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The longer, the better? Assessing the results of an eight-year citizen science initiative targeting protected insect species

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Background: Citizen science has been proven to be a valuable approach to collect data at large scales and can be of particular interest especially if it meets the requirements of the Habitats Directive, a key piece of European Union environmental legislation that orients policies of member states about conservation actions and protected species and habitats monitoring. In Italy, only few citizen science projects are dedicated to the collection of data on insect species, and rarer are those focusing on protected insect species. A long-term initiative focused on protected species and habitats started in 2012 as the "LIFE MIPP" project and continued afterwards as the "InNat" project up until 2024. The above-mentioned initiative focused on 40 protected targets, including insects, crustaceans, plants and habitats.

Results: A total of 6,130 records, collected by more than 1,400 volunteers between 2014 and 2021, were analyzed focusing on the increase of the distributional knowledge of nine insect species. On average, 83% of records were considered valid in terms of correct species identification, with more than 60% of records collected outside protected areas. Analyses revealed a clear statistically significant increase in the number of records and in distributional data coverage over the years (i.e., number of occupied UTM cells and variation of shape/density of data distribution), though most of the considered species did not reach 'saturation' yet.

Conclusion: Our project significantly contributed to increase knowledge on the distribution of protected insect species thus stressing the importance of similar long-term initiatives, also fostering a more conscious management and design of protected areas.

KEYWORDS

volunteering, Habitats Directive, beetles, butterflies, distribution data

Background

According to the European Citizen Science Association (ECSA)[1], citizen science (CS) can be defined as the participation of the general public in scientific processes through an open and inclusive approach. In this context, CS projects actively involve citizens, better defined as volunteers, in scientific endeavors that generate new knowledge or understanding in several fields of science (ECSA, 2015). However, CS has been identified in many ways, and it implies a plethora of definitions (Haklay et al., 2021; Heigl et al., 2019; Shanley et al., 2025) as well as, sometimes, terms referring to the same concepts, reflecting its broad context of application (Eitzel et al., 2017).

In general, CS provides remarkable values to scientific activities, concerning society and volunteers' personal growth, such as generating knowledge, creating learning opportunities, improving awareness about biodiversity and nature conservation, enabling civic participation (Turrini et al., 2018; Vohland et al., 2021). It has been demonstrated to represent a valid complementary approach with respect to traditional science or even as the more convenient approach for addressing some scientific questions, as CS allows gathering data faster and on a wider scale (Gardiner et al., 2012; Losey et al., 2012; Dennis et al., 2017; Soroye et al., 2018). However, the involvement of non-professional volunteers in data collection is not without problems, especially regarding data quality. In this regard, Tulloch et al. (2013) reviewed recent applications of citizen science programs to the monitoring of animal species, also addressing the data validation issue: when data are collected by non-expert volunteers, such as in iNaturalist or other similar projects, there is a risk of inaccuracy due to variations in survey effort, survey inconsistencies over time, detection biases and errors in records (Di Cecco et al., 2021; Dimson and Gillespie, 2023). For this reason, some CS projects focused on single or few species and/or on reduced geographic scale also provide a mandatory expert validation phase which reduces errors (Campanaro et al., 2017; Flaminio et al., 2021; Callaghan et al., 2019).

CS finds its main field of application in natural science research focusing on conservation, biodiversity and climate change, as demonstrated in the scientometric analysis conducted by Kullenberg and Kasperowski (2016). Within this field, a CS approach has been used worldwide in different contexts: Theobald et al. (2015) provided one of the most comprehensive assessments on biodiversity-focused CS projects, demonstrating the impact of these initiatives for the research on global change. Chandler et al. (2017) analyzed CS and community-based monitoring programmes highlighting their substantial contribution towards global biodiversity monitoring and essential biodiversity variables assessment. The EU Citizen Science database[2] gathers a comprehensive overview of ongoing projects in Europe. Despite some emerging challenges, the European Environmental Protection Agencies have recently recognized the potential of CS, which could be considered an important complement for the activities they are in charge of (Rubio-Iglesias et al., 2020), such as biodiversity assessments and species monitoring. Similar suggestions come from Young et al. (2019) who highlighted the intrinsic value of CS data as a fundamental source of information, especially in regulatory activities of Natural Heritage programmes. Furthermore, Olen (2023) explored the increasing evidence of the role of citizens in assuming the responsibility for environmental monitoring and also explored the necessity of building a "complementary knowledge" with authorities.

In this context, most CS projects aimed at species monitoring mainly focus on 'charismatic' species (Davis and Dyer, 2015; van Tongeren et al., 2023) that often are not of conservation concern. Thus, less charismatic (Barbato et al., 2021) and neglected species protected under the Habitats Directive (HD)[3] have so far not been widely targeted for CS projects in Europe (e.g., Great Stag Hunt, https://ptes.org/wp-content/uploads/2014/06/GSH-final-report.pdf; European Stag Beetle Monitoring Network) (Thomaes et al., 2021). Nevertheless, they represent a potentially worthwhile target for CS projects taking into account that: i) each country hosts a limited number of these species; ii) their distribution can be rather patchy but most territories host at least a few of these species; iii) species listed in the Annexes II and IV of HD are often flagship species, therefore easily detectable by non-professionals. Moreover, according to Art. 17 of the HD, monitoring of these protected species is mandatory for EU member states. Their distributions and conservation status are crucial for determining conservation policies as well as for conservation actions and for guiding future management decisions (Mason et al., 2015).

Given this background, the first ever European LIFE CS project targeting protected insect species started in 2012, the Project "Monitoring of insects with public participation" (LIFE11 NAT/IT/000252, from now on MIPP). It developed a web-app and an app for smartphone for collecting distributional data in 2014 and it ended in 2017 (Mason et al., 2015; Campanaro et al., 2017; Carpaneto et al., 2017). LIFE MIPP was continued and implemented by InNat project which started in 2017 under fundings from an agreement named START2000 and ended in 2024: the data gathered in both projects converged in the same database ("MIPP/InNat project" from now on). List of subsequent projects under which CS data have been gathered and which contributed to the same database as well as details on time periods and funding sources are provided in Appendix 1. The project MIPP initially focused on nine species of insects protected under the HD, but the number of targets grew to

1 https://ecsa.citizen-science.net/about-us

Abbreviations: CS, Citizen Science; HD, Habitats Directive, Council Directive 92/43/EEC; MIPP, Project "Monitoring of insects with public participation" (LIFE11 NAT/IT/000252); InNat, Project "Promozione della Rete Natura 2000 e il Monitoraggio a scala nazionale di specie di insetti protetti"; START 2000, Project "Sviluppo di strumenti di coordinamento finalizzati all'attuazione degli obiettivi e delle misure di conservazione nei siti Natura 2000 compresi nelle riserve ed altre aree demaniali gestiti dall'Arma dei Carabinieri".

2 https://eu-citizen.science/

3 The Habitats Directive (Council Directive 92/43/EEC) was adopted in 1992, and aims at ensuring biodiversity in the European Union by conserving natural habitats and wild fauna and flora species. Specifically it requires all Member States to establish a strict protection regime for species listed in Annex IV, both inside and outside Natura 2000 sites.

40 during the years, including both protected animal and plant species as well as protected habitats. MIPP/InNat project engaged citizens in collecting distribution data of protected species and habitats by uploading photographs of the encountered target either on a dedicated website[4] or using an app for smartphones ("MIPP" then "InNat"). Each record was checked and validated by expert naturalists of the project staff and the data were stored in the project database; then, validated records were shared on the project website. Dissemination aiming at reaching and involving new volunteers, was a key element for all projects. The projects used different approaches to reach the public. MIPP and the first years of InNat (2017–2019) mainly relied on the organization of public events (either in State Nature Reserves or in schools) which are known to produce long-term benefits for the project and for conservation (Jue and Daniels, 2015), as well as on the involvement of Protected Area staff (e.g., personnel of Carabinieri Biodiversity and Park Departments, Regional Forestry Corps, Regional Parks). From 2020 InNat mostly employed social media for dissemination, with a limited number of public events, in order to involve a wider range of audiences of different ages.

The present paper aims at presenting the state of the art of the MIPP/InNat project by analyzing the general results collected in eight years, considering all project targets. In this context, focusing on data of the nine insect species recorded since 2014, a specific objective is to compare the distribution of records from the first two years, partly already presented in Zapponi et al. (2017), with the six following years. The underlying hypothesis is that data coverage continuously increased during the last six years of the project and our predictions are the following.

1. The knowledge on species distribution (calculated as the number of occupied cells of the UTM 10 × 10 km grid) increased;
2. Data for new cells in species-specific annual incremental curves of the occupied area are continuously being added and a plateau has not been reached yet;
3. Species occurrence obtained by our records is subject to variation also according to α-hull range estimate.

Analyses are carried out to reveal the trends of collected records and the improvement in knowledge on the distribution of the project target species in respect to Zapponi et al. (2017) and these data will supply important information on the importance of long-term CS projects.

Methods

Data description

For the present analysis, the dataset updated to 14th January 2022, which comprises the validated records from 1 January 2014 to 31 December 2021, has been used. Analyses employ the same dataset for 2014 and 2015 as well as the same methods used in Zapponi et al. (2017) to guarantee comparable results. General results (e.g., number of records and correct identification rate) of the projects have been calculated. The validated records collected during the entire MIPP/InNat project duration (i.e., records from 2014 to 2024) are visible and downloadable on the platform GBIF[5] (Campanaro et al., 2024) and on the official Italian repository of biodiversity data (National Biodiversity Network[6]).

Although the complete dataset would include 40 targets (Table 1), analyses were performed considering only the records of the nine insect species included in the project from the beginning and falling inside Italian National territory. The geographic location of records is expressed using the ETRS89 datum and the EPSG 4258 reference system. In order to compare the advances in data coverage, the dataset was divided in two blocks: data block 1 (n = 1,113) partially overlaps the dataset from Zapponi et al. (2017) and comprises the data recorded from 1st January 2014 to 31st December 2015, corresponding to part of the MIPP project, whereas data block 2 (n = 5,017) includes the data recorded from 1st January 2016 to 31st December 2021, corresponding to the second part of MIPP and the InNat project. These two data blocks were analyzed using R 4.1.1 (R Core Team, 2021), and species distributions were assessed following the methods of Zapponi et al. (2017). Geographical information was used to assess how many species records were collected in protected areas (i.e., Natura 2000 sites and protected areas listed in "Elenco Ufficiale delle Aree Protette VI" - EUAP VI (EUAP, 2023) (published in Gazzetta Ufficiale n. 125 del 31.05.2010[7]). Geospatial vector data downloadable at http://www.pcn.minambiente.it/viewer/index.php?services=progetto_natura).

UTM grid

For each species, records were plotted on the UTM 10 × 10 km grid and the yearly number of cells with presence data was calculated using QGIS 3.16.11 (QGIS Development Team, 2022). A Chi Square test (degree of freedom = 1) was employed to assess statistical differences between the number of cells with presence data for the two data blocks, without taking into account records shared between the two data blocks.

UTM curves

The annual increment in species presence was analyzed by plotting the number of UTM cells occupied by records of the nine target species against time expressed as years from 2014 (start of MIPP project) to 2021. Linear regression models, estimating the trend of the record (i.e., UTM cells) over time, were separately fitted to each species using "lm" function in R

4 www.lifemipp.eu

5 https://cloud.gbif.org/eca/resource?r=protected_insects_of_italy&v=1.5

6 https://www.nnb.isprambiente.it/

7 geospatial vector data downloadable at http://www.pcn.minambiente.it/viewer/index.php?services=progetto_natura.

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TABLE 1 List of the target species/habitats of the MIPP/InNat citizen science initiative.

