

European Commission 2011 High-density clusters (accessed on May 2022) (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/clustersurban11)

Dijkstra L and Poelman H 2014 A harmonised definition of cities and rural areas: the new degree of urbanisation European Commission Working Papers, WP 01/2014 1–24

ESRI Inc 2021 ArcGIS Pro (Version 2.8.3), (https://esri.com/en-us/arcgis/products/arcgis-pro/overview)

R Core Team R: A language and environment for statistical computing. Available online (https://cran.r-project.org/)

Pateau-Lopez B and Rodrigues-Casal A 2010 Generalizing the Convex Hull of a Sample: The R Package alphahull pp 1–17 (https://cran.r-project.org/web/packages/alphahull/vignettes/alphahull.pdf)

Pelesma E and Bivand R 2005 Classes and methods for spatial data: the sp package, pp 51–21 (https://cran.r-project.org/package=sp/sp.pdf)

Bland I, Keith D, Miller R, Murray N and Rodriguez J 2017 Guidelines for the application of IUCN red list of ecosystems categories and criteria, version 1.1 IUCN

Troupet J, Grandcolas P, Blin A, Vignes-Lebbe R and Legendre F 2017 Taxonomic bias in biodiversity data and societal preferences Sci Rep 7 5132

Jarić L et al 2020 The role of species charisma in biological invasions Front Ecol Environ 18 345–53

Četković A, Mokrousov M V, Plečaš M, Bogusch P, Antić D, Dorovíc–Jovanović L, Krpo–Četković J and Karaman M 2011 Status of the potentially invasive species Sceliphron deforme in Europe, and an update on the distribution of S. curvatum (Hymenoptera: Sphecidae) Acta entomol Serb 16 91–114

Četković A, Ćubrilović B, Plečaš M, Popović A, Savic D and Stanisavljević J 2012 First records of the invasive american wasp Isodontia mexicana (Hymenoptera: Sphecidae) in Serbia Acta entomol Serb 17 63–72

Burkovsky O Sculptured Resin Bee (Megachile sculpturalis). Observed in Chornomorsk, Ukraine, on July 7, 2022 (accessed in July 2022) (https://facebook.com/groups/182273489248683/permalink/1285497025295604/)

Groom Q et al 2021 Species interactions: next-level citizen science Ecosphere 14 1781–9

Jeschke J M et al 2014 Defining the impact of non-native species Conserv Biol 28 1188–94

Isaac N J B and Pocock M J 2015 Bias and information in biological records Biol J Linn Soc 115 522–31

Wilson J R U, Procheq S E, Braschler B, Dixon E S and Richardson D M 2007 The (bio)diversity of science reflects the interests of society Front Ecol Environ 5 409–14

Seebens H et al 2015 Global trade will accelerate plant invasions in emerging economies under climate change Glob Chang Biol 21 4128–40

Gippert J M, Liebhörd A M, Penn-Moltu G and Bertelsmeier C 2019 Human-mediated dispersal in insects Curr Opin Insect Sci 35 96–102
[106] Koen E L and Newton E J 2021 Outreach increases detections of an invasive species in a crowdsourced monitoring program *Biol Invasions* **23** 2611–20

[107] De Felici S, Mazzei P, Sbordoni V and Cesaroni D 2021 Scientists by chance: reliability of non-structured primary biodiversity data. Insights from Italian Forums of Natural Sciences *Biogeographia* **36** s002

[108] Bautista-Puig N, De Filippo D, Mauleón E and Sanz-Casado E 2019 Scientific landscape of citizen science publications: dynamics, content and presence in social media *Publications* **7** 12

[109] Araujo A C et al 2018 Spatial distance and climate determine modularity in a cross-biomes plant-hummingbird interaction network in Brazil *J Biogeogr* **45** 1846–58

[110] Pocock M J O, Chandler M, Bonney R, Thornhill I, Albin A, August T et al 2018 A vision for global biodiversity monitoring with citizen science *Adv Ecol Res* **59** 169–223