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Optimising species checklists for protected areas in the digital age

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Introduction

Checklists play a vital role in spatial planning (Gonzalez-Maya et al. 2015:e0124480). They are essential for prioritising endemic, range-restricted, rare, or threatened species for monitoring (Brooks et al. 2006:58–61) and for identifying species most likely to be vulnerable to climate change (Coldrey et al. 2022:e13941). Additionally, checklists support the prioritisation of potentially invasive species for removal (Robertson et al. 2021:1320) and the development of management plans for protected areas (Goosen & Blackmore 2019:1–10). For centuries, academics have surveyed and inventoried biodiversity by making observations and collecting specimens (Funk 2018:175–193; O'Connell, Gilbert & Hatfield 2004:1254–1261), and these data have often been used to create species checklists.

Simple site-specific species lists have been recognised as being a potential tool to use for monitoring trends in species populations (Droege, Cyr & Larivée 1998:1134–1138; Roberts, Donald & Green 2007:332–339). Over 20 years ago, Droege et al. (1998) suggested the use of checklist projects to monitor changes in communities and recognised the value of checklists as a tool to fill a gap in the absence of systematic monitoring programmes. More recently, historical and recent surveys have been used to assess changes over a century (Iknayan & Beissinger 2018:8597–8602). Today, citizen science could be a complementary tool that contributes to checklist creation and to detecting changes in species abundances and distributions (Gouraguine et al. 2019:e0210007; O'Neill et al. 2023:e10063). The contribution of citizen science and digital occurrence data that is available online is particularly poignant in the current situation of limited capacity in protected areas for monitoring biodiversity and updating species checklists.

Despite the undeniable value of species checklists, many protected areas do not have up-to-date species checklists or standardised approaches to developing reliable checklists. In part, this is because of the low priority given to data management by conservation organisations and the often-limited capacity to spend time on such endeavours (Stephenson et al. 2017:335–340). However, this can also be the consequence of a lack of available occurrence data for species checklist compilation. The availability of checklists for protected areas is highly variable, and those that are available vary substantially in quality (Cantú-Salazar & Gaston 2013:782–793). In many cases, the reliability and completeness of species checklists remain uncertain, as the methods used to compile them and the underlying data sources are often undocumented (Reyserhove et al. 2020:baaa084). The absence of source data makes it difficult to verify species occurrences (Costello & Wieczorek 2014:68–73) and determine a confidence level for species inclusion. This is especially problematic in cases where species checklists are based solely on distribution ranges. These ranges often lack verified occurrence records for protected areas. As a result, species may be included in checklists even though they do not actually occur there (see Cantú-Salazar & Gaston 2013:782–793). However, range maps have been widely used in the past to develop species checklists, as they represent an easily available source of information. In protected areas where surveys were conducted and specimens were collected, the data are more reliable for incorporation into species checklists.

The digital age provides easily accessible species data for many protected areas. Platforms, such as the Global Biodiversity Information Facility (GBIF), offer access to large quantities of species occurrence data. These data come from sources like natural history collections and citizen science initiatives, including iNaturalist (Ivanova & Shashkov 2021:1 -8). Such platforms can be useful when protected area staff have limited capacity to conduct regular monitoring or collect their own data.

Note: Additional supporting information may be found in the online version of this article as Online Appendix 1.

Because of changes in species occurrence, availability of new information, and taxonomic changes, among other factors, checklist development is a continuous process. Checklists are most useful if they are annotated to include information that informs protected area management (Spear et al. 2023:1037282). For example, occurrence status (endemic, indigenous, alien or invasive), abundance (rare or common), threat status, year of last record and confidence level for inclusion (see Cruz-Elizalde et al. 2023:94) are more informative than a mere list of taxon names.

Current approaches used by protected area staff to develop species checklists for protected areas vary considerably in methodological rigour, particularly regarding the reliability of data sources and types of supporting evidence. Although GBIF data are increasingly accessible, their integration into checklist development remains limited and underexamined. This article seeks to provide practical guidance for the construction of species checklists in protected area management. It examines trends in checklist development as reflected in peer-reviewed literature, assesses the extent to which GBIF data have been employed and suggests best practices for the development of species checklists for protected areas.

