Recognition and completeness metrics from iNaturalist and GBIF can inform future citizen science and research projects: a case study on arthropods in Namibia

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Abstract

Arthropods are the most diverse animal phylum and play crucial roles in ecosystem functioning through their contributions to ecosystem processes. Accurate knowledge about their distribution and diversity is essential for effective ecosystem management and biodiversity conservation. Public biodiversity databases and citizen science records could contribute to our understanding of arthropod diversity. To test this assumption, we extracted arthropod observations in Namibia from iNaturalist (iNat) and the Global Biodiversity Information Facility (GBIF) and compared these data to the records in the Namibian Biodiversity Database (NBD). We assessed the proportion of observations identified to species level in each arthropod order in iNat and GBIF ("recognition" metric) and compared the number of species from the two biodiversity networks (iNat and GBIF) to the known species richness in each arthropod order in NBD ("completeness" metric). Only 54.4% of iNat and 63.1% of GBIF arthropod observations in Namibia are recorded at species level. Scorpions (Scorpiones) and dragonflies (Odonata) are the most recognised orders in both GBIF and iNat, with high completeness rates (> 60%). However, overall recognition and completeness for all arthropod orders were generally below 50% in both databases. The high recognition and completeness for certain orders could be attributed to species traits that make them recognizable (e.g. large body size, colouration), a low species richness and the taxonomic familiarity of the public. While global biodiversity networks provide valuable data, science-based databases like NBD remain essential for comprehensive biodiversity understanding. Global biodiversity networks provide insights into public perception and the suitability of taxonomic groups for citizen-involved biodiversity projects.

Introduction

Arthropods represent a substantial portion of the global biodiversity, with estimates ranging from 5 to 10 million species, and they comprise approximately 80% of all known species on Earth (Ødegaard 2000; Stork 2018). These organisms inhabit a wide range of ecological niches and play crucial roles in various ecosystems. However, despite their ecological importance, arthropods are severely under-represented in conservation initiatives (Samways 1993; Cowie, Bouchet & Fontaine 2022). The loss of arthropods from ecosystems could lead to a decline in many ecosystem services and trigger secondary extinctions of other organisms (Cardoso et al. 2020). Insects, in particular, fulfil critical ecological functions such as serving as the primary food source for many terrestrial vertebrates, play a key role in pollinating a significant proportion of flowering plants, and contributing to the biological control of agricultural pests (Birkhofer et al. 2024a). Furthermore, certain groups of arthropods, for examples mites, isopods, and diplopods, are scavengers or decomposers, contributing to the breakdown of dead plants and animals and converting organic matter into essential soil nutrients. These trophic relationships underscore the importance of conserving arthropod populations to maintain the stability and functioning of ecosystems. However, despite their ecological importance, only limited numbers of arthropod species have undergone scientific assessment with regard to their conservation status or distribution, particularly in developing countries in the Southern Hemisphere (Leandro, Jay-Robert & Vergnes 2017, Troudet et al. 2017; Hochkirch et al. 2020; IUCN 2022).

The effective conservation and management of biodiversity requires data on species status and distribution to inform decision-making and facilitate adaptive management practices (Gillson et al. 2018; Hoffmann 2022). However, challenges pertaining to the availability, accessibility, and quality of data present significant obstacles. For instance, the scope of biodiversity assessment undertaken solely by proficient researchers is constrained in terms of spatial, temporal, and financial dimensions (Dickinson, Zuckerberg & Bonter 2010). Therefore, there is a need to identify additional means of obtaining data required to comprehend and monitor biodiversity in an effective manner. Accordingly, citizen science has emerged as an increasingly prominent paradigm globally, enabling the collection of ecological data for biodiversity monitoring, management decisions and policy making (McKinley et al. 2017; Callaghan et al. 2020; Sun, Hurst, & Fuller 2021). Citizen science essentially represents a collaborative effort towards the generation of scientific knowledge, involving the collection and analysis of data by members of the public (McKinley et al. 2017; Haklay et al. 2021).

The concept of citizen science is becoming increasingly popular around the world, particularly in countries such as the United States of America (USA), Canada, Australia and some parts of Europe, where members of the general public and schoolchildren are involved in collecting scientific data for long-term environmental monitoring. In the USA, for example, the establishment of online community platforms such as BugGuide has contributed to increased knowledge about under-sampled arthropod taxonomic groups (Kittelberger, Hendrix, & Şekercioğlu 2021). Data from the FrogID system in Australia has enabled the early detection of invasive frog species, documentation of threatened and rare frog species, and the decline of native frog species, which has been successfully used to develop effective management plans and understand ecological interactions between species and habitats (Rowley et al. 2019). In the last decade, the emergence of online networks such as iNaturalist (hereafter iNat) or the Global Biodiversity Information Facility (hereafter GBIF) has revolutionised citizen science engagement by enabling the documentation and dissemination of species observations worldwide. This advancement has resulted in a significant influx of biodiversity records, with GBIF accumulating approximately 2.5 billion records (GBIF 2024) and iNat accumulating approximately 1.5 million records (iNaturalist 2024) on a global scale.

In the context of Namibia, a country endowed with remarkable biodiversity hotspots and a treasure of endemic species (Simmons et al. 1998; Thuiller et al. 2006) there exists a critical imperative for the advancement of knowledge concerning its diverse arthropod fauna. The Namibian Biodiversity Database (hereafter NBD) is an important source of information for the national biodiversity and together with a book focusing on the first comprehensive assessment of biodiversity in the country (Barnard 1998), provides the resources to assess the state of biodiversity. Compared to our knowledge of the number and identity of species in the country from this database, information on the spatial distribution of species is considerably scarcer. The existing scientific information, which is mainly scattered across scientific publications often behind a paywall, is outdated or documented in (to many Namibians) foreign languages. Two key metrics derived from GBIF and iNat could make a significant contribution to inform future research and conservation effort as previously exemplified by Mesaglio et al. (2023) for Australia. First, the concept of “recognition” pertains to the proportion of observations within iNat and GBIF that has been identified to the species level for each arthropod order. This metric combines aspect such as how easy it is to identify species within a particular arthropod order and how active experts are in assisting species identification in iNat and GBIF. Explanations for high recognition values include the presence of numerous distinct, easy to identify species in the taxonomic order or an engaged community of amateur and professional specialists contributing identifications. However, it is important to note that recognition rates can be misleadingly high in cases where only a small fraction of species within an arthropod order are identified to species level, but these species dominate the recorded observations. Therefore, the second metric, “completeness”, provides an insight into the proportion of species observed in iNat and GBIF compared to the total known number of species within a given arthropod order known in a country (here obtained from NBD). These metrics can serve to inform the planning of future citizen science projects aimed at enhancing our understanding of arthropod distribution and identification. They do not only highlight gaps in data, but also shed light on the inherent constraints within species monitoring across various arthropod orders and highlight particularly suitable taxonomic groups that can be addressed in citizen science projects.

