Journal of Insect Conservation
https://doi.org/10.1007/s10841-024-00613-z

ORIGINAL PAPER

The role of citizens in conservation science: a case study with threatened Brazilian butterflies

Augusto H. B. Rosa[1] · **André V. L. Freitas**[1]

Received: 6 July 2023 / Accepted: 4 July 2024

Abstract
Many records from citizen science (CS) are used in scientific research related to biodiversity. Photographs of living species are valuable data from CS that are applicable to a range of ecological studies. The geographical ranges of threatened Brazilian butterflies were estimated based exclusively on data from photographs from CS sources, and these results were compared with estimates obtained without CS data. A total of 37 butterfly taxa (58.7% of all threatened butterflies from the Brazilian Red List) were identified from 335 photographic records taken by 187 citizen scientists from various CS surveyed sources. Comparing the estimates of geographical range with and without CS data, changes (all increases) were obtained for 26 taxa (70.3% of the taxa in this study). The presented results demonstrate the importance of CS to increase knowledge on threatened Brazilian butterflies, especially in data related to their conservation status. The involvement of general public in scientific research should be constantly encouraged, as the simple act of sharing photographs on the internet of a living organism in nature has the potential to contribute accurately and valuably to conservation science.

Implications for insect conservation: The use of citizen science data is opportune and useful for many porpouses, as in the case of this study in improving the estimates of the geographical range of threatened species. Such data may lead to a new perspective in the conservation assessments of these taxa.

Keywords Citizen science · Wildlife photography · Extent of occurrence · Area of occupancy · Red List

Introduction

Life on Earth is constantly changing, and scientists are unable to discover everything on their own. Bearing this in mind, each year the interaction between scientists and the wider public grows (Follett and Strezov 2015; Theobald et al. 2015; Kosmala et al. 2016; Pocock et al. 2017a, b). This growth in public participation provides many opportunities for scientific research, which generates collaboration between scientists and citizen volunteers – a concept called citizen science (CS) (Dickinson and Bonney 2012; Bonney et al. 2014; Frigerio et al. 2018). Citizen science provides an invaluable opportunity to collect information that would otherwise be challenging for researchers due to time and resource constraints (Cohn 2008; Kobori et al. 2016).

Citizen science bridges science and society by involving members of the general public in scientific research in many areas of study, especially in subjects related to biodiversity, such as species population data (Dennis et al. 2017; Callcutt et al. 2018; Harvey et al. 2018; Crawford et al. 2020; García et al. 2021; Sanderson et al. 2021), general ecology (Washitani et al. 2020; Olsen et al. 2020; Herremans et al. 2021; Barahona-Segovia et al. 2023; Shumskaya et al. 2023), new taxa (Alther et al. 2021; Fagan-Jeffries et al. 2021; Rosa et al. 2021; Mota et al. 2022), invasive species (Pocock et al. 2017b; Ryan et al. 2019; Johnson et al. 2020; Streito et al. 2021; Tran et al. 2022), geographic distribution (La Sorte and Somveille 2020; Marcenò et al. 2021; DiBattista et al. 2021; Diao et al. 2022; Wangyal et al. 2022), and rare or threatened species (Kaminski et al. 2015; Sullivan et al. 2019; Wilson et al. 2020; Mesaglio et al. 2021; Fontaine et al. 2022; Rosa et al. 2023a).

✉ Augusto H. B. Rosa
augustohbrosa@hotmail.com

✉ André V. L. Freitas
baku@unicamp.br

[1] Departamento de Biologia Animal and Museu de Diversidade Biológica, Instituto de Biologia, Universidade Estadual de Campinas, Campinas, São Paulo, Brazil

Another valuable source of ecological data is passive citizen science (PCS). Similar to the CS approach, PCS involves the participation of non-experts unconnected to any particular CS program, and datasets are collected without the organisation or oversight of specific campaigns. Data are retrieved from internet resources, particularly social media, where members of the public have uploaded observations such as photos of wildlife (Edwards et al. 2021). The use of internet sources (such as Facebook, Flickr, and iNaturalist) for gathering wildlife-related data in citizen science initiatives has emerged in recent years (Barve 2014; Liberatore et al. 2018; Marcenò et al. 2021; Geller et al. 2021; Mesaglio et al. 2021; Cranswick et al. 2022). In an overview of the impact of internet social networks on traditional biodiversity data collection methods, Di Minin et al. (2015) are optimistic that social media can potentially play an important role in conservation science.

Regardless of the type of citizen science approach (conventional CS or PCS), photographs of specimens (dead or alive) from internet sources represent a type of data that is largely applicable to a range of ecological studies. A photograph of a specimen provides a record for the scientific community to view and discuss, both in the quest for consensus regarding the taxonomic identification of the organism photographed, and as a permanent record for any necessary future revision (Casanovas et al. 2014). This kind of data can provide preliminary information on the distribution and/or biology of the organism, even if studies of this type are still incipient (Jimenez-Valverde et al. 2019; Fontaine et al. 2022). Opportunely, data from citizens (especially distribution records) are used to calculate trends and geographical ranges of species (Maes et al. 2015), which are two important criteria to estimate a species' extinction risk (Mace et al. 2008; IUCN 2012; Vantieghem et al. 2017; Rosa et al. 2023a).

The butterflies represent one of the biological groups for which citizen scientists have provided reliable and abundant information on geographic distribution (Dennis et al. 2017; Lewandowski and Oberhauser 2017; Ryan et al. 2019; Washitani et al. 2020; Herremans et al. 2021; Sanderson et al. 2021; Plummer et al. 2024). These organisms have great popular acceptance, due to their strikingly colored wings, easy of observation and photography, abundance, wide distribution and taxonomic diversity (Heppner 1991; Boggs et al. 2003; Mitter et al. 2017).

Therefore, the purpose of the present study is to validate the importance of data provided by citizens as a valuable source of information to support conservation assessments, including estimates of the geographical range of threatened Brazilian butterflies.

Materials and methods

Data collection

The target butterflies in this study are those present in the current Brazilian Red List (63 taxa) (MMA 2022); some examples from amateur photographers are shown in Fig. 1. All recent taxonomic changes were followed for the sake of taxonomic stability.

From 2015 to April 2023, images (photographs) of adult and/or larvae of butterflies from the Brazilian Red List were searched (using their current names, previous names, synonyms, and for subspecies determinations) in the world wide web, on the Google Images online platform, and other specific websites (Flickr (https://www.flickr.com/), Biofaces (https://www.biofaces.com/), iNaturalist (https://www.inaturalist.org/), YouTube (https://www.youtube.com/), and also on the social media website Facebook (https://www.facebook.com/), both in general search and in specific groups for photos of butterflies and animal-related topics ("Borboletas e Mariposas Neotropicais", "Borboletas e Mariposas", "Passarinhandos e Borboletando", "Entomologia Brasileira", "Entomos", "Insetos", "Insetos do Brasil", "Fotonaturalistas – Insetos", "Fauna Brasileira", and "Borboletas"). Duplicate records in different databases were considered from only one source (in this case, the database where the image was posted first) (e.g. the same record on Facebook and iNaturalist). In order to obtain the most accurate geographical coordinates of the localities where the photographic record was made, each of the citizens was contacted, most of whom provided accurate data. Records from personal communication with citizen scientists (eg. Via personal email and Facebook Messenger) were also compiled, along with the photograph of the taxon to prove their identity. All photographs in this study were verified by the authors (both are experts on Brazilian butterflies) and/or by external specialists. Additionally, the photographs were also compared with images or specimens of the threatened Brazilian butterflies by the authors themselves and/or by external specialists (see also Rosa and Freitas 2023).