Research methods and design

Literature search and inclusion criteria

We conducted a systematic review following Page et al. (2021:372; see also Online Appendix S1) to assess trends in species checklists published in peer-reviewed publications. We reviewed the scientific literature on checklists for protected areas by searching the Web of Science (WoS) for publications before and including 2023 using the search criteria: 'checklist', 'protected area' or 'national park'. This search culminated in 581 results. Some papers were published online in 2023, but later received a publication date in 2024. The review was delimited by the exclusive use of WoS, yielding a focused and manageable collection of relevant literature for examining trends. We downloaded the full bibliographic records for the WoS search results, including titles and abstracts. Then, we evaluated the search results for suitability for further assessment, and we obtained papers likely to be relevant to the study.

Papers were considered relevant to the study if they contained a checklist for a protected area or section of a protected area in the main body or supplementary material of the paper. At least two of the authors conducted a screening of each paper. Relevant papers included an objective to develop a checklist, incorporated a checklist to answer a question or provided a checklist as an output. Papers were not considered for analysis if they were not obtainable, focused on countries or regions (and not a protected area), did not include a checklist, included checklists for areas that were not yet designated as protected areas (e.g. Mulcahy et al. 2018:85–152) or for which checklists included areas adjacent to protected areas where it wasn't possible to determine which species were found in the protected area (see Online Appendix S1). After preselection, we considered 210 peer-reviewed publications, which were published online between 1997 and 2023, for further evaluation (Online Appendix S2). Two publications in Russian and 12 in Spanish were translated into English using Google Translate.

Checklist classification framework

For each publication record, we recorded the type of protected area, country, taxonomic focus, why the checklist was created, what it was used for and what data records the checklist was based on. Additionally, a decision tree was used to allocate Darwin Core bases of record to each publication (Online Appendix S3). The evidence used to list each species on each checklist was categorised as preserved specimen, machine observation, human observation or material citation. There were no instances of a material sample being the basis of record. In cases where the evidence used to list most species was preserved specimens and the evidence for one species was human observation, then both preserved specimens and human observation were recorded for that paper. We only classified records as preserved specimens if the storage location was clearly stated. Without this information, these specimens cannot be accessed for verification and used in future studies. If photographs were taken of collected specimens without any mention of storage location, then these records were considered machine observations. Otherwise, the records without a specified specimen storage location were designated as human observations (see Online Appendix S3). All categorisations were conducted by one author and checked by another author.

Global Biodiversity Information Facility checklist data retrieval and filtering

We also assessed the checklists available on the GBIF website for protected areas using the search phrase 'national park' or 'protected area' (Online Appendix S4). This search yielded 1909 results, which we downloaded and assessed for relevance, type of protected area, taxonomic focus and country. Only 224 of the GBIF checklist results were considered as checklists for protected areas based on the titles of the checklists.

Limitations

We recognise that most species checklists are not published in the scientific literature or uploaded to the GBIF, but these sources provide examples of some checklists that have been developed. Checklists from peer-reviewed literature are considered reliable sources of information for inclusion in updated checklists. We also recognise the limitations of this literature search and that it may have missed relevant papers published in other languages, non-International Scientific Indexing (ISI)-rated journals and journals published before they were ISI rated. However, we consider the results to provide useful information on trends in species checklist creation and on the more recent use of GBIF, both by scientists and conservation practitioners. While the possibility of human error in conducting this review cannot be entirely excluded, the observed trends are sufficiently consistent to be considered reliable.

Results

Based on the search and selection criteria stated above, we found that there has been a substantial increase in the publication of species checklists over time (number of publications = (7.5281*year)–15 071; R^2 = 0.8586; Figure 1). More checklists have been published in peer-reviewed literature in the last several years than before that. The 210 assessed publications included lists of less than 10 to more than 2000 species from a range of taxonomic groups. The publications included first inventories and updated checklists, with 58 papers explicitly stating they were presenting updated checklists and 94 papers indicating they were presenting initial checklists, that is, the first published checklist for a protected area. Most (189) of the checklists were annotated, including information on specimens, collectors, distribution, occurrence status, habitat, conservation status, life form and sources. Plant checklists were included in most of the assessed journal articles (70; Figure 1). These lists included vascular plants (59), bryophytes (9), red algae (4), green algae (5) and freshwater green algae (2). Insects (46) were the next most listed group, followed by amphibians (22), fish (20), reptiles (19), arachnids (18), fungi (14), crustaceans (11), birds (11), and mammals (9). On GBIF, the largest number of checklists for protected areas was for insects (56), followed by plants (55), alien species from different taxonomic groups (45), mammals (21), arachnids (17), birds (12), amphibians (9), reptiles (9), and fungi (6). However, most of the lists of alien species were for plants, substantially increasing the tally of checklists for plants.