This study extracted, compiled and synthesized taxonomic data for all arthropods from an online social network and organism occurrence system (iNat) and an international network and data infrastructure for biodiversity data (GBIF) with a focus on arthropod biodiversity in Namibia. The country was chosen as the study area as arthropod biodiversity is severely understudied in sub-Saharan Africa compared to regions such as Europe or the USA (e.g. Birkhofer et al. 2024b). Moreover, Namibia's high level of endemism further justifies its selection, and the availability of the NBD database provides a reference for arthropod biodiversity in the country. The findings of this study provide insights into the recognition of different arthropod orders and the completeness of documentation in iNat and GBIF similar to a previous study for Australia (Mesaglio et al. 2023). The results allow us to identify major gaps and opportunities for future research, for example the identification of arthropod orders and species that could serve as flagship species for future monitoring and conservation efforts in such projects.

Methods and materials

Data analyses

The Namibia Biodiversity Database (NBD) is a regionally centred digital database established in 2003, that collates valid published records of Namibia’s biodiversity. A unique feature is that information can be presented in various indigenous Namibian languages, adding to its inclusivity and accessibility.

The Global Biodiversity Information Facility (GBIF) is an intergovernmental and central hub that facilitates the sharing of biodiversity data for biological research and conservation efforts. It is the largest data infrastructure that collects biodiversity-related information from more than 800 institutions around the world (Chandler et al. 2017). GBIF datasets contain occurrence data including natural history collections such as fossil specimens, preserved materials, citations, and human observation records. Observation in GBIF undergo validation processes grounded in evidence (i.e., photos, sonograms, audio recordings and specimens) and expert discernment, a process further reinforced by the utilization of the fully automated recognition system known as Neural Image Analysis (NIA). We performed relative comparison to compare arthropods species observations and species diversity between iNat and GBIF. Given that iNat is one of the sources feeding into GBIF, we excluded its dataset to prevent duplication during our comparative analysis. The Global Biodiversity Information Facility has collected a total of 1035282 records from Namibia (03 January 2024 & excluding iNat data). These records were contributed by 187 institutions worldwide. Among these institutions, only 78 institutions contributed observations for arthropods. These observations include a first preserved museum specimen dating back to 1807 (Fig. 1). Observation records increased beginning in the late 20th century, dominated by preserved specimens and the inclusion of reference material from renowned institutions such as the KwaZulu-Natal Museum (NMSA), the Ditsong National Museum of Natural History (formerly known as the Transvaal Museum, TMSA) and the American Museum of Natural History (AMNH). The beginning of the 21st century marked a significant turning point, as the number of observations of arthropod taxa increased rapidly, mainly driven by contributions from citizen science platforms. Geographical coverage of GBIF observations is mapped in Fig. 2.

iNaturalist serves as a prominent citizen science tool, allowing people to report the biodiversity they observe in their local environment by submitting photographic images, videos or audio files of biological sightings, which are then identified online by the community of iNaturalist users. Every observation record includes a taxonomic classification, geographic location, date of collection and an observer ID. For the purposes of this study, only observation data for arthropods were obtained. Observations within iNaturalist are assigned into three categories: “Verifiable”, “Needs ID”, and “Research Grade”. An observation is considered “verifiable” when it fulfils essential criteria, including a valid temporal reference, spatial coordinates, photo or auditory evidence, and excluding captive or cultivated organisms. From here the iNat community can assist in taxonomic identification in the category “Needs ID”. An observation advances to the "Research Grade" category after a minimum of two community members contributed to the identification of a given observation and a consensus is reached between at least two-thirds of all involved community members regarding the identification of the observed species. Only ‘Research Grade’ observations are incorporated in GBIF. For the recognition and completeness metrics, we retrieved all the observations categorised as “Need ID” or “Research Grade” in the arthropod taxa for Namibia. This selection stemmed from findings suggesting that “Need ID” observations are not necessarily less taxonomically accurate than the “research grade”, instead, this classification just represent various stages of data processing in iNat (Hochmair et al. 2020; Mesaglio et al. 2023). To ensure robustness and meaningful patterns only orders with more than 30 observation records in either iNat or GBIF were analysed and the order had to be present with some records in iNat and GBIF. Order level classification followed the NBD. As of 03 January 2024, the iNaturalist network has collected a total of 18599 arthropod biodiversity observations from Namibia with 1675 species identified. Observations cover the entire country, and geographical coverage is distinctly clustered along main routes and in popular tourist areas, but much sparser in less accessible areas (Fig. 2). The temporal dynamics of arthropod observations in iNaturalist has increased exponentially over the last decade, with an almost threefold increase in the last five years (Fig. 3). This large increase in the number of observations can be attributed to an expanding user base and integration of biodiversity observations from previous repositories with a focus on Southern Africa such as iSpot. A total of 493 contributors collectively curated records of arthropod taxa, with the user base consisting primarily of professional and amateur naturalists who are passionate about documenting biodiversity.