A citizen science project (CSP) entitled "Como a ciência cidadã pode ajudar na conservação das borboletas ameaçadas de extinção do Brasil?" ("How citizen science can aid the conservation of threatened Brazilian butterflies?") was also developed from January 2019 to January 2021 on Facebook, using the page "Labbor – Laboratório de Ecologia e Sistemática de Borboletas" ("Labbor – Laboratory of Butterfly Ecology and Systematics") (https://www.facebook.com/labborboletas/) as host. Initially, a photographic guide containing the target species was produced and previously shared in Facebook groups (same as cited before) to facilitate the identification of the target taxa by citizens (Rosa

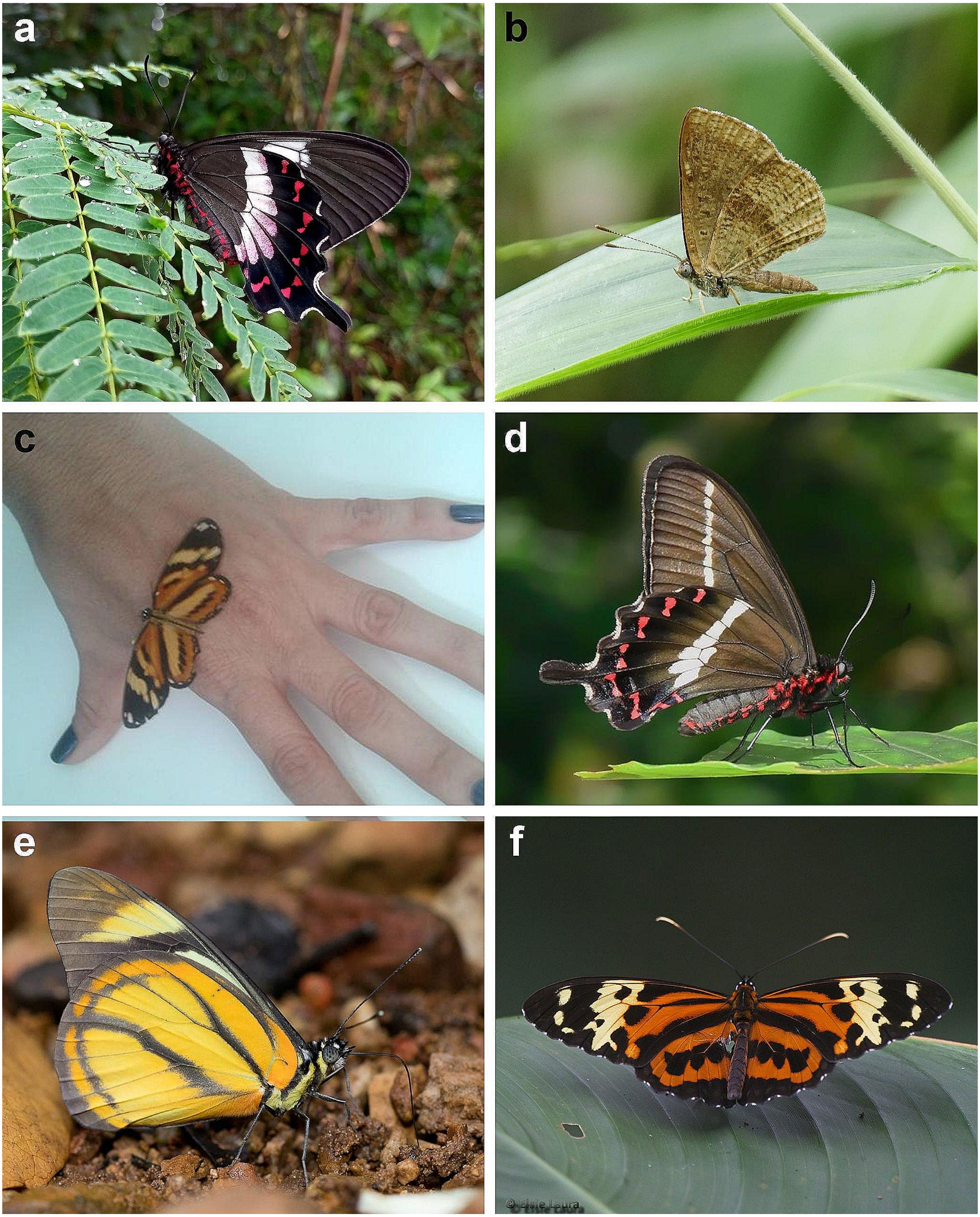

Fig. 1 Photos of some threatened Brazilian butterflies (all collaborations from citizen scientists photographers). (**A**) *Parides ascanius* (Cramer, 1775) (courtesy of Carlos Gussoni); (**B**) *Petrocerus catiena* (Hewitson, 1875) (courtesy of (Bettina Dungs); (**C**) *Eresia erysice erysice* (Geyer, 1832) (courtesy of Nilda Borges); (**D**) *Parides bunichus chamissonia* (Eschscholtz, 1821) (courtesy of Germán Murizíasco); (**E**) *Hesperocharis hirlanda planasia* (Fruhstorfer, 1910) (courtesy of Rodrigo Conte); (**F**) *Tithorea harmonia caissara* (J. Zikán, 1941) (courtesy of Elsie Laura)

and Freitas 2023). Subsequently, an infographic containing the butterfly photographs and basic information (eg. Conservation status, habitat, host plant) was posted weekly on "Labbor" page and shared in ten groups of butterfly and animal-related photographers (as mentioned above) (see the complete material in Supplementary Material 1). Records informed by comments on posts or sent by messages/email were also compiled (Supplementary material 2), however, only records that contained photos to prove the unequivocal identification of the taxon were used in the analysis of this study. The dates of when each photograph was posted were compiled to show the temporal pattern of data availability over time. All records from photographs were hereafter considered "citizen records". All "citizen science records" were separated into two categories: (1) active search (compiled by intensive search in the aforementioned databases) and (2) citizen scientists' feedback (compiled by the citizen science project (CSP), coming exclusively from citizen contact via project as well as separate personal communication (records informed by citizens, but not from the CSP).

In addition, "Non-citizen science records" (data not provided by citizen photographs) were used only for some comparisons with the "Citizen science records" and for contrasting geographical range estimates (see Rosa et al. 2023a for data). To avoid multiple "new" geographical records overlapping in the same locality, all data outside a grid of 4 km^2 where any published records was present were considered as new. The grid size (4 km^2) follows the IUCN recommendations for the area of occupancy (see further information in the next section). The distance of each "Citizen science record" from the nearest known locality of that given species was was measured using the ruler tool in the Google Earth program. All records within a diameter of 2 km^2 were considered as "same locality" and were not used to calculate the mean distances and other parameters.

Estimates of geographical range (extent of occurrence and area of occupancy)

Two metrics related to the restricted geographic distribution (International Union for Conservation of Nature (IUCN) criterion B) were used to assess the conservation status of each taxon: (1) the extent of occurrence (hereafter EOO) and (2) the area of occupancy (hereafter AOO) (IUCN 2012; IUCN Standards and Petitions Committee 2022). The EOO is defined as the area (in km^2) contained in the shortest continuous imaginary limit that can be drawn to cover all known, inferred, or projected sites of the current occurrence of a taxon, excluding cases of vagrancy. The AOO is a metric (in km^2) on a scale representing the area of suitable habitat currently occupied by a given taxon, within the limits of the EOO (IUCN 2012; IUCN Standards and Petitions Committee 2022). The EOO can be estimated as the area of the minimum convex polygon (the smallest polygon in which no internal angle exceeds 180 degrees and that embraces all locations of occurrence), while the AOO is estimated by the sum of all grid cells (usually with the size of 4 km^2) containing at least one record of the target taxon (IUCN 2012; IUCN Standards and Petitions Committee 2022). The extinction risk categories based on the thresholds of criterion B for EOO are: Critically Endangered (CR) = 100 km^2, Endangered (EN) = 5,000 km^2, and Vulnerable (VU) = 20,000 km^2. For the AOO, the thresholds are: CR = 10 km^2, EN = 500 km^2, and VU = 2,000 km^2 (IUCN 2012; IUCN Standards and Petitions Committee 2022).