Species/Habitat	Order	Family	Annex HD
Insects			
Rhysodes sulcatus (Fabricius, 1787)	Coleoptera	Carabidae	II
***Cerambyx cerdo* Linnaeus, 1758**	Coleoptera	Cerambycidae	II, IV
Morimus asper/funereus*	Coleoptera	Cerambycidae	II
***Rosalia alpina* (Linnaeus, 1758)**	Coleoptera	Cerambycidae	II, IV
Cucujus cinnaberinus (Scopoli, 1763)	Coleoptera	Cucujidae	II, IV
***Lucanus cervus* (Linnaeus, 1758)**	Coleoptera	Lucanidae	II
Osmoderma eremita* complex*	Coleoptera	Scarabaeidae	II, IV
Euplagia quadripunctaria (Poda, 1761)	Lepidoptera	Erebidae	II
Lycaena dispar (Haworth, 1802)	Lepidoptera	Lycaenidae	II, IV
Phengaris arion (Linnaeus, 1758)	Lepidoptera	Lycaenidae	IV
Phengaris teleius (Bergsträsser, 1779)	Lepidoptera	Lycaenidae	II, IV
Argynnis (*Fabriciana*) *elisa* (Godart, 1823)	Lepidoptera	Nymphalidae	IV
Coenonympha oedippus (Fabricius, 1787)	Lepidoptera	Nymphalidae	II, IV
Euphydryas aurinia (Rottemburg, 1775) *E. glaciegenita* (Verity, 1928) *E. provincialis* (Boisduval, 1828)	Lepidoptera	Nymphalidae	II
Euphydryas maturna (Linnaeus, 1758)	Lepidoptera	Nymphalidae	II, IV
***Lopinga achine* (Scopoli, 1763)**	Lepidoptera	Nymphalidae	IV
Melanargia arge (Sulzer, 1776)	Lepidoptera	Nymphalidae	II, IV
Papilio alexanor Esper, 1800	Lepidoptera	Papilionidae	IV
Papilio hospiton (Géné, 1839)	Lepidoptera	Papilionidae	II, IV
***Parnassius apollo* (Linnaeus, 1758)**	Lepidoptera	Papilionidae	IV
Parnassius mnemosyne (Linnaeus, 1758)	Lepidoptera	Papilionidae	IV
***Zerynthia polyxena* (Denis & Schiffermüller, 1775); *Z. cassandra* (Geyer, 1828)**	Lepidoptera	Papilionidae	IV
Hyles hippophaes (Esper, 1789)	Lepidoptera	Sphingidae	IV
Proserpinus proserpina (Palla, 1772)	Lepidoptera	Sphingidae	IV
Coenagrion mercuriale (Charpentier, 1840)	Odonata	Coenagrionidae	II
Cordulegaster trinacriae (Waterstone, 1976)	Odonata	Cordulegastridae	II, IV
Oxygastra curtisii (Dale, 1834)	Odonata	Corduliidae	II, IV
Gomphus flavipes (Charpentier, 1825)	Odonata	Gomphidae	IV
Lindenia tetraphylla (Vander Linden, 1825)	Odonata	Gomphidae	II, IV
Ophiogomphus cecilia (Fourcroy, 1785)	Odonata	Gomphidae	II, IV
Sympecma paedisca (Brauer, 1877)	Odonata	Lestidae	IV
Leucorrhinia pectoralis (Charpentier, 1825)	Odonata	Libellulidae	IV
Brachytrupes megacephalus (Lefèvre, 1827)	Orthoptera	Gryllidae	II, IV
***Saga pedo* (Pallas, 1771)**	Orthoptera	Tettigoniidae	IV
Crustaceans			
Austropotamobius pallipes (Lereboullet, 1858)	Decapoda	Astacidae	II, V

(Continued on following page)

TABLE 1 (*Continued*) List of the target species/habitats of the MIPP/InNat citizen science initiative.

Species/Habitat	Order	Family	Annex HD
Plant species			
Cypripedium calceolus Linnaeus	Asparagales	Orchidaceae	II, IV
Galanthus nivalis Linnaeus	Asparagales	Amaryllidaceae	V
Himantoglossum adriaticum H. Baumann	Asparagales	Orchidaceae	II, IV
Habitats			
Habitat 91E0	—	—	I
Habitat 91F0	—	—	I

List of protected species and habitats targeted in MIPP/InNat initiative. Taxonomic arrangements (Species, Order and Family), annexes of the HD, in which these species are listed. Species investigated in the present study are reported in bold.

*Habitats Directive lists only *Morimus funereus* (Mulsant, 1862), present in Italy only in a narrow part of the North-East (Carso Triestino e Goriziano within Carnic Alps). According to several authors, *cf.* Hardersen et al. (2017), *M. funereus* should be considered a subspecies of *M. asper* (Sulzer, 1776). For this reason, both MIPP, and InNat projects take in account records from the two taxa as if they came from a single species (*Morimus asper/funereus*) even if only populations of the Carso Triestino e Goriziano are officially protected by Habitats Directive.

*******Osmoderma eremita* complex comprises *O. eremita eremita* (Scopoli, 1763), *O. eremita italicum* Sparacio, 2000 and *O. cristinae* Sparacio, 1994.

4.1.1. For each species, the slopes of the two linear models calculated for the two data blocks (i.e., 2014–2015 and 2016–2021), indicating the rate of accumulation of UTM cells over time, were compared employing a Chi Square test (degree of freedom = 1) to assess the differences in the rate of data increment between the first two years and the complete eight years of data collection. Species-specific results were analyzed to estimate the distance from their asymptote, intended as a plateau, using this parameter as a proxy for 'project saturation' (i.e., the calculated maximum number of cells reachable with CS). This plateau was thus calculated on the basis of the increment of the records per year. Specifically, each species-specific result was fitted to an asymptotic model, using the SelfStart function "SSasympOrig" implemented in the function "nls" in the R 4.1.1 package "stats" ver. 3.6.2 (R Core Team, 2021), forcing each curve to start from the origin. The number of UTM cells expected at the asymptote was estimated and a Chi Square test (degree of freedom = 1) was applied to compare this number with the number of actually recorded cells.

α-hulls

To assess changes in the geographic range of the nine target species recorded in the years 2016–2021, α-hulls were calculated for data block 1 (2014–2015) as well as for data block 2 (2016–2021), following Zapponi et al. (2017). α hulls were chosen compared to traditional convex hulls, because they provide an explicit mean for excluding discontinuities within a species range, allowing more robust estimates (Burgman and Fox, 2003). For each species, all duplicate coordinates were removed from the dataset using the "distinct" function in the R 4.1.1 package "dplyr". The high density of records as well as their proximity prevented the calculation of the α-hull area for *L. cervus*: thus, only in this case, the distribution of the records was simplified using the "gridify" function in the MMQGIS plugin ver. 2021.9.10 in QGIS 3.16.11 (QGIS Development Team, 2022). Records were ordered on a regular grid of 0.01 latitudinal degrees and the redundant points were removed. Species-specific areas, expressed as km^2, were calculated using R 4.1.1 package "alphahull" (Pateiro-López and Rodríguez-Casal, 2010). As in Zapponi et al. (2017) and also suggested by the IUCN Standards and Petitions Subcommittee (IUCN Standards and Subcommittee, 2014), we set parameter α = 2, and a Chi Square test (degree of freedom = 1) was employed to assess statistical differences between the α hulls results from the two blocks.

Results

Data description

Considering all the 40 project targets (Table 1), from 2014 until the end of 2021, 6,130 records were collected in Italy, and a large proportion of these (ca. 65%) was recorded in the northern regions. Records were provided by a total of 1,439 citizen scientists. On average, 83% of the records collected each year have been considered correctly identified by volunteers after expert validation (resulting in a total of 5,152 records) (Figure 1). Focusing only on insect species, with 2,026 correct records, the coleopteran *Lucanus cervus* (Linnaeus, 1758) resulted the most recorded target species whereas the least recorded were the lepidopterans *Phengaris teleius* (Bergsträsser, 1779) and *Papilio hospiton* (Géné, 1839), with a single correct record each. The lepidopterans *Euphydryas maturna* (Linnaeus, 1758) and the odonate *Leucorrhinia pectoralis* (Charpentier, 1825) were also the species with most erroneous records, as well as the lepidopterans *Argynnis* (*Fabriciana*) *elisa* (Godart, 1823) and *Papilio alexanor* (Esper, 1800), with 1, 1, 15 and 18 incorrect records respectively.

More than 60% of the records did not fall within Natura 2000 sites and protected areas according to the 6th official list of protected areas in Italy (EUAP VI).

UTM grid

The spatial increment of occupied cells of the UTM 10 × 10 km grid for each of the nine target species are reported in Figure 2 and corresponding results from the Chi Square test are

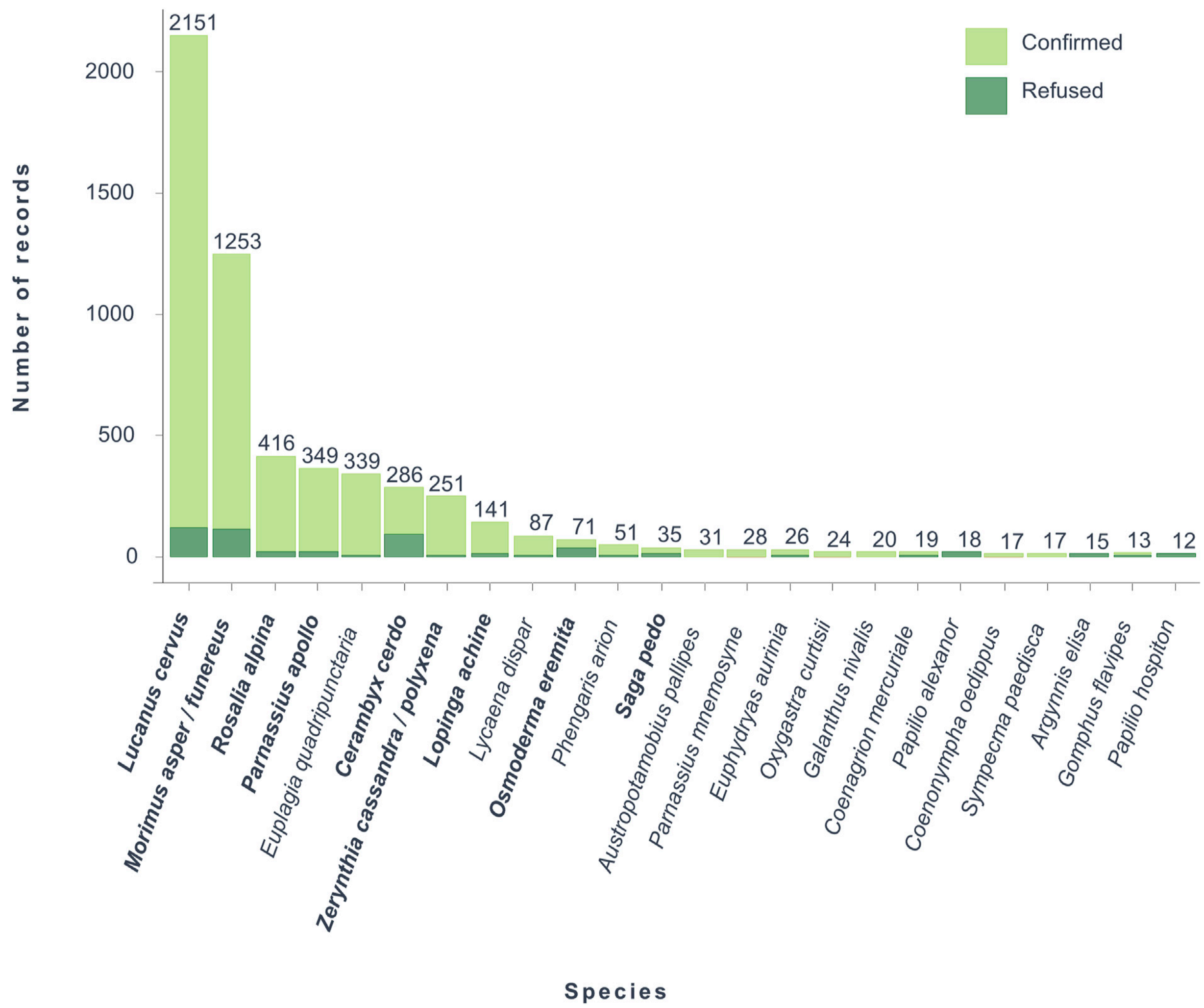

FIGURE 1
Number of records collected by volunteers for target species with more than ten records. Histogram showing the species included in MIPP/InNat initiative with the respective number of records from 2014 to 2021, in descending order. In light green records validated by experts of the projects staff (i.e., the reported species was correctly identified by the citizens), in dark green reports not confirmed and rejected. Only species with minimum 10 data have been included. The nine species analysed in the present study are reported in bold.

reported in Table 2. Differences between the number of records from the two data blocks are statistically significant for all target species (p value <0.018) except for *Saga pedo* (p value = 0.593).