Results

Namibia Biodiversity Database (NBD)

As of January 2024, NBD has catalogued 20860 species from 43 phyla across five kingdoms. Arthropods are the dominant taxonomic group, comprising 12575 species (60.3%), followed by flowering plants with 4150 species (19.9%) and Chordata with 1896 species (9.9%). Notably, at least 3385 arthropods species (26.9%) within this dataset are endemic to Namibia, showcasing the unique biodiversity of the country. Arthropods include 73 orders dominated by Coleoptera with 4062 species (32.3%), Lepidoptera with 1792 species (14.3%), Diptera with 1538 species (12.2%) and Hymenoptera with 1519 species (12.1%). A notable proportion of species from these dominant orders are endemic to Namibia, accounting for 35.8%, 13.9%, 10.5% and 12.6% of their respective totals. A total of 33 orders, such as Collembola or Amblypygi, have low species numbers with less than 10 known species in the country, with Strepsiptera known to occur but lacking published records.

A total of 9099 species documented in NBD are not recorded in iNat or GBIF, while 1572 species recorded in either iNat or GBIF are not documented in NBD. Regarding taxa present on iNat/GBIF platforms but not represented on NBD, about 50% (~ 780 species) are identified museum specimens catalogued in GBIF that have never been published. Approximately 23% appear to be missing due to nomenclatural inconsistencies (e.g. same species with different names on different platforms), while 9% represent genuine errors such as georeferencing inaccuracies or nomina nuda. Only 15% of Namibian species recorded on iNat/GBIF databases are actually missing from NBD, primarily because they have been published in inaccessible literature or may be potential new records, mostly within the order Lepidoptera.

GBIF species observations

The taxonomic classification in GBIF is systematically organized into 42 major phyla, dominated by Chordata representing a vast majority 88.7% of the total observations, followed by vascular plants with 6.1% and Arthropoda as the third most abundant phylum with 4.1%. Arthropoda, categorized by a rich diversity of 51 orders and 4390 recognised species in GBIF, showcases notable dominance of orders such as Coleoptera (28.2%), Hymenoptera (16.9%), Hemiptera (14.3%), and Diptera (10.6%). While 63.1% of arthropod observations achieve species-level identification, 35.5% are classified to the genus or family level, with a minor fraction (1.5%) remaining unclassified or only identified to order level. Recognition rates vary across orders (Fig. 4), ranging from 0–97.0%, with an overall average of 63.6%. The orders

Scorpiones, Odonata and Lepidoptera had the highest recognition rate at the species level with a percentage of 97.0%, 90.5% and 89.2% respectively, in contrast to orders such as Collembola (Entomobryomorpha), Hemiptera and Solifugae with a recognition rate of 0%, 20.4% and 45.6% respectively (Fig. 4). In terms of completeness, only a small percentage of the recognized species (25.0%) are recorded in GBIF compared to all species catalogued in NBD. Scorpiones (95.2%), Odonata (67.2%), and Orthoptera (42.8%) emerged as the orders with the highest levels of completeness, while Collembola (0.0%), Blattodea (13.3%) and Mantodea (13.8%) represent orders with the lowest percentage of known species. A total of 1237 recognised species and 4 arthropod orders documented in GBIF are not present in NBD. The recognised species are dominated by *Opistophthalmus carinatus* (order: Scorpiones), *Uroplectes planimanus* (order: Scorpiones), *Camponotus fulvopilosus* (order: Hymenoptera), *Parabuthus brevimanus* (order: Scorpiones) and *Parabuthus villosus* (order: Scorpiones).

iNaturalist species observations

The biodiversity recorded in iNaturalist for Namibia is dominated by birds with 30.8% of the total observations, followed by vascular plants with 26.0%, mammals with 14.6% and insects with 14.1%. Arachnids are relatively under-observed, accounting for only 1.7% of all 1998 observations with species identifications. The phylum Arthropoda comprises of 45 recognised orders and 1675 recognised species in iNat for Namibia. Lepidoptera emerges as the most observed order, comprising 29.4% of the observations (5461 observations), followed by Coleoptera at 20.4% (3794 observations) and Hymenoptera at 9.9% (1847 observations). More than half of all arthropod observations (54.4%) are recognised to species level, while 45.6% were classified only to the genus or order level, with a small fraction of 14 observations only identified to phylum level. The recognition rates differ between orders, reaching their maximum in Scorpiones (96%, 550 observations) and Odonata (84.3%, 685 observations), and their lowest percentages in Thysanura, Trombidiformes and Ixodida, with only 0% (32 observations), 0% (93 observations) and 1.8% (38 observations) species-level identifications achieved, respectively. In terms of taxonomic completeness, there is considerable variability between orders, ranging from < 0.1–71.4%. In particular, Scorpiones and Odonata emerge as the orders with the highest levels of taxonomic completeness at 71.4% and 62.4%, respectively. Conversely, Thysanura, Trombidiformes and Ixodida have completeness rates of < 0.2%, with a total of only 4 species identified in these orders out of 202 known NBD species. There is a clear disparity in records between iNat and NBD, with 499 species recognised in iNaturalist not documented in NBD, and 28 arthropod order recorded in NBD not observed in iNat. Observations of identified species in iNat are dominated by *Belenois aurota* (Order: Lepidoptera), *Probergrothius angolensis* (Order: Hemiptera), *Camponotus fulvopilosus* (Order: Hymenoptera), *Danaus chrysippus* (Order: Lepidoptera) and *Camponotus detritus* (Order: Hymenoptera).

Discussion

Our analyses provide valuable insights into the recognition of different arthropod orders and the completeness of documentation in global biodiversity networks and allow us to identify major gaps and opportunities for future research. Recognition and completeness data from iNat and GBIF reveal an absence of species documented only in NBD, and conversely, an exclusive presence of species documented only in iNat or GBIF, but not in NBD. In particular, a total of 9099 species documented in NBD are not recorded in the two biodiversity networks, and a cumulative total of 1572 species recorded in either iNat or GBIF are not documented in NBD. Since all NBD species are grounded on validated literature records, the absence of many observed species from iNat/GBIF indicates an under representation of described Namibian taxa within the taxonomic frameworks of both initiatives, and may actually be an impediment to the addition of Namibian records. The large number of species present in both frameworks but not in the NBD is due to unpublished records, nomenclatural inconsistencies or misidentifications. This result confirms that large citizen science biodiversity networks suffer from outdated taxonomic nomenclature and typographical errors, while the NBD employs more up-to-date and accurate classification systems, highlighting the ongoing challenge of taxonomy, database synchronisation and biodiversity monitoring. These results further highlight the importance of collaborative efforts by scientists, amateur entomologists, the interested public and suitable online networks to accomplish comprehensive data integration to achieve a more holistic understanding of biodiversity across taxonomic borders. Well maintained national databases, such as the Namibia Biodiversity Database, provide very valuable reference and cannot be replaced by biodiversity networks, but should rather be complemented (e.g. for termites: Hochmair et al. 2020).