For the present study, values for both EOO and AOO were estimated based on two scenarios, here named the "without citizen science records" estimate and "with citizen science records" estimate. The "without citizen science records" estimate was obtained without including the data gathered from citizen photographic records. The estimate "with citizen science data" was obtained by combining all records, including photographs from citizens. These data were analyzed using the online open-source program GeoCAT (Geospatial Conservation Assessment Tool, available at http://geocat.kew.org/) (Bachman et al. 2011). Grid cells of 4 km^2 were used following the recommendation of the IUCN for AOO analyses (IUCN 2012; IUCN Standards and Petitions Committee 2022).

Estimates were made as global (use of records inside and/or outside Brazil). Geographic data used to estimate EOO and AOO are the same used in Rosa et al. 2023a; with the addition of some data (Supplementary material 2). Localities where the original habitat of a given taxon was modified, replaced, or destroyed (based on recent visits or direct observation of Google Earth Pro images) were not used for AOO-EOO estimates (these are possible cases of local extinction). Finally, since all records refer to threatened taxa that have potential commercial trade interest (for private collections), specific geographic coordinates and specific geographical localities were deliberately omitted.

Results

A total of 37 taxa (58.7% of all threatened butterflies from the Brazilian Red List) were identified from 335 photographs (records) from 187 citizen scientists from various surveyed sources (Supplementary material 2). From this total, 121 (36%) records represent 67 new geographical localites, distributed in 48 new municipalities and two new Brazilian states (Supplementary material 2). Virtually all citizen data were concentrated in Brazil (only one record in Argentina), and are distributed in 14 states, 83 municipalities, and 106 different localities ("citizen science records only" in Fig. 2). Records and number of taxa in the Brazilian states are shown in Table 1.

The family with the most records was Papilionidae with 146 records (43.6%) from six taxa, followed by Nymphalidae (120 records, 35.8%) from 20 taxa, then Pieridae (45 records, 13.4%) from four taxa, Riodinidae (15 records, 4.5%) from four taxa, Hesperiidae (5 records, 1.5%) from three taxa and Lycaenidae (4 records, 1.2%) from one taxon. The most recorded taxon was *Parides ascanius* (Cramer, 1775) with 99 records (29.6%), followed by *Parides bunichus chamissonia* (Eschscholtz, 1821) with 26 records (7.8%), then *Anaea suprema* (Schaus, 1920) (24 records, 7.2%), and *Hesperocharis hirlanda planasia* (Fruhstorfer, 1910) and *Tithorea harmonia caissara* (J. Zikán, 1941), both with 20 records (6%). All other taxa were represented by less than 19 records (Fig. 3, Supplementary material

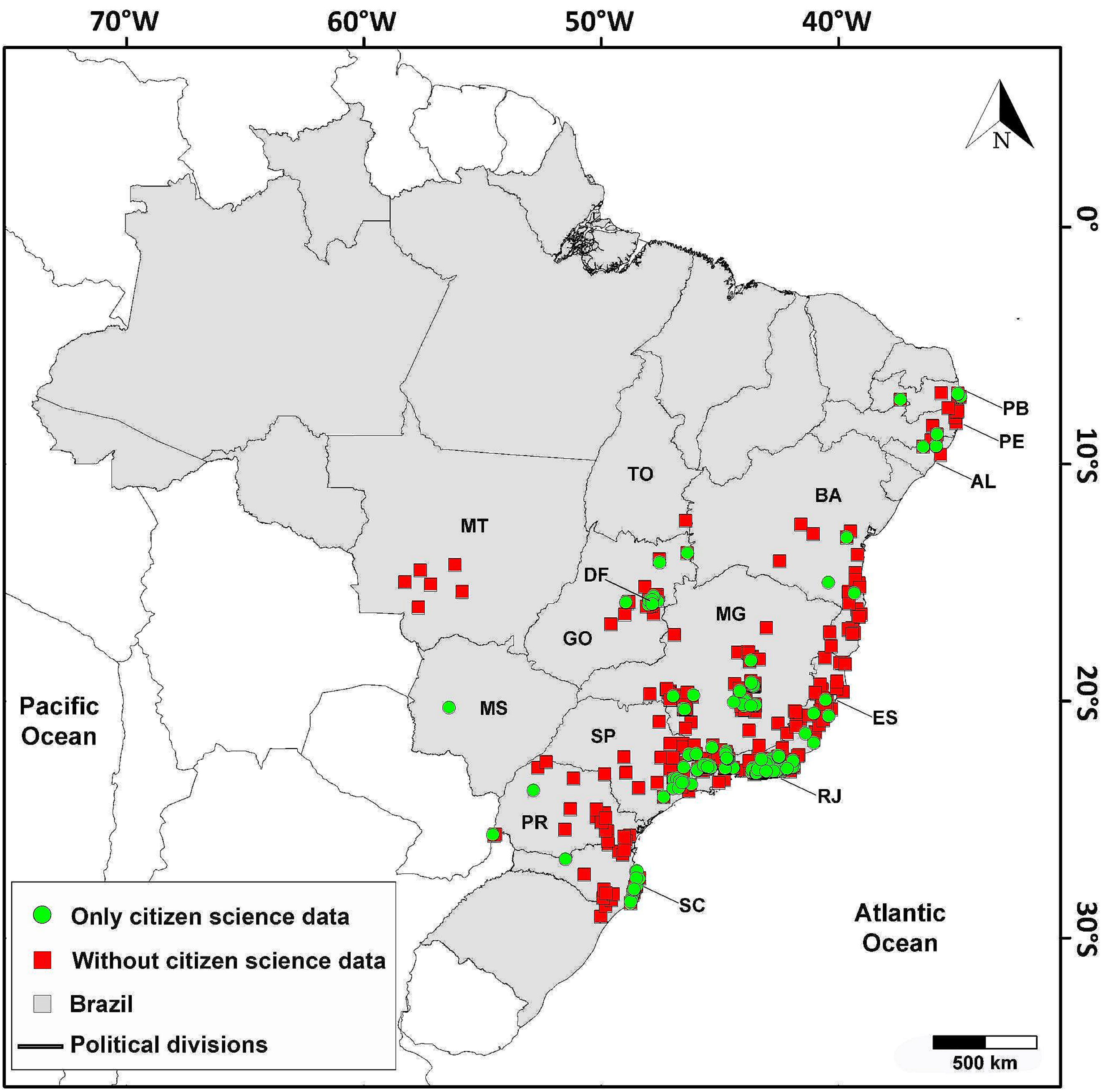

Fig. 2 All known records of threatened Brazilian butterflies. Red squares: records without citizen science data; Green circles: only citizen science data. Abbreviations of Brazilian states: AL. Alagoas, BA. Bahia, DF. Distrito Federal, ES. Espírito Santo, GO. Goiás, MG. Minas Gerais, MT. Mato Grosso, MS. Mato Grosso do Sul, PB. Paraíba, PR. Paraná, PE. Pernambuco, RJ. Rio de Janeiro, SC. Santa Catarina, SP. São Paulo, TO. Tocantins