Figure 2 shows that the country with the most peer-reviewed publications on checklists was Brazil (33), followed by the United States (25), Mexico (19), South Africa (15) and Italy (11). Very few papers (10%) included protected area management or research staff as authors. Protected area staff authored the most papers for protected areas in the United States (6) and South Africa (5). However, only a third of papers in both Russia (2/6) and South Africa (5/15) were authored by the staff of protected areas. Russia is also the country with the most checklists on GBIF published by protected area staff (n = 13 of 18).

Twenty-one (9%) of the protected area checklists on GBIF were published by protected area authorities. After Russia, the only other country with lists on GBIF published by a protected area authority is Ukraine (8 of 21). South Africa is the country with the most checklists for protected areas published on GBIF, published mainly (20 of 23) by the Invasive Species Specialist Group (ISSG), with three being published by Plazi. Overall, Plazi has uploaded the most

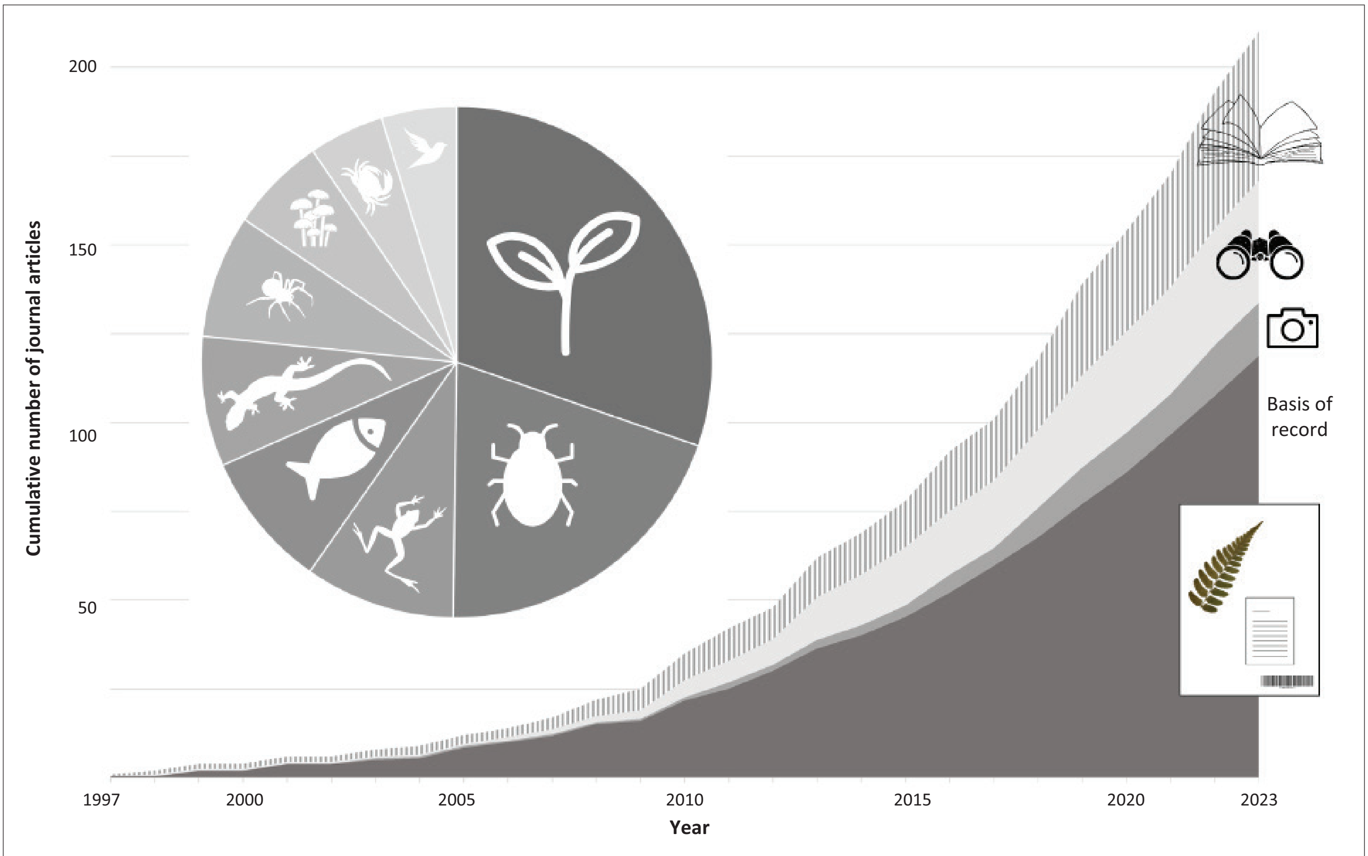

FIGURE 1: Cumulative number of peer-reviewed journal articles for species checklists in protected areas from 1997 (the year in which the first published and accessible checklist was identified for this study) to 2023, obtained through a search of Web of Science. The insert to the graph shows the most prevalent taxonomic groups represented in this literature. The trend in the number of journal articles is divided into a stacked representation of evidence on which the lists are based: preserved specimens (dark grey), machine observations (grey), human observations (light grey) and material citation (vertical lines).

FIGURE 2: Geographical distribution of published protected area checklists reviewed in this study.

checklist data (33%) to GBIF for protected areas, followed by ISSG (19%), universities (12%), other non-governmental organisations (11%) and protected area authorities (9%).

The majority (78%) of species checklists published in peer-reviewed literature included preserved specimens as their basis of record (Figure 1). Of the 165 studies incorporating preserved specimens to create checklists, new specimens were reported in 91% of cases. Another 20 papers mentioned collecting specimens, but the authors did not state where the specimens were lodged. Four of the 210 publications mentioned using data from GBIF as a data source, two papers mentioned using GBIF to check information, and two papers mentioned that the authors uploaded their collected data to GBIF.

There were fewer machine observations than human observations and material citations, which are observations obtained from the literature. The highest number of machine observations as the basis of record was for herpetofauna (8). Across taxa, the machine observations used in the creation of species checklists for protected areas included microscope images of specimens: (1), photographs of collected specimens (4), living specimens (18), where photographs were loaded onto iNaturalist (1), audio recordings (5), and videos recorded by divers (2), manned submersibles (1), Dropcams (1) and stereo baited remote underwater video stations (BRUVS; 1). Additionally, there were several other papers where a preserved specimen was considered the basis of record and photographs were also taken of live or collected specimens.