The derived datasets reveal a pronounced mismatch between the number of arthropod observations and the success of taxonomic identification. The fact that only 54.4% of observations in iNat and 63.1% in GBIF achieved species-level identification highlights the challenges associated with identification of observations in biodiversity networks. The dominance of certain orders such as Coleoptera, Lepidoptera, Hymenoptera, Hemiptera and Diptera in biodiversity networks in terms of observation numbers reflects their relatively high abundance and the presence of rather characteristic species in these taxonomic groups (Scholtz & Holm 1996; Stork 2018). However, the considerable diversity within these orders, often comprising cryptic species, presents inherent challenges to the accurate identification of observations to species level (Mesaglio et al. 2023). As a result, a subset of commonly observed species dominates observations in these orders that are recognised to species level, resulting in low completeness but intermediate to high recognition values (groups B&C, Fig. 4). A similar bias is known in the animal kingdom in general, where birds and mammals, as relatively easily identifiable taxonomic groups, tend to be disproportionately overrepresented in species-level observations relative to their actual abundance, despite representing only 2.1% of all animal species (Arazy 2021; Callaghan et al. 2021; Cowie, Bouchet & Fontaine 2022).

Contrary to these very diverse orders, Odonata and Scorpiones stand out due to their comparatively high recognition and completeness values in Namibia (group A, Fig. 4), with more than 60% of the known Namibian species recorded in iNat and GBIF. This high completeness is a consequence of their relatively low species richness, with 63 (Scorpiones) and 126 (Odonata) species in NBD, in comparison to orders in group B and C such as Coleoptera (4062 species) or Lepidoptera (1792 species). The presence of distinct morphological traits and the availability of taxonomic keys for the country (Odonata: Suhling and Martens 2007; Scorpiones: Lamoral 1979) further facilitate identification of species in these orders. The order Scorpiones, particularly the families Buthidae and Scorpionidae, are of considerable scientific and public interest due to their medical importance in various regions of the world (Petricevich 2010; Rein 2024) and have a large community of amateur experts because they are kept as pets around the world (Hauke & Herzig 2021). The high recognition value for Scorpiones in iNat, for example, can partly be attributed to the combined expertise and proficiency in wildlife photography and documentation of the observers Undine Hauptmann, Werner Schmidt, and Paul Bester.

In Namibia, Lepidoptera have considerably lower recognition and completeness values if compared to values for Australia (Mesaglio et al. 2023). The high level of documented endemism for Lepidoptera in Namibia (35.8% of all species, NBD: moths in particular) implies a high degree of specialisation. Endemic species often exhibit specialised adaptations to local environments, with numerous closely related species that may only differ subtly in morphological characteristics, making it difficult to distinguish and identify closely related species (Gardiner & Williams 2023). If endemic to a country with limited taxonomic expertise and part of a highly diverse order, it is also unlikely that comprehensive taxonomic keys for species identification exist. Identifying endemic species often requires detailed knowledge of morphological traits, geographic distributions and ecological preferences, or advanced molecular techniques, which add another layer of complexity to species identification. The observed differences in recognition and completeness values for taxonomic groups between two countries of the Southern Hemisphere (Australia and Namibia) highlight the challenges of using data from biodiversity networks for cross-country or even global studies.

Orders with low recognition and completeness values (group D, Fig. 4) such as Acari, Collembola and Solifugae, are either characterised by their diminutive size (Acari and Collembola) or specialised ecological behaviour, such as the rapid movement of nocturnal Solifugae species. These attributes make them less likely to be encountered and therefore less familiar to the public conservation (Deacon, Govender & Samways 2023). Such limitations can be addressed by prioritising targeted research efforts on these under-represented taxa (Janion-Scheepers et al. 2016). There is a need to invest in taxonomic training and capacity building initiatives to improve the expertise needed to accurately classify invertebrate biodiversity for understudied taxa especially in regions of high species diversity and endemism. These efforts should include the training of taxonomists, supporting taxonomic research facilities, collections and databases, and promoting collaboration between taxonomists and other scientists. However, following the comments of Barbato et al. (2021) on the identification of molluscs from iNat observations, we would like to emphasise that it is simply impossible to correctly identify a large proportion of arthropod species from photographs (Arazy & Malkinson 2021; Mesaglio et al. 2023). Many species require careful inspection, e.g. of genitalia under a microscope or even anatomical preparation to identify the species and these limitations will always cause a bias in networks such as iNat.

Conclusion

To improve our understanding of biodiversity worldwide collaborative efforts by scientists, amateur entomologists, the public and biodiversity networks are needed. Biodiversity networks face the challenge that there is a mismatch between the number of arthropod observations and the success of species-level identification. These challenges can be partly addressed by prioritising research on understudied taxonomic groups, by promoting the availability of taxonomic keys and by supporting communities of amateur insects. Citizen science biodiversity databases can be used to complement species classification and occurrence data, but will never replace dedicated taxonomic research. Regional centralised biodiversity databases, such as the Namibia Biodiversity Database, are a central resource for the scientific community, providing comprehensive insights into a country's biodiversity. This underscores the urgency of developing and promoting local databases to monitor regional biodiversity dynamics and potential threats to these vital components of ecosystems.

Declarations

Author Contribution

M.A. obtained and analysed the data. M.A drafted the main manuscript. All authors have contributed to subsequent revisions of the of the manuscript.