UTM curves

Species-specific annual incremental curves of the occupied area are reported in Figure 3. Slopes, as well as the results of the Chi Square tests, are reported in Table 3. According to these analyses, despite the visible drop of the slope from the first two years *versus* the complete eight years of data collection for some species, this difference is not statistically significant for almost all the evaluated species (p value >0.1). The only significant difference (p value = 0.016) is represented by *L. cervus*. However, for all species did the slope decrease and thus the rate of increment of occupied cells decreased over the years.

Moreover, almost all species show a statistical difference between the actual number of recorded 10 × 10 km UTM cells and their given mathematical plateau (p value <0.05) (Table 4). This suggests that almost all of the species investigated in our project are still far from reaching 'saturation' in distribution knowledge, intended as the maximum number of possible grid cells with records. The only two exceptions concern *Osmoderma eremita* complex (p value = 0.137) and *Rosalia alpina* (Linnaeus, 1758) (p value = 0.055) which do not result statically significant. This suggests that these are closer to reaching 'saturation' in distribution knowledge.

α-hulls

Results from the α-hulls analyses are reported in Figure 4. These α-hulls reveal that the area covered by CS records (expressed in as km^2) has sharply increased from data block 1

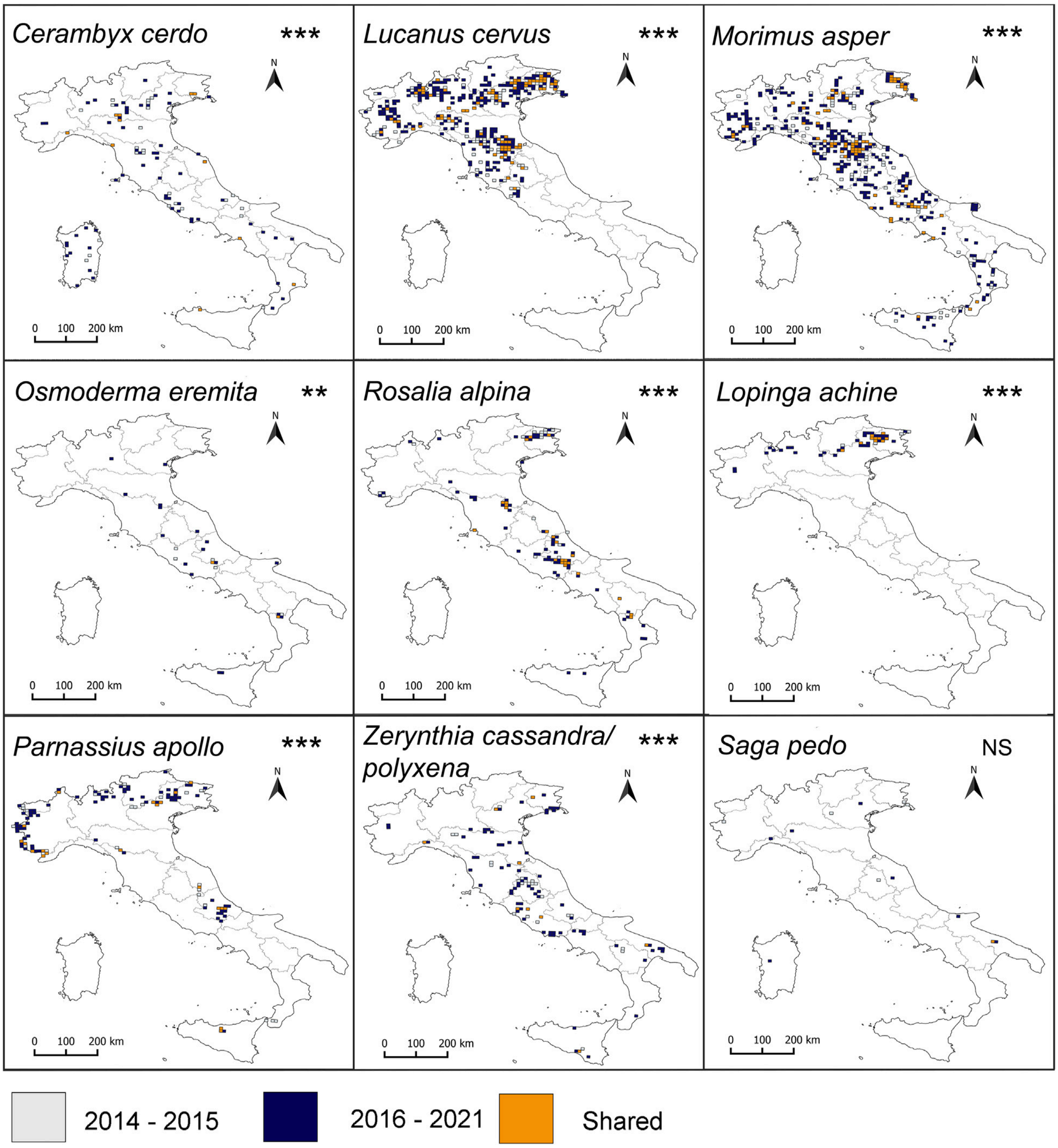

FIGURE 2
Maps showing the distribution of 10 × 10 km UTM cells occupied by the nine investigated species. Grey cells: records from data block 1 (2014–2015); blue cells: records from data block 2 (2016–2021); orange: cells shared in the two data blocks.

(2014–2015) to data block 2 (2016–2021) for all target species, with *S. pedo* (Pallas, 1771) as the only exception. However, this is an artefact created by the parameters imposed; when data points are too far apart they are not joined. For *Cerambyx cerdo* Linnaeus, 1758, *Morimus asper/funereus*, *O. eremita* complex, *R. alpina*, *Lopinga achine* (Scopoli, 1763) and *Zerynthia cassandra/polyxena*, the increase in the area covered by the records results in a change of the relative shape of the area. In contrast for *L. cervus* and *Parnassius apollo* (Linnaeus, 1758), the increase in the area covered by the records results in an increased density within the same outline. *Saga pedo* is the only species not showing an increase in the area covered by the records: this can be explained with the disjunct distribution of its records, also due to setting the parameter α = 2, as reported in Zapponi et al. (2017) and by the IUCN Standards and Petitions Subcommittee (IUCN Standards and Subcommittee, 2014). This

TABLE 2 Analysis of the differences in the distribution of the nine investigated species between the two data blocks: 2014–2015 vs. 2016–2021.

Species	Data block 1 (2014–2015)	Data block 2 (2016–2021)	Shared cells	χ^2	*p*-value	Statistical significance
Cerambyx cerdo	36	70	11	10.906	<2.2e-16	***
Lucanus cervus	135	299	78	61.972	<2.2e-16	***
Morimus asper/funereus	143	356	74	90.920	<2.2e-16	***
Osmoderma eremita complex	7	19	2	5.538	0.018	**
Rosalia alpina	39	82	23	15.281	<2.2e-16	***
Lopinga achine	14	41	10	13.255	<2.2e-16	***
Parnassius apollo	43	96	20	20.209	<2.2e-16	***
Zerynthia cassandra/ polyxena	31	80	9	21.631	<2.2e-16	***
Saga pedo	6	8	1	0.285	0.593	NS

Results from the Chi Square tests assessing statistical differences among the UTM cells of the involved species over the two given time periods (data block 1 and data block 2). In particular, the Chi Square value (χ^2) and the p-value are reported, as well as the statistical significance level (*** = high statistical significance, ** = medium statistical significance, NS = non-significant). The number of shared cells is given for full reporting, but it was not included in the analyses of the present work.

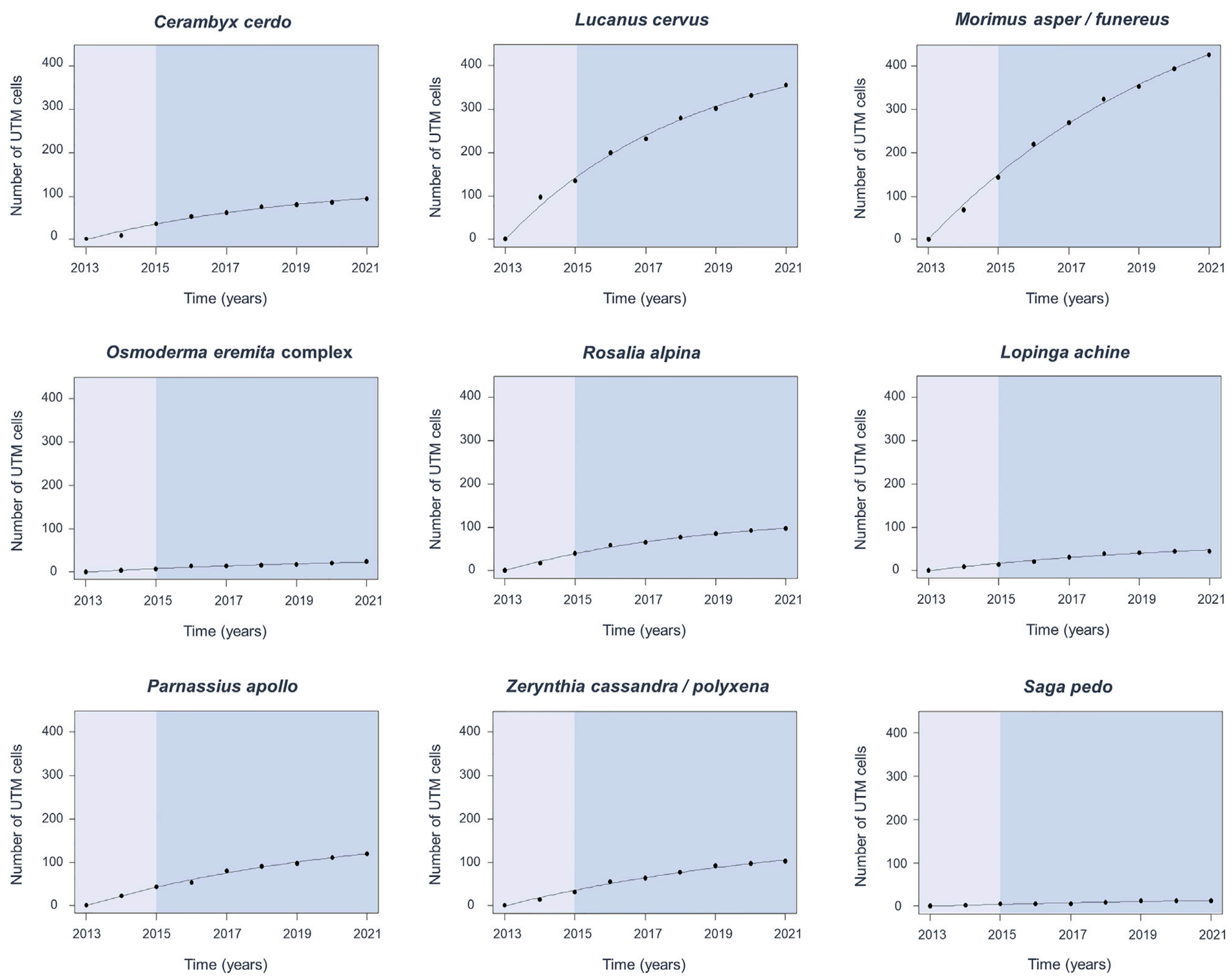

FIGURE 3
Annual incremental curves calculated on the 10 × 10 km UTM cells collected each year for the nine selected species. Light blue represents data block 1 (2014–2015), dark blue represents data block 2 (2016–2021).