Table 1 Number of records and taxa of threatened Brazilian butterflies in different states of Brazil

Brazilian state	Number of records from CS	Percentage of records from CS (%)	Number of taxa from CS	Total of taxa of butterflies in Brazilian Red List 2022
Rio de Janeiro	156	46.6	15	36
Minas Gerais	48	14.3	12	27
São Paulo	45	13.4	12	24
Santa Catarina	27	8.1	2	9
Distrito Federal	22	6.6	3	4
Espírito Santo	11	3.3	4	23
Alagoas	10	3.0	2	3
Bahia	4	1.2	3	10
Paraíba	4	1.2	3	3
Goiás	2	0.6	2	6
Pernambuco	2	0.6	1	4
Mato Grosso do Sul	1	0.3	1	2
Paraná	1	0.3	1	10
Pará	-	0.3	-	1
Mato Grosso	-	-	-	3
Rio Grande do Sul	-	-	-	1
Tocantins	-	-	-	2

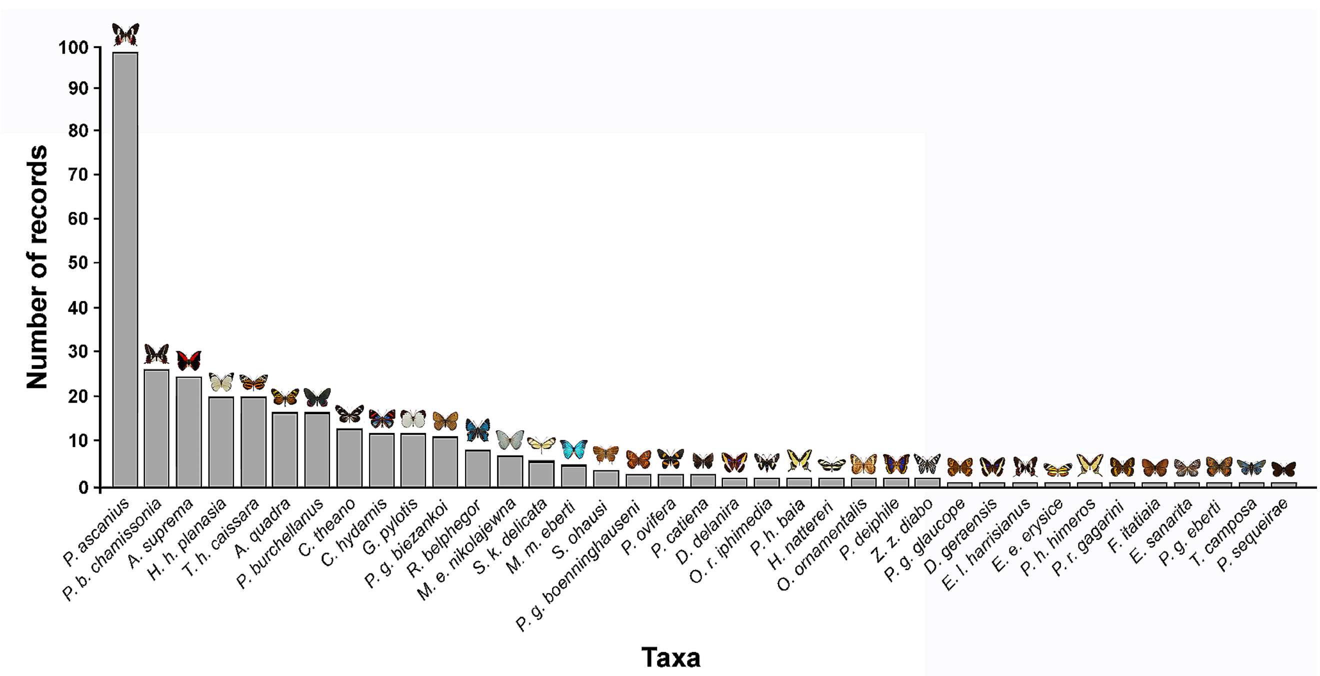

Fig. 3 Abundance rank of threatened Brazilian butterflies from citizen data

2). Considering the two categories of search, 257 records (76.7%) for 35 taxa came from active search and 78 (23.3%) for 20 taxa came from citizen science feedback (Table 2, Supplementary material 2). The temporal distribution of records (posted on websites or citizen personal communications of threatened butterflies photographs) showed a clear increase in numbers in the last decade (2014–2023), with a well-marked peak in 2019 (Fig. 4).

Based on the CSP alone, approximately 27,300 people were aware of the project (mainly through the posts advertising the photographic guide of the Brazilian threatened butterflies). The average number of views for the infographics that were posted and shared on Facebook groups was approximately 2,450 views. However, the feedback and correct identification rate was relatively low; only 197 records (personal communications with 151 citizen scientists) were shared by citizen scientists, and only 26 records (13%) were

Table 2 Number of records of threatened Brazilian butterflies from different sources of citizen data. CSP = Citizen science project

Category	Source	Number of records	Percentage of records (%)	Number of taxa
Active	iNaturalist	132	51.4	17
	Facebook	77	30.0	21
	Flickr	33	12.8	6
	Biofaces	14	5.4	4
	Youtube	1	0.4	1
Citizen feedback	Personal communication	54	69.2	19
	CSP	24	30.8	11

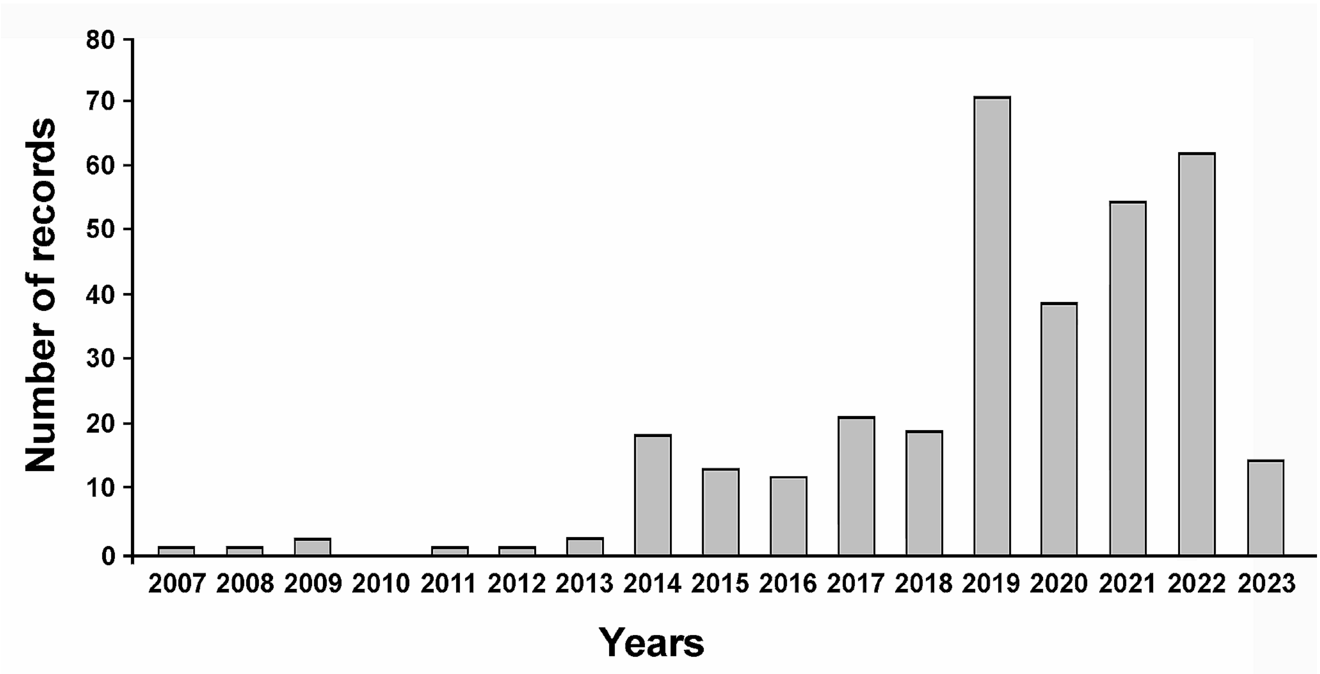

Fig. 4 Number of records of threatened Brazilian butterflies from citizen data per year (based on the year the record was posted on the internet platform or the contact of the citizen scientist)

proven to be of threatened butterflies (11 taxa). The other putative records received were only visual (no photographs available) or were of other similar species. Total records of CSP are distributed in 110 municipalities from 19 states (Supplementary Material 2).