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References

1. Arazy O, Malkinson D (2021) A framework of observer-based biases in citizen science biodiversity monitoring: semi-structuring unstructured biodiversity monitoring protocols. Front Ecol Evol 1–13. 10.3389/fevo.2021.693602
2. Barbato D, Benocci A, Guasconi M, 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
3. Barnard P (ed) (1998) Biological diversity in Namibia. A country study. Namibian National Biodiversity Task Force, Windhoek, Namibia
4. Birkhofer K, Bird T, Alfeus M, Arvidsson F, Buxton M, Djoudi E, Nyamukondiwa C (2024) Smallholder agriculture in African dryland agroecosystems has limited impact on trophic group composition, but

affects arthropod provision of ecosystem services. Agric Ecosyst Environ 363:1–11. https://doi.org/10.1016/j.agee.2023.108860

5. Birkhofer K, Buxton M, Feng L, Simba L, Diekoetter T (2024) Conserving insects for the provision of ecosystem services. In: Pryke JS, Samways MJ, New TR, Cardoso P, Gaigher R (eds) Routledge Handbook of Insect Conservation. Earthscan
6. Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Samways MJ (2020) Scientists' warning to humanity on insect extinctions. *Biological conservation*, *242*. https://doi.org/10.1016/j.biocon.2020.108426
7. Callaghan CT, Poore A, Hofmann M, Christopher JR, Henrique MP (2021) Large-bodied birds are over-represented in unstructured citizen science data. Sci Rep 11:1–11. https://doi.org/10.1038/s41598-021-98584-7
8. Callaghan CT, Roberts JD, Poore AG, Alford RA, Cogger H, Rowley JJ (2020) Citizen science data accurately predicts expert-derived species richness at a continental scale when sampling thresholds are met. Biodivers Conserv 29:1323–1337. https://doi.org/10.1007/s10531-020-01937-3
9. Chandler M, See L, Copas K, Bonde A, Lo´pez BC, Danielsen F, Turak E (2017) Contribution of citizen science towards international biodiversity monitoring. Biol Conserv 280–294. http://dx.doi.org/10.1016/j.biocon.2016.09.004
10. Cowie RH, Bouchet P, Fontaine B (2022) The sixth mass extinction: fact, fiction or speculation? Biol Rev 640–663. https://doi.org/10.1111/brv.12816
11. Deacon C, Govender S, Samways MJ (2023) Overcoming biases and identifying opportunities for citizen science to contribute more to global macro-invertebrate conservation. Biodivers Conserv 32 1789 – 1806. https://doi.org/10.1007/s10531-023-02595-x
12. Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: challenges and benefits *Annual Review of Ecology, Evolution, and Systematics, 41*, 149–72 doi:101146/annurev-ecolsys-102209-14463
13. Gardiner A, Williams M (2023) The endemic butterflies of Angola and Namibia and their evolutionary implications. Namibian J Environ 8:205–230
14. GBIF (2024) Retrieved January 03, 2024, from https://www.gbif.org/occurrence/search
15. Gillson L, Biggs H, Smit IP, Virah-Sawmy M, Rogers K (2018) Finding common ground between adaptive management and evidence-based approaches to biodiversity conservation. Trends Ecol Evol 1–14. 10.1016/j.tree.2018.10.003
16. Haklay M, Dörler D, Heigl F, Manzoni M (2021) What is citizen science? The challenges of definition. In K. Vohland, L. C. Anne Land-Zandstra, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.), *The science of citizen science* (pp. 13–33). Springer Nature. https://doi.org/10.1007/978-3-030-58278-4_2
17. Hauke TJ, Herzig V (2021) Love bites – Do venomous arachnids make safe pets? Toxicon 190:65–72

18. Hochkirch A, Samways MJ, Gerlach J, Böhm M, Williams P, Cardoso P, Danie A (2020) A strategy for the next decade to address data deficiency in neglected biodiversity. Conserv Biol 35(2):502–509. 10.1111/cobi.13589
19. Hochmair HH, Scheffrahn RH, Basille M, Boonel M (2020) Evaluating the data quality of iNaturalist termite records. PLoS ONE 15(5):1–19. 10.1371/journal.pone.0226534
20. Hoffmann S (2022) Challenges and opportunities of area-based conservation in reaching biodiversity and sustainability goals. Biodivers Conserv 31:325–352. 10.1007/s10531-021-02340-2
21. INaturalist (2024) Retrieved January 03, 2024, from https://www.inaturalist.org/
22. IUCN (2022) *The IUCN Red List of Threatened Species. Version 2022-2.* Retrieved August 21, 2023, from https://www.iucnredlist.org
23. Janion-Scheepers C, Measey J, Braschler B, Chown S, Coetzee L, Colville JRU, Wilson (2016) Soil biota in a megadiverse country: Current knowledge and future research directions in South Africa. Pedobiologia 59(3):129–174. https://doi.org/10.1016/j.pedobi.2016.03.004
24. Kittelberger KD, Hendrix SV, Şekercioğlu ÇH (2021) The value of citizen science in increasing our knowledge of under-sampled biodiversity: An overview of public documentation of Auchenorrhyncha and the hoppers of North Carolina. Front Environ Sci 9:1–15. 10.3389/fenvs.2021.710396
25. Lamoral B (1979) The scorpions of Namibia (Arachnida: Scorpionida). Annals Natal Museum 23(3):497–784
26. Leandro C, Jay-Robert P, Vergnes A (2017) Bias and perspectives in insect conservation: A European scale analysis. Biol Conserv 215:213–224. https://doi.org/10.1016/j.biocon.2017.07.033
27. McKinley DC, Miller-Rushing AJ, Ballard HL, Bonney R, Brown H, Cook-Patton SC, Soukup M (2017) Citizen science can improve conservation science, natural resource management, and environmental protection. Biol Conserv 208:15–28. 10.1016/j.biocon.2016.05.015
28. Mesaglio T, Callaghan CT, Samonte F, Gorta SB, Cornwell WK (2023) Recognition and completeness: two key metrics for judging the utility of citizen science data. Front Ecol Environ 21(4):167–174. 10.1002/fee.2604
29. NBD (2024) Retrieved January 2024, from https://www.bioidversity.org.na
30. Ødegaard F (2000) How many species of arthropods? Erwin's estimate revised. Biol J Linn Soc 71(4):583–597. 10.1111/j.1095-8312.2000.tb01279.x
31. Petricevich VL (2010) Scorpion Venom and the Inflammatory Response. Mediat Inflamm 1–16. 10.1155/2010/903295
32. Potapov RS, Kolosova YS, Gofarov MY, Bolotov IN (2020) Dragonflies and damselflies (Odonata) from Flores Island, Lesser Sunda Archipelago: New occurrences in extreme environments and an island-level checklist of this group. Ecol Montenegrina 35:5–25. 10.37828/em.2020.35.2
33. Rein JO (2024) *The Scorpion Files*. Retrieved from https://www.ntnu.no/ub/scorpion-files/index.php
34. Rowley JJ, Callaghan CT, Cutajar T, Portway C, Potter K, Mahony S, Woods A (2019) FrogID: citizen scientists provide validated biodiversity data on frogs of Australia. Herpetological Conserv Biology