Discussion

Trends in checklist publication

The marked increase in checklist publications could reflect a growing interest in documenting biodiversity or greater ease and incentives to publish checklists. However, geographic and taxonomic biases persist, with an underrepresentation of invertebrates. The four countries with the most species checklist papers (Brazil, United States of America, Mexico and South Africa) are four of the world's 17 megadiverse countries. Additionally, Brazil is a large country (8.5 million km^2) with an extensive system of ~76 national parks. Literature on protected areas in Brazil suggests that Brazilian parks are behind in their level of protection and effective management (De Omena, Macedo-Soares & Hanazaki 2022:e20211311), perhaps accounting for more recent checklist creation compared to countries with a longer history of nature conservation. The United States of America is another large country (9.8 million km^2) with many national parks. In addition to published checklists, the United States National Park Services have a comprehensive online species checklist (https://irma.nps.gov/NPSpecies/Search/SpeciesList), which provides information that is useful to assist with determining the reliability of the records and decision making, such as occurrence status and abundance information.

The increasing trend in checklist publications is similar to the recent temporal trends in global data accumulation. Biodiversity occurrence data have become more accessible over the last decade, with thousands of institutions globally digitising records of preserved specimens (Blagoderov et al. 2012:133; Nelson & Ellis 2018:20170391), contributing extensive data sources for use in species checklist compilation. However, although there might be more data available online in global datasets that could be used to compile species checklists, most checklists that are published in the peer-reviewed literature are compiled using observations based on specimens collected by the authors.

Contributions of different data sources

To develop robust species checklists for protected areas, a wide range of data sources and record types should be consulted. The greater the diversity of validated data, the higher the confidence in including species on a checklist, with preserved specimens often being considered most reliable. While preserved specimens were the most used evidence for checklist compilation, none of the papers examined used material samples such as environmental DNA (eDNA). This is understandable, as eDNA is a novel method that can provide inaccurate identifications (Cristescu & Hebert 2018:209–230).