In total, 254 "Citizen science records" were considered as "same locality"; concerning the new records, five classes of distance were defined: 1) from 0 to 10 km ($n = 28$); 2) > 10 to 50 km ($n = 38$); 3) > 50 to 100 km ($n = 2$); 4) > 100 to 200 ($n = 3$) and 5) > 200 km ($n = 3$). Considering only records of new localities (see methods), the distances from the nearest known locality ranged from 4.4 to 486 km, with a mean of 34.4 km (median = 11.5 km).

Geographical range (EOO-AOO)

Comparing the estimates of species' geographical ranges "without citizen science records" to "with citizen science records", changes were reported for 26 taxa (70.3% of the taxa with new data obtained in the present study), which represent 41.3% of all taxa in Brazilian Red List (Table 3). Comparing "without citizen science records" to "with citizen science records" estimates for EOO, changes were reported for 20 taxa (54.1%) with increases in EOO for all these taxa. Concerning the AOO, changes were reported for 26 taxa, with increases in AOO for all these taxa (Table 3). There was an increase of more than 50% in the EOO of eight taxa, with this increase in percentage in AOO observed only in one taxon (Table 4).

Table 3 Estimates of extent of occurrence (EOO) and area occupancy (AOO) and their percentages of change for the 37 threatened Brazilian butterfly taxa studied

Taxon	EOO without citizen data (km^2)	EOO with citizen data (km^2)	EOO Change (%)	AOO without citizen data (km^2)	AOO with citizen data (km^2)	AOO Change (%)
Hesperiidae						
Oxynetra roscius iphimedia	80,524.68	81,177.30	1%	44	52	18%
Turmosa camposa	132.00	604.17	358%	8	12	50%
Zonia zonia diabo	279,135.98	285,504.61	2%	20	28	40%
Lycaenidae						
Strymon ohausi	475,242.96	475,242.96	0%	60	64	7%
Nymphalidae						
Actinote quadra	73,590.26	74,049.23	1%	76	92	21%
Anaea suprema	3,654.05	4,260.66	17%	84	104	24%
Catagramma hydarnis	31,593.67	34,323.09	9%	44	56	27%
Dasyophthalma delanira	47.10	90.19	91%	12	16	33%
Dasyophthalma geraensis	1,291.64	2,336.36	81%	36	40	11%
Eresia erysice erysice	910.758	1,932.30	112%	16	20	25%
Forsterinaria itatiaia	790.23	790.23	0%	12	12	0%
Heliconius nattereri	29,721.65	29,721.65	0%	32	32	0%
Morpho epistrophus nikolajewna	6,901.55	9,968.86	44%	24	36	50%
Morpho menelaus eberti	225,379.51	230,094.82	2%	112	120	7%
Orobrassolis ornamentalis	70.17	70.17	0%	24	24	0%
Pampasatyrus glaucope boenninghauseni	2,458.09	2,458.09	0%	68	68	0%
Pampasatyrus glaucope eberti	47.06	47.06	0%	24	24	0%
Pampasatyrus glaucope glaucope	42,967.73	48,563.03	13%	40	44	10%
Pampasatyrus gyrtone biezankoi	51,008.24	51,008.24	0%	68	68	0%
Pampasatyrus reticulata gagarini	724.68	724.68	0%	44	44	0%
Praepedaliodes sequeirae	2.44	2.44	0%	12	12	0%
Prepona deiphile	204,124.29	204,124.29	0%	84	84	0%
Scada karschina delicata	5,638.60	5,638.60	0%	24	24	0%
Tithorea harmonia caissara	79,767.11	83,780.05	5%	72	108	50%
Papilionidae						
Eurytides lysithous harrisianus	31,868.89	32,033.00	1%	92	96	4%
Heraclides himeros baia	215,935.49	328,982.75	52%	16	20	25%
Heraclides himeros himeros	41,304.76	41,304.76	0%	64	68	6%
Parides ascanius	25,375.67	25,927.47	2%	240	316	32%
Parides bunichus chamissonia	313.02	1,572.72	402%	32	76	138%
Parides burchellanus	183,733.00	183,733.00	0%	168	184	10%
Pieridae						
Charonias theano	352,361.18	352,361.18	0%	164	208	27%
Glennia pylotis	1,168,112.48	1,170,441.04	0%	152	168	11%
Hesperocharis hirlanda planasia	773,630.08	1,023,668.32	32%	100	136	36%
Riodinidae						
Eucorna sanarita	7,968.56	7,968.56	0%	48	48	0%
Panara ovifera	491.58	985.84	101%	24	36	50%
Petrocerus catiena	252	5,965.26	2271%	12	16	33%
Rhetus belphegor	11,416.86	11,416.86	0%	72	76	6%

Discussion

In the present study, citizen scientists have contributed data for more than half of the taxa of threatened Brazilian butterflies. Citizen science records increased knowledge with 67 new geographic localities of threatened species in two new states in Brazil and various municipalities, as well as the first record of *Zonia zonia diabo* O. Mielke & Casagrande, 1998 in Argentina. These data represent new opportunities for further studies (e.g. population or immature biology) on threatened species in these areas.

Parides ascanius (Cramer, 1775) was the species most recorded by citizen scientists, representing alone almost 30% of all records. This is probably because this species

Table 4 Percentages of change in extent of occurence (EOO) and area of ocupancy (AOO) and number of studied taxa of threatened Brazilian butterflies

Change (%)	EOO (*n*)	AOO (*n*)
0	17	11
1–10	8	7
11–50	4	18
51–100	3	1
100–999	4	-
> 1000	1	-

is easily found in urban parks in the municipality of Rio de Janeiro and surrounding areas, as well as because of its conspicuous coloration, large size, and easy detection when present (as several other species of Papilionidae). Finally, this is an iconic threatened species that is well known to the local people in Rio de Janeiro (Otero and Brown Jr 1986).

The active search of data resulted in more records than the citizen scientist's feedback (both in numbers of distribution records and in the number of registered taxa). Moreover, the active search was more efficient in terms of results. However, the citizen feedback was also important, contributing data for 20 butterflies on the Brazilian Red List. Regardless of the type of search, we briefly introduced ourselves to each citizen and explained the type of study that was being carried out, also asking for additional information for each record (e.g., more precise geographic coordinates, dates of the record, among other details). This type of interaction with the citizen scientist is very rewarding for both actors, as most were very eager in providing the additional requested information and mentioned that were happy to contribute in some way to a scientific study. It worth noting that in the data obtained through active search by the authors, most of the time the photographers did not know that the butterfly taxa were threatened. This information is important because it minimizes potential bias such as photographers actively searching for threatened species. However, this scenario, along with the low number of new information obtained from CSP, indicates a necessity for improved engagement strategies or educational initiatives to enhance the accuracy and quantity of citizen-contributed data in future projects centeresd on this source of information.