TABLE 3 Analysis of the differences in the slopes of the incremental curves of the nine investigated species between the two data blocks: 2014–2015 vs 2016–2021.

Species	Slope of the linear model fitted for years 2014–2015	Slope of the linear model fitted for years 2014–2021	χ^2	*p*-value	Statistical significance
Cerambyx cerdo	18.0	12.0	1.200	0.273	NS
Lucanus cervus	67.5	42.3	5.783	0.016	**
Morimus asper/ funereus	71.5	53.3	2.654	0.103	NS
Osmoderma eremita complex	3.5	2.8	0.077	0.78	NS
Rosalia alpina	19.5	12.1	1.732	0.188	NS
Lopinga achine	7.0	5.9	0.093	0.759	NS
Parnassius apollo	21.5	14.7	1.277	0.258	NS
Zerynthia cassandra/ polyxena	15.5	13.3	0.168	0.681	NS
Saga pedo	3.0	1.6	0.426	0.513	NS

Results from the Chi Square tests assessing statistical differences among the species-specific slopes of the linear models fitted for years 2014–2015 versus years 2014–2021. In particular, the Chi Square value (χ^2) and the p-value are reported, as well as the statistical significance level (** = medium statistical significance, NS = non-significant).

TABLE 4 Differences between the mathematically calculated asymptote and the number of cells recorded for the nine investigated species until December 2021.

Species	Asymptote (number of UTM cells)	SD	Natural logarithm of rate change (LRT)	SD (LRT)	Number of cells recorded until December 2021	χ^2	*p*-value	Statistical significance
Cerambyx cerdo	132.590	18.720	−1.850	0.228	95	6.208	0.0127	**
Lucanus cervus	450.694	26.908	−1.662	0.105	356	11.116	0.000856	***
Morimus asper/ funereus	661.148	43.437	−2.043	0.098	425	51.343	7.76E-13	***
Osmoderma eremita complex	35.465	7.465	−2.015	0.317	24	2.210	0.137	NS
Rosalia alpina	126.645	6.969	−1.679	0.096	98	3.652	0.055	NS
Lopinga achine	70.959	14.190	−1967	0.307	45	5.811	0.015	**
Parnassius apollo	181.977	18.750	−2.014	0.155	119	13.177	0.0002833	***
Zerynthia cassandra/ polyxena	176.844	30.035	−2.174	0.241	102	20.089	7.39E-06	***
Saga pedo	25.560	12.610	−2.369	0.661	13	4.091	0.043	*

Species-specific mathematical plateaus (i.e., maximum number of UTM cells possibly covered by each species). The relative results from the Chi Square tests assess statistical differences among the asymptote and the number of cells recorded until December 2021. In particular, the Chi Square value (χ2) and the p-value are reported, as well as the statistical significance level (*** = high statistical significance, ** = medium statistical significance, * = low statistical significance, NS = non-significant).

resulted in a low threshold for the inclusion of distant data points in the α-hull.

Chi Square test highlighted that all differences result highly statistically significant (p value <0.0001) (Table 5). Differences in the area covered by records of *S. pedo* were statistically significant but they have not been considered in the following discussion due to the above-mentioned limits of the α-hulls analysis for this sparse distributional data.

Discussion

Our results highlight that a CS project, which investigates the presence of protected insect species, benefits from collecting data for a long time as data coverage continuously increased during eight years of the project and none of the investigated species has already reached a plateau of grid cells covered. Similarly, Méndez and Cortés-Fossati (2021) showed that 15 years of citizen science were unable to yield a complete view of the distribution of the stag beetle in Spain. Thus, the time necessary to complete information about coverage is important and should be considered in similar future CS projects.

Results on the most and least recorded species are rather easy to interpret: the coleopteran *L. cervus* is widely distributed in Central and Northern Italy and easily detectable during its summer flights (Bardiani et al., 2017). In contrast, the lepidopterans *P. teleius* and *P. hospiton* have a very limited distribution in Italy (Stock and Genovesi, 2016) and detectability of these butterflies is presumably much lower (e.g., difficulty in observing the target closely and long enough for identification, need for specific entomological skills, dedicated photographic equipment, *etc.*). Similarly, results on the most mis-recorded species can be justified by the distribution of these targets; in fact, *A.* (*Fabriciana*) *elisa*, *E. maturna, L. pectoralis* and *P. alexanor* share a very limited distribution (Stock and Genovesi, 2016) and can easily be confused with similar species.

The high number of records provided by volunteers in Northern Italy, as also highlighted in Redolfi de Zan et al. (2023), suggests that this area played a leading role in our project. This may be explained by two main reasons: a greater involvement of the public in our CS project and a different attitude to this kind of initiatives. Moreover, it must also be stressed that among the northern regions in Italy, Lombardy alone accounts for approximately one-sixth of the whole Italian population, leading to a strong bias towards northern regions in the results of any volunteer-based research over national territory.

Another important result concerns the high percentage (ca. 61%) of records that were collected outside protected areas indicating that many of the populations of these species are currently inhabiting also outside of these dedicated areas. This result is particularly meaningful considering that many of the target species (e.g., *L. cervus*, *R. alpina*, *C. cerdo*, *O. eremita*) are listed in Annex II of the Habitats Directive and therefore require the designation of special areas of conservation. It would be interesting to better understand the relationship between citizen scientists and protected areas and the reasons why the majority of records of MIPP/InNat project fall outside protected areas. Among the possible explanations for this, it could be that volunteers do not commonly frequent protected areas and that they might collect data on the target species during routine activities (e.g., traveling from home to work route, walking the dog, *etc.*). Information aimed at profiling the volunteers involved in our project have been collected through a sociological survey and will be the target in an upcoming paper. Indeed, it must be noted that the protected target species of our project can be found outside protected areas. These results stress the ecological importance of the areas between the Natura 2000 network areas in the context of biodiversity, species conservation and ecological connectivity (D'Amen et al., 2013).

From a European point of view, results from the MIPP/InNat project tend to be comparable with other similar European CS projects. For example, the Vadonleso project (https://xn--vadonles-8sb.hu/) (Bagolyné Geng et al., 2018), a Hungarian CS project targeting species protected under the Habitats Directive, shares *L. cervus* with MIPP/InNat, and the data from 2021 are comparable. In fact, *L. cervus* reached 156 records in 2021 in the Vadonleso project and this species was the most recorded insect target. In our project, in 2021, 214 records of *L. cervus* were collected thus this species resulted the most represented in our project as well. Moreover, in 2021, also the percentage of validated (hence correct) records are comparable in the two projects: 95% and 89% for Vadonleso and InNat projects respectively.

UTM grid

Differences in the number of records from the two analyzed data blocks (2014–15 vs 2016–21) resulted statistically significant for all target species except for *S. pedo*. This means that our project contributed to improving the knowledge on the distribution of our targets. Similarly, a number of other studies have found that knowledge on the distribution of insects has been greatly improved thanks to CS (Smyth et al., 2013; Zapponi et al., 2017; Méndez and Cortés-Fossati, 2021). The fact that the differences between the number of records from the two data blocks were not statistically significant for *S. pedo* was most probably caused by the paucity of the data available for the analysis (i.e., 22 validated records and 13 UTM cells for *S. pedo* compared to an average of 500 validated records and 142 UTM cells for the other species, respectively). However, even if the number of occupied cells increased also for *S. pedo* (Table 2), we cannot base our evaluation of the effectiveness of the project with regard to this species.

UTM curves

Concerning the annual incremental curves of the occupied areas for our target species, a drop of the slope from the first two years *versus* the complete eight years of data collection for some species was observed, possibly due to natural accustomization to the project. In particular, the slowdown is remarkable – and statistically significant - for *L. cervus* with a higher recording rate in the first two years in respect to the following ones. This could be explained by the charisma of the species, used as a flagship for the project promotion, especially in the first years. On the other hand, this slowdown in the accumulation curve is not statistically significant for all the other the evaluated species (p value >0.1): in fact, data for new cells is continuously being added for all target species.

The increase of the occupied areas found with CS data underlies the high effort needed over many years in order to map the distribution of the target species. These findings highlight the need of long-term initiatives at country level, thus encouraging the continuation of similar projects, to completely map the areas occupied by the species.

None of the evaluated species approached the estimated asymptote and this means that eight years of recording are not sufficient to map the distribution of the target species within our CS project and according to Méndez and Cortés-Fossati, (2021) even 15 years of citizen science were not sufficient to complete the distribution of the stag beetle in Spain. Only *O. eremita* complex and *R. alpina* seem to be approaching the mathematically calculated asymptote. Even though these results could reflect the paucity of the data available for these analyses, there could be some ecological factors affecting the results, especially considering that the plateau is mathematically calculated on the basis of yearly data collection rate. On one hand, *O. eremita* in Italy suffers from detectability issues: in

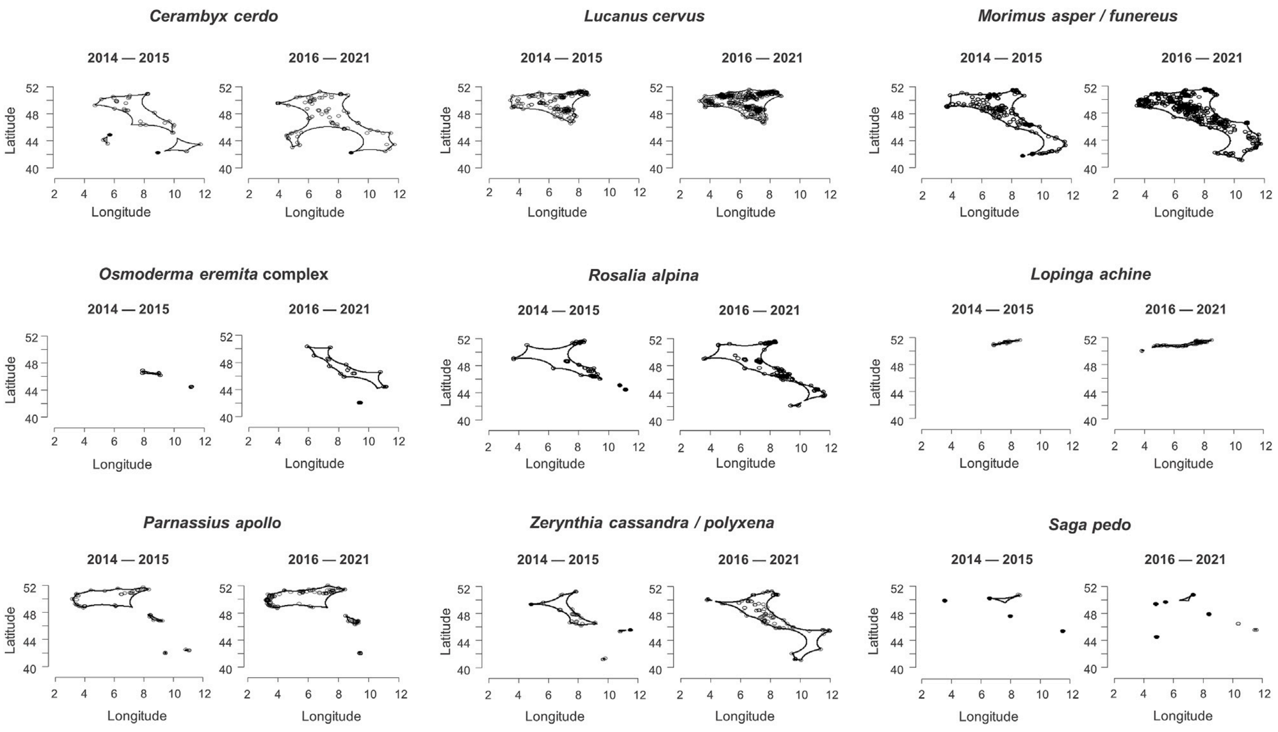

FIGURE 4
Graphic outputs of α-hulls analyses. Distributiuons of the two data blocks (2014-2015, 2016-2021) are compared for the nine selected species.

fact, it can usually be found at very low densities, possibly due to the reduced number and volume of tree hollows in our national territory, thus occasional observations are quite rare. For monitoring, the use of attractive traps is recommended (Maurizi et al., 2017). Therefore, in the case of *O. eremita*, it seems likely that the species is present in other suitable areas and might be detected only with appropriate monitoring techniques (e.g., as in Lenzi et al. (2022)). On the other hand, *R. alpina* is characterized by a patchy distribution due to its close association with an extremely specific microhabitat (i.e., mature, dead or moribund and sun-exposed trees of *Fagus* spp.), where the species is highly visible. This often results in the multiple records being collected by citizen scientists from the same grid cells which limits the increase in additional cells. These different issues influence the calculation of the mathematical plateaus for the two species and the calculated increase of the distribution was more modest for these targets. However, for these very reasons, any newly discovered grid cell for the two above-mentioned species is highly relevant at national level. Again, as for the other analyses, results for *S. pedo* should be interpreted with caution due to the low number of records collected.