14(1):155–170

35. Scholtz CH, Holm E (1996) Insects of Southern Africa, 5th edn. University of Pretoria, Pretoria
36. Simmons RE, Griffin M, Griffin RE, Marais E, Kolberg H (1998) Endemism in Namibia: patterns, processes and predictions. Biodivers Conserv 7:513–530. 10.1111/j.1365-2486.2006.01140.xr2006
37. Stork NE (2018) How many species of insects and other terrestrial arthropods are there on Earth. Ann Rev Entomol 63:31–45
38. Suhling F, Martens A (2007) Dragonflies and Damselflies of Namibia. Gamsberg Macmillan, Windhoek, Namibia
39. Sun CC, Hurst JE, Fuller AK (2021) Citizen science data collection for integrated wildlife population analyses. Front Ecol Evol 9:1–10. https://doi.org/10.3389/fevo.2021.682124
40. Thuiller W, Midgley GF, Hughes GO, Bomhard B, Drew G, Rutherford MC, Woodward FI (2006) Endemic species and ecosystem sensitivity to climate change in Namibia. Glob Change Biol 12(5):759–776. 10.1111/j.1365-2486.2006.01140.xr2006
41. Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Sci Rep 7(1):1–14. 10.1038/s41598-017-09084-6

Figures

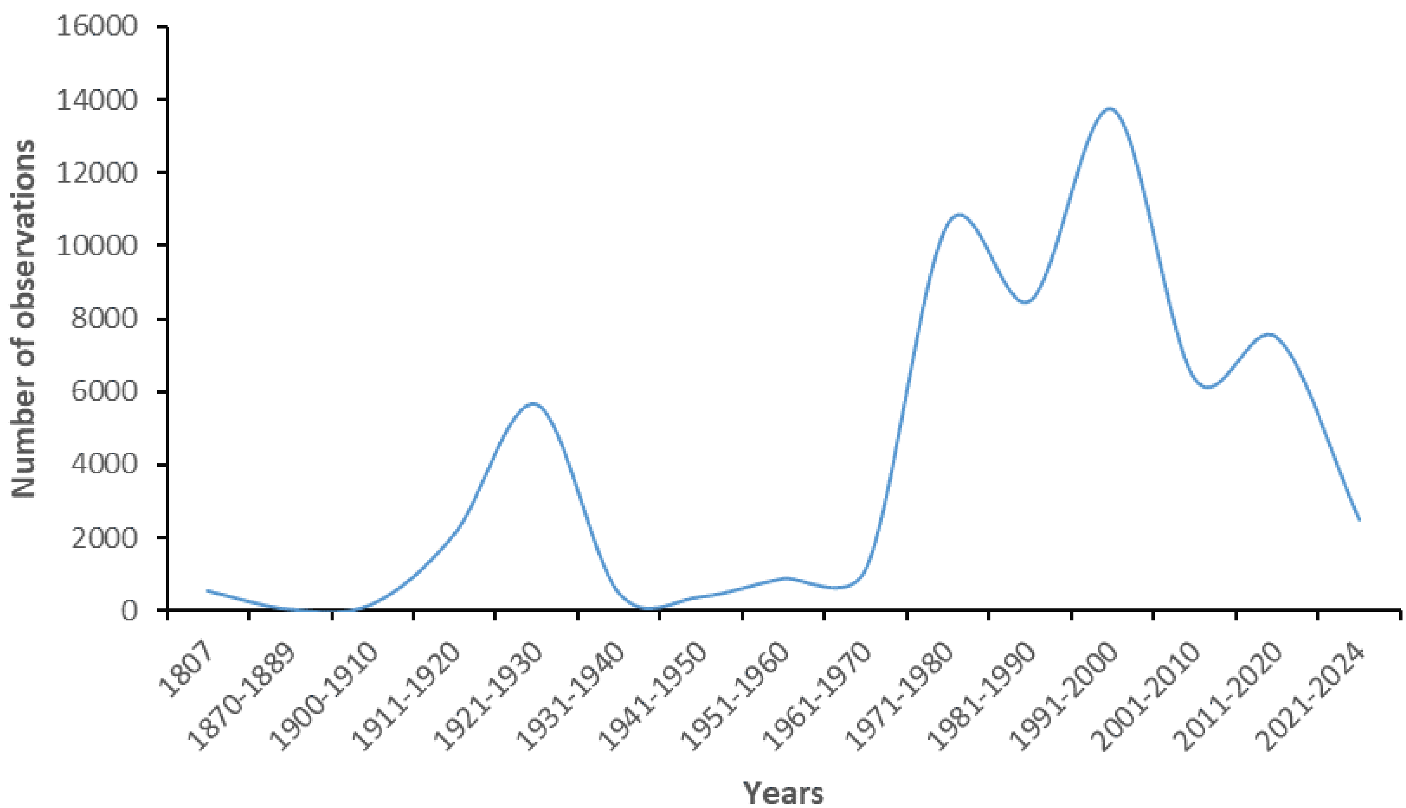

Figure 1

Temporal dynamics of species observation records for Namibian arthropods documented in the Global Biodiversity Information Facility (GBIF) over a century, from 1807 to January 2024. The timeline represents the historical trajectory of documented observations records