The citizen science project (CSP) developed on Facebook received a moderate number of views on the social network (average views of 2,450 per post), however, as previously mentioned, the feedback was relatively low; from the available data, only 13% represented threatened butterflies. Despite this relatively low rate, when the CS data were summed with the full dataset, it resulted in effective changes in the estimates of geographic range. With the inclusion of CS data, there was an increase in geographic range (for both EOO and AOO) of 26 taxa (41%) of the 63 butterfly taxa present in the Brazilian Red List. For some taxa, there was more than a 100% increase in EOO, with the most notable being *Petrocerus catiena* (Hewitson, 1875), a species previously known only from two municipalities in the mountainous region of the state of Rio de Janeiro. With the new record for the municipality of Castelo, in the state of Espírito Santo, the EOO increased by 2271% (see Rosa et al. 2023b). Both the records and geographic range estimates from this study can be used in future conservation status assessments of these taxa, resulting in a more realistic status than those in the current Brazilian Red List. We expect the greatest increases in species in the families Riodinidae (as is the case), Hesperiidae, and Lycaenidae. Butterflies in these three families are usually not easy to observe, and their rarity could many times be an artifact of low detectability. Accordingly, in two recent examples, a picture of a butterfly in the field expanded considerably the geographical ranges of two supposedly threatened species of Hesperiidae (Rosa et al. 2017) and Riodinidae (Greve et al. 2013).

The temporal distribution of records clearly showed an increase in the last decade, possibly as a result of the advance in the technology of mobile devices and online data sources (Cohn 2008; Silvertown 2009; Bik and Goldstein 2013; Arts et al. 2015). However, the noticeable reduction in the number of records in 2020 could be a direct effect COVID-19 pandemic and the restricted mobility imposed by the quarantine in Brazil. This underscores a potential vulnerability associated with reliance on citizen science data, as it can be susceptible to external influences. Other studies have also discussed the impacts of COVID-19 on the development of CS projects, supporting our results (Basile et al. 2021; Crimmins et al. 2021; Lynch and Miller 2023). Accordingly, the number of records began to grow after the first year of the pandemic and is now approaching the rates observed before the pandemic (Fig. 4).

Based on the distance between the new geographic record and the closest known locality, most of the new records (77%) fell into the category "same locality". However, several records here considered as "new localities" were considerably distant from the previous known records, representing potential areas for specific studies on the biology of these organisms and contributing to changes in the conservation assessments of various species (see Rosa et al. 2023a). One valuable advantage of CS data is that information is consistently recent and up to date compared to data available in the literature and/or scientific collections and can serve as a confirmation that a given taxon is still present in a historical locality. A good example is the occurrence of *Parides ascanius* in the Deodoro neighborhood in the municipality of Rio de Janeiro; a single specimen was collected there in 1938 (voucher number CEIOC 20,707), and recently, four individuals were photographically recorded at the same locality (one in 2021 and three in 2022).

The current results illustrate the significance of citizen science in advancing our understanding of endangered Brazilian butterflies. However, while this study specifically addressed threatened butterflies in Brazil, the findings may not directly apply to other regions or species. However, a similar approach using data from various social media platforms could be used to gather information on a wider range of organisms and geographic locations. The involvement of the general public in scientific research should be constantly encouraged, as the simple act of sharing photographs on the internet of a living organism in nature has the potential to contribute to researchers in their studies by providing accurate and quality data, in addition to relieving them of limiting factors in research, such as time in the field and financial resources.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10841-024-00613-z.

Acknowledgements We thank all citizen scientists who directly or indirectly contributed with information for this study (full name list Supplementary Material 2). We thank all curators in charge of the visited collections for facilitating access (full name list Supplementary Material 2). We thank Alexandre Antonelli for valuable comments and suggestions to improve the last version of the manuscript. We also thank Carlos Gussoni, Bettina Dungs, Nilda Borges, Germán Muriziasco, Rodrigo Conte, and Elsie Laura for providing beautiful photographs for Fig. 1 of this study. We thank Natalie Diesel for English review. AVLF acknowledges support from FAPESP (BIOTA-FAPESP 2021/03868-8), from the Brazilian Research Council–CNPq (421248/2017-3 and 304291/2020-0), and from the National Science Foundation (DEB-1256742). AHBR thanks the CNPq (grant 130314/2016-1) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–Brazil (CAPES) - Finance Code 001, for the present scholarship. This publication is part of the RedeLep 'Rede Nacional de Pesquisa e Conservação de Lepidópteros' SISBIOTABrazil/CNPq (563332/2010-7). The present study is registered in the SISGEN (A3BD4BE).

Author contributions Authors make substantial contributions to conception and design, and/or acquisition of data and participate in drafting the article or revising it critically for important intellectual content.

Declarations

Conflicts of interest/Competing interests The authors declare that they have no conflict of interest.

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consente Informed consent was obtained from all individual participants included in the study.

References

Alther R, Bongni N, Borko Š, Fišer C, Altermatt F (2021) Citizen science approach reveals groundwater fauna in Switzerland and a new species of *Niphargus*. Niphargidae) Subterr Biol 39:1–31. https://doi.org/10.3897/subtbiol.39.66755. Amphipoda

Arts K, van der Wal R, Adams WM (2015) Digital technology and the conservation of nature. Ambio 44(Suppl 4):661–673. https://doi.org/10.1007/s13280-015-0705-1

Bachman S, Moat J, Hill AW, De La Torre J, Scott B (2011) Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. ZooKeys 150:117–126. https://doi.org/10.3897/zookeys.150.2109

Barahona-Segovia RM, Duran-Sanzana V, Murua M (2023) This flower is our bed: long-term citizen science reveals that hummingbird flies use flowers with certain shapes as sleeping places. Arthropod-Plant Inte 17(1):1–10. https://doi.org/10.1007/s11829-022-09936-7

Barve V (2014) Discovering and developing primary biodiversity data from social networking sites: a novel approach. Ecol Infor 24:194–199. https://doi.org/10.1016/j.ecoinf.2014.08.008

Basile M, Russo LF, Russo VG, Senese A, Bernardo N (2021) Birds seen and not seen during the COVID-19 pandemic: the impact of lockdown measures on citizen science bird observations. Biol Conserv 256:109079. https://doi.org/10.1016/j.biocon.2021.109079

Bik HM, Goldstein MC (2013) An introduction to social media for scientists. PLoS Biol 11:e1001535. https://doi.org/10.1371/journal.pbio.1001535

Boggs CL, Watt WB, Ehrlich PR (2003) Butterflies: ecology and evolution taking flight. University of Chicago Press

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next steps for citizen science. Science 343(6178):1436–1437

Callcutt K, Croft S, Smith GC (2018) Predicting population trends using citizen science data: do subsampling methods produce reliable estimates for mammals? Eur J Wildl Res 64:1–6. https://doi.org/10.1007/s10344-018-1189-7

Casanovas P, Lynch HJ, Fagan WF (2014) Using citizen science to estimate lichen diversity. Biol Conserv 171:1–8. https://doi.org/10.1016/j.biocon.2013.12.020

Cohn JP (2008) Citizen science: can volunteers do real research? Bioscience 58:192–197. https://doi.org/10.1641/B580303

Cranswick AS, Constantine R, Hendriks H, Carroll EL (2022) Social media and citizen science records are important for the management of rarely sighted whales. Ocean Coast Manag 226:106271. https://doi.org/10.1016/j.ocecoaman.2022.106271

Crawford BA, Olds MJ, Maerz JC, Moore CT (2020) Estimating population persistence for at-risk species using citizen science data. Biol Conserv 243:108489. https://doi.org/10.1016/j.biocon.2020.108489

Crimmins TM, Posthumus E, Schaffer S, Prudic KL (2021) COVID-19 impacts on participation in large scale biodiversity-themed community science projects in the United States. Biol Conserv 256:109017. https://doi.org/10.1016/j.biocon.2021.109017

Dennis EB, Morgan BJ, Brereton TM, Roy DB, Fox R (2017) Using citizen science butterfly counts to predict species population trends. Conserv Biol 31(6):1350–1361. https://doi.org/10.1111/cobi.12956

Di Minin E, Tenkanen H, Toivonen T (2015) Prospects and challenges for social media data in conservation science. Front Environ Sci 3:63. https://doi.org/10.3389/fenvs.2015.00063

Diao Y, Zhao Q, Weng Y, Huang Z, Wu Y, Gu B, Zhao Q, Wang F (2022) Predicting current and future species distribution of the raccoon dog (*Nyctereutes procyonoides*) in Shanghai, China.