The annual increment of the occupied UTM cells highlights how our project increased the knowledge on our target species distribution, but our knowledge on the true distribution of these species is still far from complete. It is obvious that time is an important factor for such projects and thus this kind of initiatives should be set up as long-term monitoring programmes since an increase in their duration results in an increase in useful data recording. Additionally, climate change is a key driver of insect distributional changes which results in directional range shifts (Hassal, 2015; Engelhardt et al., 2022). Thus, our current knowledge on the distributional ranges of protected species needs to be investigated continuously.

α-hulls

α-hulls reveal that the area covered by CS records (expressed in as km^2) has sharply increased from data block 1 (2014–2015) to data block 2 (2016–2021) for all target species, with *S. pedo* (Pallas, 1771) as the only exception. Therefore, two main species categories are identified by our analysis: easily detectable and relatively well-known species (i.e., *L. cervus* and *P. apollo*) and the less easily detectable and relatively neglected species (i.e., *C. cerdo*, *M. asper/funereus*, *O. eremita* complex, *R. alpina*, *L. achine* and *Z. cassandra/polyxena*). The first category did not experience a change in the shape of the α-hulls and differences among the two analyzed data blocks can be found mainly in a greater density of data within the same α-hull shapes. In contrast, for the less easily detectable target species we found a drastic change in the shape of their α-hulls. Interestingly, both species categories did not show changes in the position of their α-hull core over the years. This result might mean that the very first two years of data recording already defined the core of the species' distribution and the last six years dramatically impacted the α-hulls shapes with the collection of records from the edges of the distributional area. Thus, for most of our species CS records greatly enlarged the known distribution and similar results have been found by Zapponi et al. (2017) and Méndez and Cortés-Fossati (2021) (Bardiani et al., 2017) and thus CS records can

TABLE 5 Results from the Chi Square tests assessing statistical differences among species-specific α-hulls from the two data blocks: 2014–2015 vs 2016–2021.

Species	Data block 1 (2014–2015) (km^2)	Data block 2 (2016–2021) (km^2)	χ^2	*p*-value	Statistical significance
Cerambyx cerdo	123501.300	233725.400	34010.000	<2.2e-16	***
Lucanus cervus	123222.000	129938.900	178.210	<2.2e-16	***
Morimus asper/funereus	182511.000	276333.400	19184.000	<2.2e-16	***
Osmoderma eremita complex	2330.455	63091.300	56432.000	<2.2e-16	***
Rosalia alpina	97233.700	134982.300	6136.300	<2.2e-16	***
Lopinga achine	2456.260	9403.167	4069.300	<2.2e-16	***
Parnassius apollo	93131.150	103391.900	535.730	<2.2e-16	***
Zerynthia cassandra/ polyxena	45660.960	137290.100	45892.000	<2.2e-16	***
Saga pedo	4026.352	1682.898	961.910	<2.2e-16	***

The Chi Square value (χ^2) and the p-value are reported, as well as the statistical significance level (*** = high statistical significance).

provide records vital for the identification of new areas of importance for the conservation of protected species.

Conclusion

The present paper analyses data from a CS project targeting species protected under the Habitats Directive. Comparison between the two data blocks, first two years of the project (2014–2015) vs last six (2016–2021), revealed a significant and encouraging increase in distributional data coverage. Moreover, it is interesting to highlight the differences with previous analyses performed by Zapponi et al. (2017), which, in turn, compared cells records exclusively provided by citizens with the ones provided by professional scientists involved in CKMap, i.e., Stoch (2005).

The MIPP/InNat project significantly contributed to increasing knowledge on the distribution of species protected under the Habitats Directive. These data not only prove to be essential information for the scientific community, but they are also of paramount importance in meeting the demands of the European Commission (i.e., Article 11 and 17 of the Habitats Directive (92/43/EEC)) and in fostering a more conscious management and design of protected areas. In light of these results on species distribution, CS projects therefore prove to be extremely beneficial for their impacts on protected areas managers, conservation executives and policymakers (Redolfi de Zan et al, 2023).

New opportunities for the MIPP/InNat project concern increasing project targets. Up to date, for the newly added targets, records do not reach the same numbers of the previously included ones (i.e., from MIPP on). This result is important in highlighting the limits of CS approach with insect species that are not easy to identify and to detect due to their size and or habitat preferences (e.g., *Cucujus cinnaberinus*, *Rhysodes sulcatus*). In fact, good data and statistically robust trends require a serious investment of time and money and the chosen methods need to be scientifically sound (Schmidt and Van der Sluis, 2021). CS has a great potential, also for recording distributional data of protected insects, as shown above. However, it is also important to recognize the limits and biases of this approach (e.g., Kallimanis et al. 2016; Deacon et al. 2023) and to identify the targets that are best investigated by professionals. For example, targeted monitoring of specific species with the aim of getting population trends are usually carried out by professionals (Schmidt and Van der Sluis 2021). Thus, methods can be validly selected from volunteer-based and professional-based solutions and these choices depend also on the culture of a specific country as well as on the availability of resources (Schmidt and Van der Sluis 2021).

Eventually, two of the major challenges related to all CS projects concerns project promotion and attractiveness towards non-professional volunteers (i.e., not biologists/naturalists or similar) so that the largest possible part of the public can be involved in the proposed activities. Analysis of InNat volunteer profiling will be reported in an upcoming paper which, as mentioned above, will be based on a sociological survey submitted to all our volunteers.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.gbif.org/dataset/ad5c93fc-905a-47c1-8208-bdbd7f960076.

Author contributions

SG: Conceptualization, Data curation, Investigation, Writing – original draft. AL: Conceptualization, Visualization, Writing – review and editing, Investigation. MB: Conceptualization, Data curation, Writing – review and editing. CB: Conceptualization, Formal Analysis, Writing – review and editing. SH: Conceptualization, Data curation, Writing – review and editing. EM: Data curation, Writing – review and editing. FM: Data curation, Writing – review and editing. GN: Data curation, Writing – review and editing. PR: Conceptualization, Writing – review and editing, Resources. AC: Conceptualization, Funding acquisition, Supervision, Writing – review and editing, Investigation, Project administration.

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Stefano, CFS San Godenzo, Charles, checco, chiandet, Chiara, Chiara Giraudo, Chiara L., chiara moretti, Chiara zorzetto, Chiara80, Chiara92, Chiara98k, ChiaraC, Chiaracarlotta, chiarag86, Chiarini, ChondroCasteddu%20, Choose a State, chopper, Chris.om, Christian, Christian Gervasoni, chrystal, CiakNatura, Cicco, Cikkyo, ciliegia, cirucci, cisky, Cla', clamasta, classe II B Scuola Primaria "Turoldo" Tolmezzo", Clau641, Claudia, Claudia Candido, Claudia Deidda, Claudia dicasale, Claudio, Claudio berselli, Claudio Cagnan, claudio necci, Claudio Nieddu, Claudio Solimano, Clorrt, Cloudxjr, Cocci Marco, coccinella, coleottero%20, Consigli_verdi??, Cooperativa In Quiete - Foreste Casentinesi, Corrado Zanini, CORRADO60, corriere53, Cosimo, Cosimo Gabbani, cosmin latan, Costantino, COT, cp, Cri, cristian.1977, Cristiana, Cristiana Cocciufa, Cristiana Merli, Cristiano, Cristina, Cristina Ferrari, Cristina Lamana Sanz, Cristina Martellotti, Cutone Luciano, Cuzziol Simone, Dafrass, daghalfio, dagonet, Damianvalerio Barca, Daniel, Daniel Li Veli, daniel parkour, Daniel91, Daniela, Daniela Frattura, Daniela ONC BL, Daniele, Daniele Avesani, Daniele Birtele, Daniele Celestini, Daniele Di Santo, Daniele Frigida, Daniele Matteucci, Daniele Nasci, 10.3389/fenvs.2025.1566160