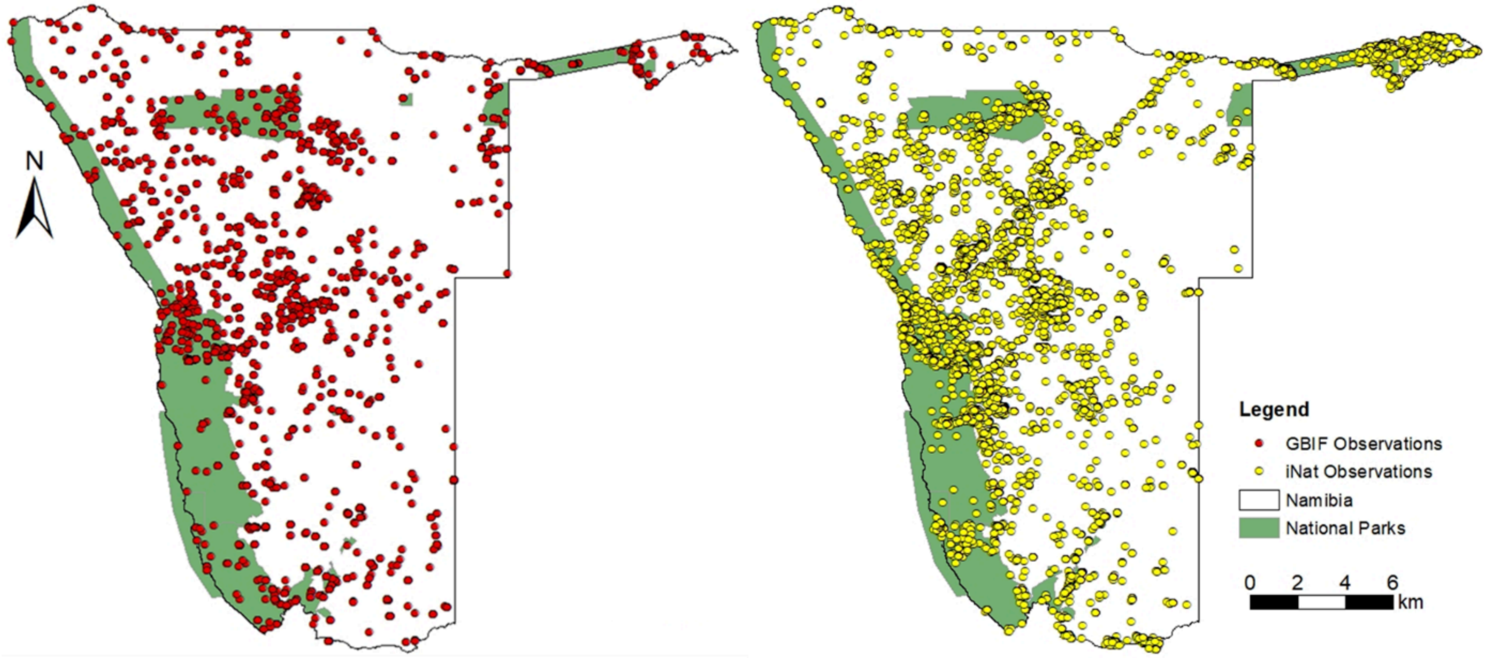

Figure 2

The spatial distribution of observation records for arthropods within the Global Biodiversity Information Facility (GBIF) (depicted on the left, excluding data from iNaturalist) and iNaturalist (iNat) (depicted on the right), illustrating their geographical coverage across the country