Landsc Urban Plan 228:104581. https://doi.org/10.1016/j.landurbplan.2022.104581

DiBattista JD, West KM, Hay AC, Hughes JM, Fowler AM, McGrouther MA (2021) Community-based citizen science projects can support the distributional monitoring of fishes. Aquat Conserv: Mar Freshw 31(12):3580–3593. https://doi.org/10.1002/aqc.3726

Dickinson JL, Bonney R (2012) Citizen science: public participation in environmental research. Cornell University Press, Ithaca, NY, USA

Edwards T, Jones CB, Perkins SE, Corcoran P (2021) Passive citizen science: the role of social media in wildlife observations. PLoS ONE 16(8):e0255416. https://doi.org/10.1371/journal.pone.0255416

Fagan-Jeffries EP, Austin AD (2021) Four new species of parasitoid wasp (Hymenoptera: Braconidae) described through a citizen science partnership with schools in regional South Australia. Zootaxa 4949(1):79–101. https://doi.org/10.11646/zootaxa.4949.1.4

Follett R, Strezov V (2015) An analysis of citizen science based research: usage and publication patterns. PLoS ONE 10(11):e0143687. https://doi.org/10.1371/journal.pone.0143687

Fontaine A, Simard A, Brunet N, Elliott KH (2022) Scientific contributions of citizen science applied to rare or threatened animals. Conserv Biol 36(6):e13976. https://doi.org/10.1111/cobi.13976

Frigerio D, Pipek P, Kimmig S, Winter S, Melzheimer J, Diblíková L, Wachter B, Richter A (2018) Citizen science and wildlife biology: synergies and challenges. Ethology 124(6):365–377. https://doi.org/10.1111/eth.12746

García MB, Silva JL, Tejero P, Pardo I (2021) Detecting early-warning signals of concern in plant populations with a Citizen Science network. Are threatened and other priority species for conservation performing worse? J Appl Ecol 58(7):1388–1398. https://doi.org/10.1111/1365-2664.13890

Geller IV, Garcia DAZ, Pereira AD, Casimiro ACR, Cochak C, Vitule JRS, Orsi ML (2021) New conservation opportunities: using citizen science in monitoring non-native species in Neotropical region. J Appl Ichthyol 37(5):779–785. https://doi.org/10.1111/jai.14231

Greve RR, Callaghan C, Kaminski LA, Freitas AVL (2013) The rediscovery of *Joiceya Praeclarus* Talbot 1928 (Lepidoptera: Riodinidae), more than 80 years after its description. J Lepid Soc 67(1):56–57. https://doi.org/10.18473/lepi.v67i1.a7

Harvey GK, Nelson TA, Paquet PC, Ferster CJ, Fox CH (2018) Comparing citizen science reports and systematic surveys of marine mammal distributions and densities. Biol Conserv 226:92–100. https://doi.org/10.1016/j.biocon.2018.07.024

Heppner JB (1991) Faunal regions and the diversity of Lepidoptera. Trop Lepid Res 2(1):1–85

Herremans M, Gielen K, Van Kerckhoven J, Vanormelingen P, Veraghtert W, Swinnen KR, Maes D (2021) Abundant citizen science data reveal that the peacock butterfly *Aglais Io* recently became bivoltine in Belgium. Insects 12(8):683. https://doi.org/10.3390/insects12080683

IUCN (2012) IUCN Red List Categories and Criteria: Version 3.1. Technical Report, IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK

IUCN Standards and Petitions Committee (2022) Guidelines for Using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee. https://www.iucnredlist.org/resources/redlistguidelines. Accessed 2 April 2023

Jiménez-Valverde A, Peña-Aguilera P, Barve V, Burguillo-Madrid L (2019) Photo-sharing platforms key for characterising niche and distribution in poorly studied taxa. Insect Conserv Divers 12(5):389–403. https://doi.org/10.1111/icad.12351

Johnson BA, Mader AD, Dasgupta R, Kumar P (2020) Citizen science and invasive alien species: an analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. Glob Ecol Conserv 21:e00812. https://doi.org/10.1016/j.gecco.2019.e00812

Kaminski LA, Soares GR, Seraphim N, Wahlberg N, Marini-Filho OJ, Freitas AVL (2015) Natural history and systematic position of *Rhetus belphegor* (n. comb.) (Lepidoptera: Riodinidae), an endangered butterfly with narrow distribution in Southeast Brazil. J Insect Conserv 19:1141–1151. https://doi.org/10.1007/s10841-015-9829-7

Kobori H, Dickinson JL, Washitani I, Sakurai R, Amano T, Komatsu, N., Kitamura W, Takagawa S, Koyama K, Ogawara T, Miller-Rushing AJ (2016) Citizen science: a new approach to advance ecology, education, and conservation. Ecol Res 31:1–19. https://doi.org/10.1007/s11284-015-1314-y

Kosmala M, Wiggins A, Swanson A, Simmons B (2016) Assessing data quality in citizen science. Front Ecol Environ 14(10):551–560. https://doi.org/10.1002/fee.1436

La Sorte FA, Somveille M (2020) Survey completeness of a global citizen-science database of bird occurrence. Ecography 43(1):34–43. https://doi.org/10.1111/ecog.04632

Lewandowski EJ, Oberhauser KS (2017) Butterfly citizen scientists in the United States increase their engagement in conservation. Biol Conserv 208:106–112. https://doi.org/10.1016/j.biocon.2015.07.029

Liberatore A, Bowkett E, MacLeod CJ, Spurr E, Longnecker N (2018) Social media as a platform for a citizen science community of practice. Citiz Science: Theory Pract 3(1):3. https://doi.org/10.5334/cstp.108

Lynch L, Miller J (2023) Accessibility of participation in a pollinator-focused Community Science Project. Citiz Science: Theory Pract 8(1):15. https://doi.org/10.5334/cstp.557

Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akçakaya HR, Leader-Williams N, Milner-Gulland EJ, Stuart SN (2008) Quantification of extinction risk: IUCN's system for classifying threatened species. Conserv Biol 22(6):1424–1442. https://doi.org/10.1111/j.1523-1739.2008.01044.x

Maes D, Isaac NJ, Harrower CA, Collen B, Van Strien AJ, Roy DB (2015) The use of opportunistic data for IUCN Red List assessments. Biol J Linn 115(3):690–706. https://doi.org/10.1111/bij.12530

Marcenò C, Padullés Cubino J, Chytrý M, Genduso E, Salemi D, La Rosa A, Gristina AS, Agrillo E, Bonari G, del Galdo GG, Ilardi V, Landucci F, Guarino R (2021) Facebook groups as citizen science tools for plant species monitoring. J Appl Ecol 58(10):2018–2028. https://doi.org/10.1111/1365-2664.13896