Daniele Salvi, Daniele tufo, DaniGP, Danilo, Danilo Allasia, Danilo giusti, Danilo Russo, Danilo Tomaccio, Danilo61, Danilos, Danivet, Dany, DanyEla, Dar73, Daria, Dario, Dario Cancian, Dario Quattrin, Dario Vassallo, Dario2014, dav, DaveCast, David Bonaventuri, David GuixÃ©, davide, Davide Galli, Davide Meggiorini, Davide Mosetti, davide paolo strangio, Davide Scaccini, Davide Vallotto, DavideB, davideboz, Daviderusso94, Davidittero, Davidoski, ddfgp, Debora Pelosi, Denise, Dennis, derosa.l, dervisci, desanio, Destroyer99, detta, Di Daniel Alessandro, Diana, DianaDulces, Dianne Poulin, Diego, Diego 89, Diego Giacomuzzi, Diego Lunardi, Diego Mecchi, Dilkia, Dino Caliaro, Domagoj ?uk, DomDalelio, domenico, Domenico vinci, Domenico Vitale, Dona, Donatella Castellucci, dpraste, dramis, druido95, dscopig, Durito, dusky&checco, E.Cavallini, edo, edp, Eduardo Quarta, Edy, efisio cabula, EgidioFabris, El Griso, El_jo, El70, ele2611, Elena, Elena Di Filippo, Elena G, Elena Lupoli, Elena vigano, Elenaf, Elettra D'Amico, eli mordasini, Eliaferro, Elide carboni, elipela, Elisa, Elisa Mangolini, elisa leger, Elisa Torretta, Elisabetta, elisabetta_do, ElisaZ, Elsa, Elvire, Emanuela, emanuela c., Emanuela Maurizi, emanuela vanda, Emanuela30384, emanuelamaset, Emanuele, Emanuele Cheli, emanuele lucioli, Emanuro, Emilia, Emiliano Mancini, Emiliano Trinito, Emilio, Emilio Acone, Emma Minari, emmanuelle, emmeibas, Enrico, Enrico Bortolotto, Enrico Busato, Enrico Dolgan, Enrico Ferraro, Enrico Marchignani, ENRICO VALENTI, Enrico Vettorazzo - Parco Nazionale Dolomiti Bellunesi, enrico.fr, EnricoG, Enricopiana89, Enry, Enzo Ruma, Eraldo Bocca, erica, Erika, Erika F., Ermes Fuzzi, Esakki, ester polentes, ET52, Ettore Rivalta, Eugenio, Eugenio Marano, Eugenio%20Ferrari%20, EUSEBIA FERRARI, Eva, F.D.S., fabfranconi, fabiana, Fabio, Fabio Cianferoni, Fabio Esposito, Fabio Garzuglia, Fabio Marconcini, Fabio Marino, Fabio Mastropasqua, Fabio Mosconi, fabio romiti, FabioMinati, Fabmartin, fabri, fabrichris, Fabrizio, Fabrizio Bulgarini, Fabrizio Foschi, Fabrizio71, faranci, Fausto Leandri, Fb, Fede, Federica, Federica Candelato, Federica D'Amico, Federica Valli, Federico, Federico Del Barba, Federico Moroni, Federico Romiti, federico80, FedericoB, federicocastellano, FedFranBo, Felice Puopolo, Ferrarini Roberto, ferrogt, Ferron Giancarlo, Filardi Tiziano, Filippo Alessio Bentivegna, Filippo La Civita, Filippo magni, Fill, Fina, Fiorenzo Rossetti, Fioretto Mauro, fiorrancino, FLAVIA, Flavio, Flavio gev, Flavio Marzialetti, Fra, -FRA'-, Fra&Pippo, FraFiori, FraMars, Franc.Franz, France, Francesca, Francesca Galli, francesca graziani, Francesca Mattei, Francesca Tantalo, francesca26, francesco, Francesco Boldrin, francesco cancellieri, Francesco Chiappetta, Francesco e Edoardo Pozzi, Francesco Ferreri, FRANCESCO GATTI, francesco iacoella, francesco maria sabatini, Francesco Paoli, Francesco Parisi, Francesco petrino, Francesco Pilat, Francesco R., francesco rossi, francesco tomasinelli, Francesco Tortorici, Francesco Troiano, francescocarlomagno, franco, franco amata, Francy, Frang, Frank, FraPinUTBCZ, Freddy, Frenk, frignano, fripit, FRoncali, Fulvio Fraticelli, Fulvio Tolazzi, furetto, G.Soletta, Gabriele, GABRIELE BANO, Gabriele Cristiani, gabriele oddi, Gabriele S, Gabriele Semboloni, gabriele senczuk, Gabriele.tanese, Gabriele2007, Gabriella, Gabriella Marconi, Gabriella Tiribelli, Gabrio Alberini, gaetano lombardo, Gaia, gaia.marani, Galluccio, Game2046, Garden, Gazzola luisa, GBianchi, genzano2014, Germana, germano, Germano Commessatti, Germano Ferrando, Gessica, GEV Valle del Lanza, ggiord, Gherfrac, Giacomix72, Giacomo Bruni, Giacomo Galli, Giacomo Gasparini, Giacomo.Sanquerin, giacomo92, Giacomo95, Giada, Giamma, Giampiero Tirone, Giampio D'Amico, Gian Luca Tonelli, gianandrea, Gianantonio Governatori, gianbattista, Giancarlo, Giancarlo Ferrario, Giancarlodidio, Gianfrancesco, Gianluca, Gianluca Albertini, gianluca bonavigo, Gianluca D.M., Gianluca Doremi, Gianluca Governatori, Gianluca Marchi, gianluca scaglioni, Gianluca Torcolacci, Gianmichele, Gianni Ciabattini, GIANNI DE MARCO, GIANNI DE MARCO 2, Gianni Facchin, Gibe_chiro, Gidenish, Gil, Gilli, ginger, Gino, Gio76, Gio76i, GioCar, Giocle, Giogiurb, GioMat64, giomatLTER, giorgia, Giorgia Montali, giorgia#GAE, Giorgiangela%20, Giorgio, Giorgio de Simon, Giorgio Mariottini, Giorgio Silvestre, Giorgio Venturini, Giorgio_ B, GiorgioB, giosue08, Giovanna, Giovanna Misiano, Giovanna Saija, giovannasquaquara, Giovanni, Giovanni Bettacchioli, Giovanni Degrati, Giovanni Magno, Giovanni Pisciottu, Giovanni Ravalli, Giovanni%20Corbino, giubas, giulia, Giulia Albani Rocchetti, Giulia Assogna, Giulia Gagliardi, Giulia Leonarduzzi, Giulia Ricciardi, giulia.imperiale86, Giulia:P, Giulia13, giuliaflowers, GiuliaLuzi, giuliana, giuliana renzi, Giuliano79, Giulio, Giulio Ferrante, giulio martinuzzi, Giulio Picchi, Giulore, Giuls, Giuly, Giuricci, Gius, Giuseppe, Giuseppe #35, Giuseppe Bonanno, Giuseppe Campanella, Giuseppe Cillis, Giuseppe Cosenza, Giuseppe Martino, Giuseppe Parenti, Giuseppe Saba, Giuseppe Visalli, Giuseppe Visconti, GiuseppeVolta, Giusi, Gladyston, glaur.68, Glo, Gloria, Gpv65, Grandi Federico, grazia salvadori, Graziana Talamonti, Gregory, guernica, GUGLIELMOTTI M. Teresa - CFR FVG, Guido Bernazzani, guido granello, Hal, Herzog, HPLC, hulotte, Humanist117, HYOGA78, igf, Il tornia, ilaguj, ilaria, Ilaria Alice Muzzolon, ILARIA FILIPPONE, Ilaria Franco, Ilaria Toni, Ilaria Zappitelli, Ilaria93, IlariaL, IlCalve, ilSignorS@m, inanotherlife, Inge, Ingrid Bond, insecta, insettoprogetto, Irene, Irene Botturi, Irene lisi, Isadora Moreira, Ivan e zakhar e andrea, Ivan Mattana, Ivan Mazzon, Ivan69, IVANO, Ivo Pecile, Jacopo Cristoni, Jacopo Cucciolillo, Jordi, Julesdomalain, Julia Sass, Juliane, Julocoleo, Kabbuby, Kajetan Kravos, Karen, kat92, katebog, Katia, Katona, JÃ³zsef SÃ¡muel, KatonÃ¡nÃ© KovÃ¡cs Erika, Katty Giacomini, kekko, Kia, Kia1123, kinny, Klaus13, KraKaj, L. Centeleghe, L.M., L7U5A, LaEle, Laga, Lalula, lamedelcaos, ara, laura, Laura Bonanno, Laura ferrari, Laura Riva, laura roca, Laura Santopadre, Laura Spada, Laura.canalis, Laura14, LauraB, Laurent Sonet, lbertoldi, LCameroni, Lele, Lele71, Lella, lelly_chelli?, leo, leo.pacenti, leogodown%20, leon, Leonardo, Leonardo Gelli, Leonardo Mengoli, Leonardo Paolo Lastilla, Leonardo Perrone, leonardoancillotto, Leonetti Daniele, leosong, lessismore, Letizia Di Biase, letizia.bottinelli, Letterio Ferrara, Leyla, liana, Lidia follesa, LifeEsc360 Murge Orientali, Lijsje, linda, Linda Canale, Lisa, lisa causin, Lisa Man, Lisa76, LittleGiant, livia ferrante, Livia M, Livio, livio-56, livza, Lollo, Loredana Olivieri, Loredana Tanga, Lorena, lorena.pistritto, lorenser24, Lorenzi Alberto e Ferron Giancarlo, Lorenzo, Lorenzo gale, Lorenzo Generali, Lorenzo Giamp, Lorenzo Panella, Lorenzo Petrizzelli, Lorenzo Rapa, Lorenzo72, LorenzoD, LORENZOdibi, LorenzoPettavino, Loreto Giordani, Loris Matani, Loveandspritz, LP, Luana, Luana Bruniera, luca, Luca Bartolozzi, luca coppari, Luca Deganutti, Luca Giraudo, Luca Man, Luca Morlino, Luca Paglia, Luca%