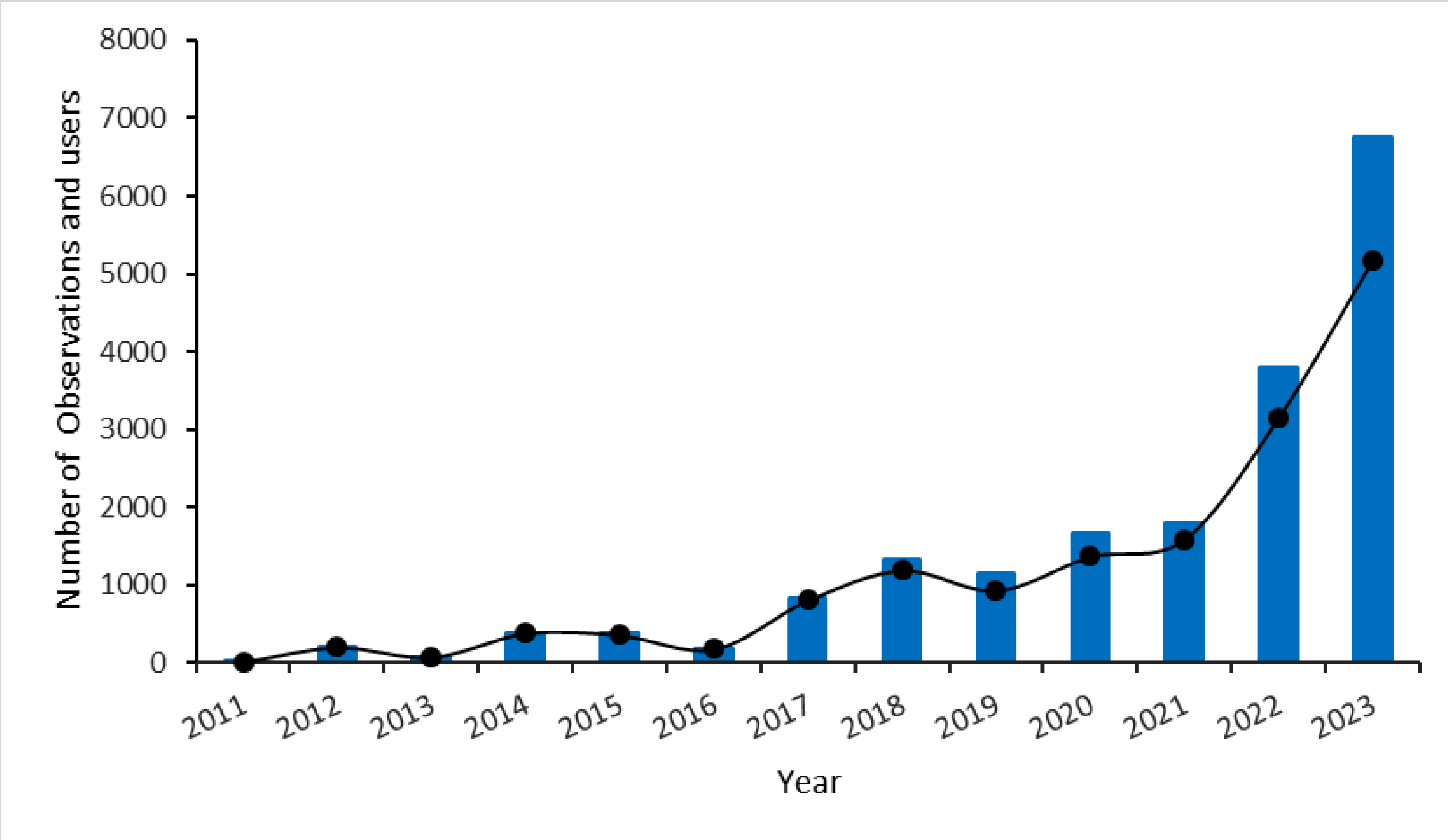

Figure 3

Temporal dynamics of species observation records arthropod*s* documented in iNaturalist for Namibia. The bar chart depicts the cumulative number of observations over time and the line graph is the cumulative number of observers contributing to iNaturalist

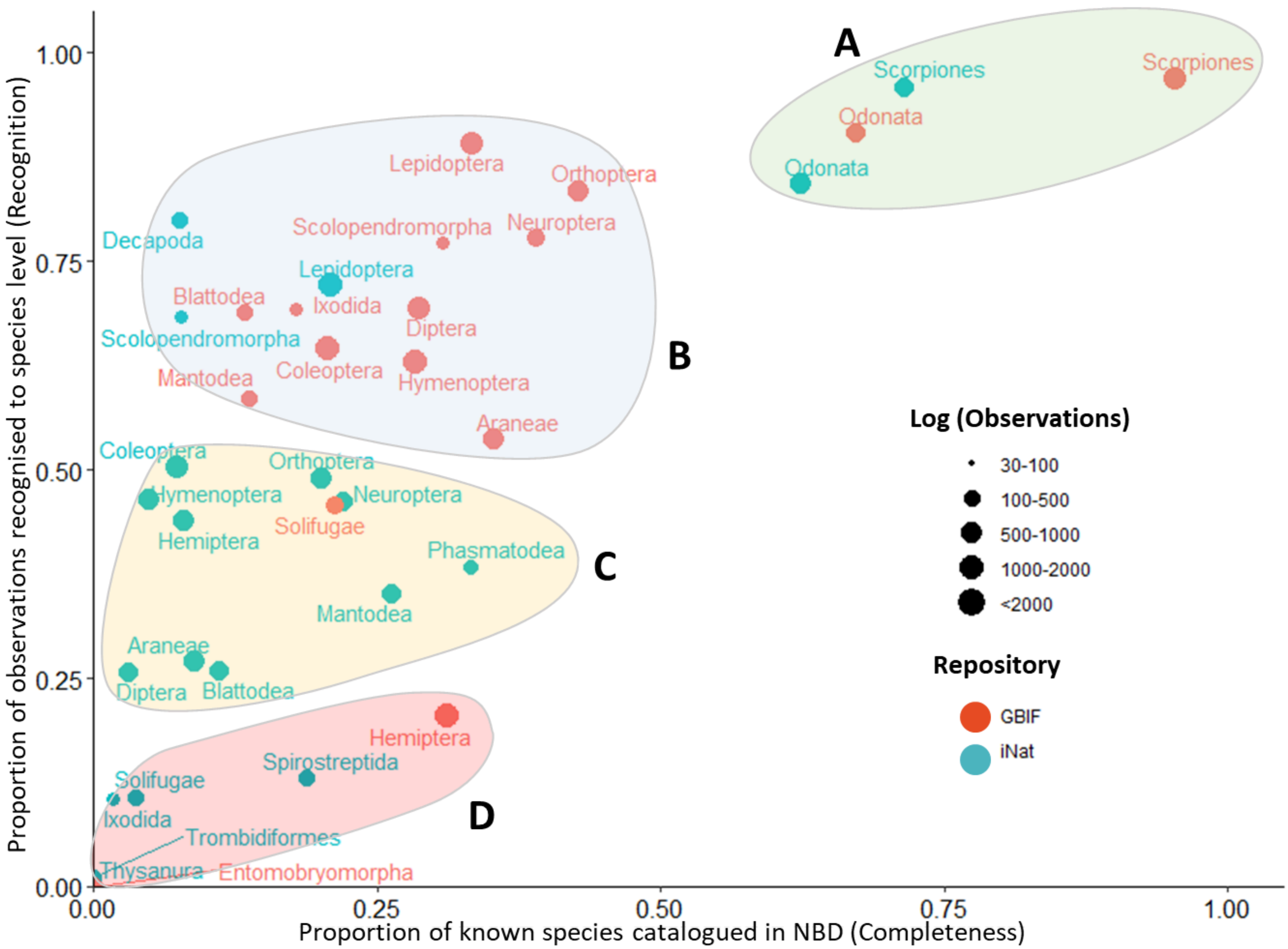

Figure 4

The proportion of arthropods recorded in the Global Biodiversity Information Facility (GBIF) (orange dots) and in the social network iNaturalist (iNat) (green dots) that are recognized to species level (y-axis) compared to the proportion of all known species documented in NBD (x-axis). The size of each point is scaled proportionally to the number of observations for the taxon in iNat or GBIF. Taxa were manually grouped into four categories (A-D) (the coloured sections) to group taxa with similar recognition or completeness scores