Mesaglio T, Soh A, Kurniawidjaja S, Sexton C (2021) First known photographs of living specimens': the power of iNaturalist for recording rare tropical butterflies. J Insect Conserv 25:905–911. https://doi.org/10.1007/s10841-021-00350-7

Mitter C, Davis DR, Cummings MP (2017) Phylogeny and evolution of Lepidoptera. Annu Rev Entomol 62:265–283. https://doi.org/10.1146/annurev-ento-031616-035125

MMA (2022) Portaria MMA Nº 148, de 7 de junho de 2022 - Atualiza o teor do Anexo da Portaria nº 443, de 17 de dezembro de 2014, Lista oficial de espécies da flora brasileira ameaçadas de extinção. Diário Oficial da União, Brasilia, DF. Seção 1, 108:74

Mota LL, Rosa AHB, Vasconcellos LR, Willmott KR, Freitas AVL (2022) A new subspecies of *Mechanitis lysimnia* from southern Amazonia (Nymphalidae: Danainae: Ithomiini). Trop Lepid Res 32:47–51. https://doi.org/10.5281/zenodo.6604683

Olsen K, Holm TE, Pape T, Simonsen TJ (2020) Natural history museum collection and citizen science data show advancing phenology of Danish hoverflies (Insecta: Diptera, Syrphidae) with increasing annual temperature. PLoS ONE 15(5):e0232980. https://doi.org/10.1371/journal.pone.0232980

Otero LS, Brown KS Jr (1986) Biology and ecology of *Parides Ascanius* (Cramer, 1775) (Lepidoptera, Papilionidae), a primitive butterfly threatened with extinction. Atala 10–12:2–16

Plummer KE, Dadam D, Brereton T, Dennis EB, Massimino D, Risely K, Siriwardena GM, Toms MP (2024) Trends in butterfly populations in UK gardens - new evidence from citizen science monitoring. Insect Conserv Divers 17(2):345–357. https://doi.org/10.1111/icad.12645

Pocock MJ, Tweddle JC, Savage J, Robinson LD, Roy HE (2017a) The diversity and evolution of ecological and environmental citizen science. PLoS ONE 12(4):e0172579. https://doi.org/10.1371/journal.pone.0172579

Pocock MJ, Roy HE, Fox R, Ellis WN, Botham M (2017b) Citizen science and invasive alien species: predicting the detection of the oak processionary moth *Thaumetopoea processionea* by moth recorders. Biol Conserv 208:146–154. https://doi.org/10.1016/j.biocon.2016.04.010

Rosa AHB, Freitas AVL (2023) Guia básico das borboletas ameaçadas de extinção do Brasil – V2. http://labbor.ib.unicamp.br/wp-content/uploads/2023/04/Guia-b%C3%A1sico-Borboletas-Amea%C3%A7adas-Brasil_V2.pdf [accessed June 17, 2024]

Rosa AHB, Campis MC, Freitas AVL (2017) New record of the threatened butterfly *drephalys mourei* (Hesperiidae) in a heavily disturbed area in southeastern Brazil. J Lepid Soc 71:278–280. https://doi.org/10.18473/lepi.71i4.a1

Rosa AHB, Huertas B, Willmott KR, Barbosa EP, Machado PA, Mielke OHH, Canaan CHP, Freitas AVL (2021) Fifty years without a name: a new species of *Splendeuptychia* Forster (Lepidoptera: Nymphalidae: Satyrinae). Zootaxa 5061(1):95–114. https://doi.org/10.11646/zootaxa.5061.1.4

Rosa AHB, Ribeiro DB, Freitas AVL (2023a) How data curation and new geographical records can change the conservation status of threatened Brazilian butterflies. J Insect Conserv 27:403–414. https://doi.org/10.1007/s10841-023-00464-0

Rosa AHB, Braga L, Siewert RR, Magnago GR, Freitas AVL (2023b) Distribution expansion of *Petrocerus catiena* (Hewitson, 875) (Lepidoptera: Riodinidae) and description of the previously unknown female. J Insect Biodivers 44(1):14–20. https://doi.org/10.12976/jib/2023.44.1.2

Ryan SF, Lombaert E, Espeset A, Vila R, Talavera G, Dincă V, Doellman MM, Renshaw MA, Eng MW, Hornett EA, Li Y, Pfrende ME, Shoemaker D (2019) Global invasion history of the agricultural pest butterfly *Pieris rapae* revealed with genomics and citizen science. Proc Natl Acad Sci USA 116(40):20015–20024. https://doi.org/10.1073/pnas.1907492116

Sanderson C, Braby MF, Bond S (2021) Butterflies Australia: a national citizen science database for monitoring changes in the distribution and abundance of Australian butterflies. Austral Entomol 60(1):111–127. https://doi.org/10.1111/aen.12513

Shumskaya M, Filippova N, Lorentzen L, Blue S, Andrew C, Lorusso NS (2023) Citizen science helps in the study of fungal diversity in New Jersey. Sci Data 10(1):10. https://doi.org/10.1038/s41597-022-01916-z

Silvertown J (2009) A new dawn for citizen science. Trends Ecol Evol 24:467–471. https://doi.org/10.1016/j.tree.2009.03.017

Streito JC, Chartois M, Pierre É, Dusoulier F, Armand JM, Gaudin J, Rossi JP (2021) Citizen science and niche modeling to track and forecast the expansion of the brown marmorated stinkbug *Halyomorpha halys* (Stål, 1855). Sci Rep 11(1):1–14. https://doi.org/10.1038/s41598-021-90378-1

Sullivan M, Robinson S, Littnan C (2019) Social media as a data resource for# monkseal conservation. PLoS ONE 14(10):e0222627. https://doi.org/10.1371/journal.pone.0222627

Theobald EJ, Ettinger AK, Burgess HK, DeBey LB, Schmidt NR, Froehlich HE, Wagner C, HilleRisLambers J, Tewksbury J, Harsch MA, Parrish JK (2015) Global change and local solutions: tapping the unrealized potential of citizen science for biodiversity research. Biol Conserv 181:236–244. https://doi.org/10.1016/j.biocon.2014.10.021

Tran TT, Carter BE, Castillo Vardaro JA (2022) Predicted threats to a native squirrel from two invading species based on citizen science data. Biol Invasions 24(11):3539–3553. https://doi.org/10.1007/s10530-022-02859-7

Vantieghem P, Maes D, Kaiser A, Merckx T (2017) Quality of citizen science data and its consequences for the conservation of skipper butterflies (Hesperiidae) in Flanders (northern Belgium). J Insect Conserv 21:451–463. https://doi.org/10.1007/s10841-016-9924-4

Wangyal JT, Bower D, Vernes K, Thinley P (2022) Employing citizen science to understand amphibian and reptile diversity and distribution in the Himalayan Kingdom of Bhutan. Glob Ecol Conserv 37:e02157. https://doi.org/10.1016/j.gecco.2022.e02157

Washitani I, Nagai M, Yasukawa M, Kitsuregawa M (2020) Testing a butterfly commonness hypothesis with data assembled by a citizen science program Tokyo Butterfly Monitoring. Ecol Res 35(6):1087–1094. https://doi.org/10.1111/1440-1703.12161

Wilson JS, Pan AD, General DEM, Koch JB (2020) More eyes on the prize: an observation of a very rare, threatened species of Philippine Bumble bee, *Bombus irisanensis*, on iNaturalist and the importance of citizen science in conservation biology. J Insect Conserv 24:727–729. https://doi.org/10.1007/s10841-020-00233-3