20Fabrizio, luca%20gio, Luca34565241, LucaGallitelli, lucagio, LucaKNX, Lucas, LucaS7, Lucia, Lucia Clara Breghi, Lucia Eusepi, Luciana, Luciano, Luciano Caporale, Luciano cutone, luciob, luigi, Luigi Concio, Luigi Vatta, Luigiloffredi, Luisa Tomarelli, lukeddu, lupi, lupo85, LupoAbruzzo86, Lurui, M.pia, m.teresacernoia, MAD MAX, Mae, mafabris, Mafalda, Magius, Magma, Make, Makka, manero, manubo, Manubrio, Manuela, mapinna, Mara, Mara Marcucci, Marcello Casetta, Marcello De Meo, Marcello Miozzo, marcelo ferro, Marche in Spalla, Marco, Marco Alberto Bologna, Marco Antonelli, Marco Azzusi, Marco Bascietto, Marco Chiarini, Marco Corradi, Marco Cortandone, Marco De Mutiis, MARCO DEL PRINCIPE, Marco Di Lenardo, Marco Doneda, Marco Falconi, Marco Fede, Marco Gasponi, Marco Giovanardi, Marco Laino, MARCO LUCCHESI, Marco Maggesi, marco mattei, marco mencuccci, marco muraro, Marco Pascolino, Marco rinaldi, Marco Rizzi, Marco Scapin, Marco Simonazzi, Marco Uliana, Marco Vaccari, Marco Villani, Marco27, marco632, marco64, Marco65, marco70, marcobaldini66, MarcoBaldo, Marcodaga, Marcogallo, Marcolino, Marcolinux, MarcoMolfini, Marcomountain, marcone, MarcoP, Marcopiz, Mare, marga, Margherita Norbiato, Margine, Maria, Maria Assunta, Maria Castrovilli, Maria Chiara Sibille, maria ida spinaci, Maria Messier, Maria Teresa Cernoia, Maria Trombetta, maria vichi, Maria-Caterina Sighel, mariaelisa, Marialuisa Dal Cortivo, Mariangela, marianna, Mariano Ciaravolo, maricozza, Marietta Evans, Marilena Izzo, Marilina, Marina, Marina Solari, Marino Bellini, mario, Mario Cefalu, Mario D'Agostino, Mario Posillico, Mario Romano, Mario%20Rossetti, mariopos, Marisol Zangarelli, Marpo, marsicano, Marta DP, Marta Mingucci, marta villa, Marti, martina, Martina Colussi, martina lombardi, Martina.c, Martina.Doldi, Martino Vallazza, Marx22, mary, MaryCry1983, MASSARO Franco, Massimiliano, Massimiliano Centorame, Massimiliano Luppi, Massimiliano Pitea, Massimiliano Proietti, MassimilianoA, Massimo, Massimo Barbarotto, Massimo Favaron, Massimo G, Massimo Gasparini, Massimo Pettavino, Massimo Tessiore, Massimo.fabbroni, massimo.fabbroni56, massishots, Matilda71, matrix04, Matte_89, Matteo, matteo faggi, Matteo Magnani, Matteo Munari, Matteo Serlupi, Matteo Silvestri, matti_mene, Mattia, Mattia clavenna, mattia sterza, mattia690, MAU76, Maura, Maurizio, Maurizio Brunelli, Maurizio Di Marco, MAURIZIO FABBRI, Maurizio Mercati, Maurizio Sighele, Maurizio Teruzzi, Maurizio Toniolo, Maurizio&Mariangela, mauro, Mauro Barbazza, Mauro Caldana, Mauro Cederle, Mauro Fabbro, mauro menghini, Mauro sessy, Mauro Varaschin, Max, Max73, Maxricci76, maz, mazzeip, MB_ diaries, mbondini, mcristina, Mctaveck, mela, mellows, mercury27, MGM, micans, Michael Barbieri, Michela, Michela Maura, michele, Michele Cassol, michele cassol cassol, Michele Dall'O', Michele De Bonis, Michele forestaumbra, Michele Iannizzotto, Michele Selis, Michele_Lodi, micheleiannizzotto, MichelePerottoni, MicheleTorrisi, Michelle., Mick Allen, Micky, micmas, micpera, Midori7, Mik, Mikybord, Milanesi Leonardo, milmel, Mimmo, mippnik85, Mirco, Mirco Palmieri, Mirco Pervilli, MircoPervilli, miri, Mirko, Mirko Tomasi, Mirko01, Mm, mmenc, modigliani, Moica Piazzai, Molamola, Monib62, Monica, Monica Mambelli, Monica Verzin, Monichi, more, Morena, Moreno Nalin, Mpar1975, mpasco, Mrk%20, MSalvatori1964, MTG, Mulorix, Mureddu Costantino, Nadia, Nadia Gavazzi, Nanadegenere, Natalia, natchiara, Nazza, NCA Parco Nazionale Foreste Casentinesi, Nerchia88, Nicholas, Nicholas10, nicmal, nicnan, NICO, Nicola Bartolone, Nicola Carbone, Nicola de Crecchio, Nicola Destefano, Nicola Di Ponzio, Nicola Larroux, Nicola Mazzolini, Nicola Regine, NicolÂ Borgianni, Nicolix84, Nicrophorus, Nivaldo, Noemi, Nostadani73, Notti, Nuath, nube che corre, nuegli, nunzioalessandrolippa, NuovoNuova, Oldboy, Olivianna, Omar, Omar e Greta, OphrysFla, Orchidea, Ornella Sclauzero, Oryctes, oryctesnasicornis, Oscar, oxalisart, pabrio, Paco, Pallino, palmi, Pamela, Panda, Paola, Paola Agostini, Paola Antonia, paola candotti, paola di falco, Paola Paolicchi, Paola Priori, paolafazzi, paolarosini, Paolasc, Paoletta, Paolo, Paolo Baglioni, PAOLO BENINI, Paolo Casula, Paolo Gennari, paolo giampaoletti, Paolo Iezzi, paolo marenzi, Paolo Marotto, paolo mastrobattista, Paolo Pantini, Paolo Perone, Paolo Pifferi, Paolo Santicioli, Paolo Tizzoni, Paolo68, Paolo76, Paoloarnwil, Paolocosta27, PaoloV, paperinik, parcomughetti, Parri, pasquale, Pasquale Buonpane, Pasquale-moffa, Patrizia, Patrizia DelCol, Patrizia P., Patrizio, Patrycja Grygierczyk, Patty Giangregorio, Patty R., Paul, Paul A. Smith, Peiti Daniela, Perla Cateni, persial, Pes, Petemme, Peter, Petito Matteo, Petrucci stefano, PFR, phileas, piacerematteo, pier17, PIERGIORGIO BRANCA, PiergiorgioG_74_Roma, Piero Patteri, pierpaolo, Pierpaolo Sassano, Pietro, Pietro Vio, Pietro zanon, pignasca, pino, Pino Marrocco, Pinuccia pisano, Pipolo66, Pisegna Giovanna, Pispolina, Pit, pogliano, Pol, Polmarco, polmarco13, Pontarini Renato, ponza, popinjaykev, PoWa1957, Prilla, Princeofagharti, profborti, prova, psyco lush, puffetta, Quechua, quesito, R La Rosa, Rabbia Antonietta, RacheleN, Ragnoboy, Randa, Randy, raton, Rebecchi, Reka Futo, remo, Rena, Renato, Renato Carini, Renzo, retlav, Reziero, ricca miche, riccardo, Riccardo Bartoli, Riccardo Bonazzo, Riccardo D., Riccardo Galbiati, Riccardo Mancinone, Riccardo Missagia, Riccardo Santoro, RiccardoPoli, Riccrardo, Richardsson, rigioco, Riky2011, Rinaldo, Riserva Naturale Cratere degli Astroni - Andrea Vitolo, Rita, Ritaed, rmannu, Rob Arm, RobangUtan, Roberta, ROBERTA FORMENTINI, Roberta Morselli, Roberta R, Roberta rigo cfr, Roberta Roveta, roberta_donato, RobertaDonato, RobertaR, robertino81, Roberto, Roberto Antonelli, Roberto Garavaglia, Roberto Pegolo, Roberto Rinaldi Cooperativa SO.R.T. Opi (AQ), roberto.ciaffaroni, Roberto67, robertob, Robi, Roby, Roby Pistoia, Roby77, Roby78, robybadia, RobyDelB, rocco viggiani, rock1973, RoLling18, roma rossano, Roma171, Romanin Celeste, Romano, romano romanini, RominaD, Rontola, rosaria%20, Rosella.Salari, Rosfas, ROSSI ENRICO ANNIBALE, rossi giovanni, rosy fezzardi, rubyblu, S, S. Hardersen, sönke hardersen, Sabba, Sabine Ment, Sally, Salvatore, Salvatore Caiazzo, Salvatore campanaro, Salvatore Canu, Salvatore Ferraro, salvatore Murgia, Salvatore Travagliante, Salvo, Sam, sam200176, Samantha, Samantha C., Samantha Caprioglio, Samantha De Bernardin, samir sayed abdellattef, Samuele, Sandra, Sandra tura, sandro 57, sara, Sara Baldini, Sara Barbarossa, Sara Bernardini, Sara Bompieri, Sara Castiglia, Sara Ceccoli, Sara G, Sara Gianoncelli, Sara Masetti, Sara Petracchini, Sara.Balugani, Sara_canterino, SaraDaRodda, Sarah, SaraZ, SaraZaro, sarettacon, SarettaConnor, Sari, Sarinka, Save, saverio, Saverio Rocchi, Sbiseranda, Scarpetta, scarso.federico, Scirimp, Scn Parco fluviale gesso e stura, Seba, Sebabes, Sebastian k., Sebastian kr, Selena, SerAntBruni, sere876, Serena Corezzola, Sergio Muratore, SERGIO PAGANI, Sergion, Serse56, SetaNera, Sgali, Shade Amini, silvai81, Silvia, Silvia Biondini, SILVIA BISCACCIANTI, silvia furlan, Silvia Ghignoli, Silvia M. Rossi, Silvia Maria, Silvia Rinaldi, silvia romano, Silvia Stefanelli, Silvia07, SilviaInve, silvio valenti, simo, Simo simo, Simona, Simona Spaziani, Simona ZAGHI, Simonazzi Fabio, Simone, simone ciocca, Simone Duranti, Simone Giovacchini, Simone Marcato, Simone Sabatelli, Simonr, simottico, So3fia, Sofia, Sofia Bedin, sofialalli, Sorella, Spappi, Spider691, Spike, sscalercio, sslinky, starmariano, Stazione Forestald di Seneghe, Stazione Forestale Oschiri (Sardegna), Stazione Parco la verna vallesanta, Stef, Stefanello, Stefani, Stefania, Stefania Agresti, Stefania P, Stefanie Hermsen, Stefaniotta, stefano, stefano aguzzi, Stefano Belacchi, Stefano benini, Stefano Bigiarini, Stefano Calabrese, Stefano Chiari, Stefano D'Alterio, Stefano Ghiano, Stefano mancinelli, Stefano Piazzini, Stefano Properzi, Stefano S, Stefano Severi, Stefano Tito, Stefano Tribuzi, Stefano Zannol, Stefano Zoia, Stefano71, Stefano994, StefanoAgliata, stefanocfs, stefanodirektor, Stefi, Stefy, Stefy66, Steicymari, Stella, Strato2006, Strider, Summer, SuperSimo, tama, tamara, Tamburini Pietro, Tammaro Pedana, Tangia72, tanktoy, temolo59, Tenny75, Teo77a, TeoStone, Terry, Terry85, Thaibay, Thomas, Timothy Mayberry, tintin, tipula, Tiziana, TizianaDinolfo, Tiziano Filardi, TizNordEst, Tjitske Lubach, Tobao, Tobia Entropia, Tomandtoby, Tomaso, Tommaso Andrea Balliera, Tommaso Baldrati, Tonci.m, Toner, tonino, ToniPuma, Tony, Tony la spina, Topo18, tore62, torgian, Totonno, Trento, tribal71, ttttt, Tuomaz Mauro, Ubial, ugorossi, Ulisse, Umberto, Umberto Cinalli, Ursula.mazzola, UTB Foresta Umbra, Valar, vale, Vale M., vale56, valeanto, Valentina, VALENTINA CARRACOI, Valentina Amorosi, Valentina Balestra, Valentina C., Valentina Colaoni, valentinabuono, Valentinadg, ValentinaS, Valentino, Valentino Borza, Valentino Galasso, Valentino Mastrella, valeria, Valerio, Valy, vega, vendettis, Veneris, Vera Adiantum, veronica, Veronica Borsato, Veronica_S, veronicavico, vicente avola, Vidoni Matteo, Viel Stefano, vilmavla, Vincenzo, Vincenzo Bio, Vincenzo Bonvicini, Vincenzo Pescolanciano, Virgilio Caleca, Vito, Vito78, Vittorio DC, Vittorio Sandoni, viviana, viza, Vlad, Vlady, Vulcano13, Walter Romanelli, Wanda, Werner, Werner1, William Bucci, willy, wilmanna, wolf1983, Xirihan, yacyreta, Yuri, yuri2001, Zalimo, zamarian rosanna, zampa, Zifro96, Ziguli.

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References

Bagolyné Geng, I., Bakò, B., Bata, K., Bokor, V., Koczka, K., Sashalmi, E., et al. (2018). Wildwathce programme: volunteer based, biodiversity data-collector system, results of the first ten years. *Hung. Agric. Res.* 4, 11–18.

Barbato, D., Benocci, A., Guasconi, M., and Manganelli, G. (2021). Light and shade of citizen science for less charismatic invertebrate groups: quality assessment of iNaturalist nonmarine mollusc observations in central Italy. *J. Molluscan Stud.* 87 (4), eyab033. doi:10.1093/mollus/eyab033

Bardiani, M., Chiari, S., Maurizi, E., Tini, M., Toni, I., Zauli, A., et al. (2017). "Guidelines for the monitoring of *Lucanus cervus*,". *Guidelines for the monitoring of the saproxylic beetles protected in Europe*. Editors G. M. Carpaneto, P. Audisio, M. A. Bologna, P. F. Roversi, and F. Mason, 20, 37–78. doi:10.3897/natureconservation.20.12687

Burgman, M. A., and Fox, J. C. (2003). Bias in species range estimates from minimum convex polygons: implications for conservation and options for improved planning. *Anim. Conserv.* 6, 19–28. doi:10.1017/S1367943003003044

Callaghan, C. T., Poore, A. G. B., Major, R. E., Rowley, J. J. L., and Cornwell, W. K. (2019). Optimizing future biodiversity sampling by citizen scientists. *Proc. R. Soc. B* 286, 20191487. doi:10.1098/rspb.2019.1487

Campanaro, A., Bardiani, M., Hardersen, S., Gisondi, S., and Lenzi, A. (2024). Occurrences of protected species of insects in Italy. *Counc. Agric. Res. Econ. Res. Centre Plant Prot. Certif. Occur. dataset*. doi:10.15468/m5sfc6

Campanaro, A., Hardersen, S., Redolfi de Zan, L., Antonini, G., Bardiani, M., Maura, M., et al. (2017). Analyses of occurrence data of protected insect species collected by citizens in Italy. *Nat. Conserv.* 20, 265–297. doi:10.3897/natureconservation.20.12704

Carpaneto, G. M., Campanaro, A., Hardersen, S., Audisio, P., Bologna, M. A., Roversi, P. F., et al. (2017). The LIFE Project "Monitoring of insects with public participation" (MIPP): aims, methods and conclusions. *Nat. Conserv.* 20, 1–35. doi:10.3897/natureconservation.20.12761

Chandler, M., See, L., Copas, K., Bonde, A. M. Z., López, B. C., Danielsen, F., et al. (2017). Contribution of citizen science towards international biodiversity monitoring. *Biol. Conserv.* 213, 280–294. doi:10.1016/j.biocon.2016.09.004

D'Amen, M., Bombi, P., Campanaro, A., Zapponi, L., Bologna, M. A., and Mason, F. (2013). Protected areas and insect conservation: questioning the effectiveness of Natura 2000 network for saproxylic beetles in Italy. *Anim. Conserv.* 16 (4), 370–378. doi:10.1111/acv.12016

Davis, A. K., and Dyer, L. A. (2015). Long-term trends in eastern North American monarch butterflies: a collection of studies focusing on spring, summer, and fall dynamics:. *Ann. Entomol.* 108, 661–663. doi:10.1093/aesa/sav070

Deacon, C., Govender, S., and Samways, M. J. (2023). Overcoming biases and identifying opportunities for citizen science to contribute more to global macroinvertebrate conservation. *Biodivers. Conserv.* 32, 1789–1806. doi:10.1007/s10531-023-02595-x

Dennis, E. B., Morgan, B. J. T., Brereton, T. M., Roy, D. B., and Fox, R. (2017). Using citizen science butterfly counts to predict species population trends. *Conserv. Biol.* 31, 1350–1361. doi:10.1111/cobi.12956

Di Cecco, G. J., Barve, V., Belitz, M. W., Stucky, B. J., Guralnick, R. P., and Hurlbert, A. H. (2021). Observing the observers: how participants contribute data to iNaturalist and implications for biodiversity science. *Sci. Biosci.* 71 (11), 1179–1188. doi:10.1093/biosci/biab093

Dimson, M., and Gillespie, T. W. (2023). Who, where, when: observer behavior influences spatial and temporal patterns of iNaturalist participation. *Appl. Geogr.* 153, doi:10.1016/j.apgeog.2023.102916

ECSA (European Citizen Science Association) (2015). *Ten principles of citizen science*. Berlin. doi:10.17605/OSF.IO/XPR2N

Eitzel, M., Cappadonna, J., Santos-Lang, C., Duerr, R., West, S. E., Virapongse, A., et al. (2017). Citizen science terminology matters: exploring key terms. *CSTP* 2 (1), 1–20. doi:10.5334/cstp.96

Engelhardt, E. K., Biber, M. F., Dolek, M., Fartmann, T., Hochkirch, A., Leidinger, J., et al. (2022). Consistent signals of a warming climate in occupancy changes of three insect taxa over 40 years in central Europe. *Glob. Change Biol.* 28 (13), 3998–4012. doi:10.1111/gcb.16200

EUAP. (2023). Dataset: elenco ufficiale aree protette (EUAP). Available online at: http://data.europa.eu/88u/dataset/m_amte-299fn3-06c67978-18c8-4da7-ff26-443d4f700c2d. (Accessed June 06, 2023)

Flaminio, S., Ranalli, R., Zavatta, L., Galloni, M., and Bortolotti, L. (2021). Beewatching: a project for monitoring bees through photos. *Insects* 12 (9), 841. doi:10.3390/insects12090841

Gardiner, M. M., Allee, L. L., Brown, P. M., Losey, J. E., Roy, H. E., and Smyth, R. R. (2012). Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. *Front. Ecol. Environ.* 10 (9), 471–476. doi:10.1890/110185

Haklay, M., Dörler, D., Heigl, F., Manzoni, M., Hecker, S., and Vohland, K. (2021). "What is citizen science? The challenges of definition," in *The science of citizen science*. Editor K. Vohland, et al. (Cham: Springer), 13–33. doi:10.1007/978-3-030-58278-4_2

Hardersen, S., Bardiani, M., Chiari, S., Maura, M., Maurizi, E., Roversi, P. F., et al. (2017). "Guidelines for the monitoring of Morimus asper funereus and Morimus asper asper,". *Guidelines for the monitoring of the saproxylic beetles protected in Europe*. Editors G. M. Carpaneto, P. Audisio, M. A. Bologna, P. F. Roversi, and F. Mason, 20, 205–236. doi:10.3897/natureconservation.20.12676

Hassall, C. (2015). Odonata as candidate macroecological barometers for global climate change. *Freshw. Sci.* 34 (3), 1040–1049. doi:10.1086/682210

Heigl, F., Kieslinger, B., Paul, K. T., Uhlik, J., and Dörler, D. (2019). Opinion: toward an international definition of citizen science. *PNAS* 116 (17), 8089–8092. doi:10.1073/pnas.1903393116

IUCN Standards and Subcommittee. (2014). *Guidelines for using the IUCN red list categories and criteria, version 11.0*. IUCN, Gland, Switzerland, and Cambridge, United Kingdom. Available online at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf

Jue, D. K., and Daniels, J. C. (2015). A successful model for citizen scientist involvement in building a statewide at-risk butterfly database. *J. Insect Conserv.* 19, 421–431. doi:10.1007/s10841-014-9733-6

Kallimanis, A. S., Panitsa, M., and Dimopoulos, P. (2017). Quality of non-expert citizen science data collected for habitat type conservation status assessment in Natura 2000 protected areas. *Sci. Rep.* 7 (8873), 8873. doi:10.1038/s41598-017-09316-9

Kull, T., Sammul, M., Kull, K., Lanno, K., Tali, K., Gruber, B., et al. (2008). Necessity and reality of monitoring threatened European vascular plants. *Biodivers. Conserv.* 17, 3383–3402. doi:10.1007/s10531-008-9432-2

Kullenberg, C., and Kasperowski, D. (2016). What is citizen science? – a scientometric meta-analysis. *PLoS One* 11, e0147152. doi:10.1371/journal.pone.0147152

Lenzi, A., Maurizi, E., Mosconi, F., Francescato, S., Cecchetti, M., Valle, D., et al. (2022). *Osmoderma eremita* (scopoli, 1763) (Coleoptera scarabaeidae cetoniinae) in circeo state forest (Central Italy). *Redia* 105, 71–75. doi:10.19263/REDIA-105.22.08

Losey, J., Allee, L., and Smyth, R. (2012). The lost ladybug project: citizen spotting surpasses scientist's surveys. *Am. Entomol.* 58, 22–24. doi:10.1093/ae/58.1.0022

Mason, F., Roversi, P. F., Audisio, P., Bologna, M. A., Carpaneto, G. M., Antonini, G., et al. (2015). Monitoring of insects with public participation (MIPP; EU LIFE project 11 NAT/IT/000252): overview on a citizen science initiative and a monitoring programme (Insecta: Coleoptera; Lepidoptera; Orthoptera). *Fragm. Entomol.* 47, 51–52. doi:10.4081/fe.2015.134

Maurizi, E., Campanaro, A., Chiari, S., Maura, M., Mosconi, F., Sabatelli, S., et al. (2017). "Guidelines for the monitoring of *Osmoderma eremita* and closely related species,". *Guidelines for the monitoring of the saproxylic beetles protected in Europe*. Editors G. M. Carpaneto, P. Audisio, M. A. Bologna, P. F. Roversi, and F. Mason, 20, 79–128. doi:10.3897/natureconservation.20.12658

Méndez, M., and Cortés-Fossati, F. (2021). Relative contribution of citizen science, museum data and publications in delineating the distribution of the Stag Beetle in Spain. *Insects* 12, 202. doi:10.3390/insects12030202

Olen, S. M. (2023). Civic sentinels. *Nat. Sustain* 6, 352–353. doi:10.1038/s41893-023-01103-x

Pateiro-López, B., and Rodríguez-Casal, A. (2010). Generalizing the convex hull of a sample: the R package alphahull. *J. Stat. Softw.* 34 (5), 1–28. doi:10.18637/jss.v034.i05

QGIS Development Team (2022). *QGIS geographic information system*. Open Source Geospatial Foundation Project. Available online at: http://qgis.osgeo.org.

R Core Team (2021). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Available online at: https://www.R-project.org/.

Redolfi de Zan, L., Rossi de Gasperis, S., Andriani, V., Bardiani, M., Campanaro, A., Gisondi, S., et al. (2023). The big five: species distribution models from citizen science data as tool for preserving the largest protected saproxylic beetles in Italy. *Diversity* 15 (1), 96. doi:10.3390/d15010096

Rubio-Iglesias, J. M., Edovald, T., Grew, R., Kark, T., Kideys, A. E., Peltola, T., et al. (2020). Citizen science and environmental protection Agencies: engaging citizens to address key environmental challenges. *Front. Clim.* 2, 600998. doi:10.3389/fclim.2020.600998

Schmidt, A. M., and Van der Sluis, T. (2021). *E-BIND Handbook (Part A): improving the availability of data and information on species, habitats and sites*. Wageningen, Netherlands: Wageningen Environmental Research/Ecologic Institute/Milieu Ltd., 87.

Shanley, L. A., Hulbert, J., and Haklay, M. (2025). CitSciDefinitions: citizen science definitions (v1.2, 2019). *Data Set. Zenodo*. doi:10.5281/zenodo.3552753

Smyth, R. R., Allee, L. L., and Losey, J. E. (2013). The status of *Coccinella undecimpunctata* (L.) (Coleoptera: coccinellidae) in North America: an updated distribution from citizen science data. *Coleopt. Bull.* 67, 532–535. doi:10.1649/0010-065X-67.4.532

Soroye, P., Ahmed, N., and Kerr, J. T. (2018). Opportunistic citizen science data transform understanding of species distributions, phenology, and diversity gradients for global change research. *Glob. Chang. Bio.* l (24), 5281–5291. doi:10.1111/gcb.14358

Stoch, F. (2005). Checklist of the species of the Italian fauna. Italian Ministry of environment, territory protection and sea. *Data Set.*

Stoch, F., and Genovesi, P. (2016). *Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: specie animali*. Rome: ISPRA, Serie Manuali e linee guida.

Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., et al. (2015). Global change and local solutions: tapping the unrealized potential of citizen science for biodiversity research. *Biol. Conserv.* 181, 236–244. doi:10.1016/j.biocon.2014.10.021

Thomaes, A., Barbalat, S., Bardiani, M., Bower, L., Campanaro, A., Fanega Sleziak, N., et al. (2021). The European stag beetle (Lucanus cervus) monitoring network: international citizen science cooperation reveals regional differences in phenology and temperature response. *Insects* 12 (9), 813. doi:10.3390/insects12090813

Tulloch, A. I. T., Possingham, H. P., Joseph, L. N., Szabo, J., and Martin, T. G. (2013). Realising the full potential of citizen science monitoring programs. *Biol. Conserv.* 165, 128–138. doi:10.1016/j.biocon.2013.05.025

Turrini, T., Dörler, D., Richter, A., Heigl, F., and Bonn, A. (2018). The threefold potential of environmental citizen science - generating knowledge, creating learning opportunities and enabling civic participation. *Biol. Conserv.* 225, 176–186. doi:10.1016/j.biocon.2018.03.024

van Tongeren, E., Sistri, G., Zingaro, V., Cini, A., Dapporto, L., and Portera, M. (2023). Assessing the aesthetic attractivity of European butterflies: a web-based survey protocol. *PLoS ONE* 18 (5), e0283360. doi:10.1371/journal.pone.0283360

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., et al. (2021). The science of citizen science evolves, in: *The science of citizen science*. Editors K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, and M. Ponti, Springer. 1–12. doi:10.1007/978-3-030-58278-4

Young, B. E., Dodge, N., Hunt, P. D., Ormes, M., Schlesinger, M. D., and Shaw, H. Y. (2019). Using citizen science data to support conservation in environmental regulatory contexts. *Biol. Conserv.* 237, 57–62. doi:10.1016/j.biocon.2019.06.016

Zapponi, L., Cini, A., Bardiani, M., Hardersen, S., Maura, M., Maurizi, E., et al. (2017). Citizen science data as an efficient tool for mapping protected saproxylic beetles. *Biol. Conserv.* 208, 139–145. doi:10.1016/j.biocon.2016.04.035