Preserved specimens

The collection and preservation of specimens is a valuable resource (Nualart et al. 2017:303–325). Preserved specimens provide a verifiable, well-curated data source. Large volumes of such data are now available on GBIF. Very few of the reviewed publications mentioned compiling checklists using occurrence data from GBIF or uploading data to GBIF. However, many specimen collection datasets are uploaded to GBIF, and records that are lodged at these facilities are likely to be incorporated into the GBIF platform.

Observations based on specimens remain more reliable than machine observations and observations by citizen scientists. Additionally, collected specimens could be used in global change studies and future DNA analysis (e.g. Shepherd 2017:e0183555). The continued collection of plant and animal specimens is encouraged, as they are important for validation in science and add value to other forms of validation, such as photographs.

Machine observations

Machine observations, which include observations from image, audio, remote sensing, and telemetry recording equipment, are becoming more prevalent. Although machine observations are not widely used in the reviewed papers, they are being collected in large volumes over short periods (Kays, McShea & Wikelski 2020:644–648). Only one paper mentioned the use of BRUVS, and none of the papers examined used images from camera trap photographs. This is understandable, as camera traps usually capture data on mammal species, which are well known, with many sources of distribution information and few recent checklist publications.

Audio recording provides a promising additional method for recording animals that exhibit acoustic behaviour. It can detect more species than camera traps, as this method samples over a larger area and can detect cryptic species (Enari et al. 2019:753–762). Low-cost, automatic audio recording technology, such as AudioMoth, is effective for monitoring threatened species (Manzano-Rubio et al. 2022:101910) and provides a potential resource for protected area monitoring going forward. Additionally, some citizen science platforms, like iNaturalist, include functionality for recording vocalisations, providing another source of audio data that could contribute towards the development of species checklists for sites.

Recommendations for practitioners

Species checklists are still an important tool in the conservation toolkit. With the advent of easy-to-access online specimen and citizen science data (Ivanova & Shashkov 2021:1–8), it is becoming easier to construct species checklists for areas where data exists. Most of the papers published on species checklists in protected areas are written by scientists, with checklist creation being an output or component of their research and not incorporating digital data. The inclusion of protected area staff as collaborators in the development of species checklist publications would be beneficial for protected area management. It would build capacity in specimen collection, identification and checklist development skills. Additionally, it would foster a support network and motivation for ongoing specimen collection and regular updates to species checklists. Protected area staff who develop checklists for management reasons are less likely to publish these checklists, but they can benefit from all the digital biodiversity occurrence data that is easily available for producing checklists from digital data platforms, such as GBIF. They can also contribute by recording field observations on citizen science platforms, such as iNaturalist, which make data publicly accessible for future checklist updates (Spear et al. 2023:1037282).

To assist the staff of protected areas with increasing the utility of checklists in decision-making, we have compiled a set of guidelines to assist with the creation of checklists for protected areas (see Online Appendix S5). The first step is to collate occurrence data from different sources, including GBIF. Once this is completed, the occurrence data needs to be put into the same format: for example, columns in the same order in MS Excel (Spear et al. 2023:1037282). After this, an appropriate taxonomic backbone should be selected and accepted names should be assigned to each occurrence record. The GBIF species lookup tool can be useful for this step. However, checks need to be made that matching is accurate and at the correct taxonomic level.

A checklist can then be created for the accepted names and their associated synonyms for which there is occurrence data, along with a record of the sources used to include each taxon. This list should be checked for inaccurate names that could be the result of misidentification, for example, in iNaturalist. A more comprehensive approach would be to validate all the occurrence records before creating the final checklist, but this isn’t always possible. Including the information source for listed species is critical for users to judge the information accuracy of checklists. For example, a species merely being listed on a previous checklist without an indication of the sources used to develop that checklist does not provide confidence that the species is present, whereas verifiable museum or herbarium specimens or direct observations across multiple sources provide a more reliable indication of occurrence. As such, tracking all the sources that identify a particular species in a particular area is an important step in the validation of checklists. Once the final list of names has been created, additional information can be added as annotations, such as International Union for Conservation of Nature (IUCN) Red List status, level of endemism and year of most recent record. Such data are useful for prioritising monitoring and decision-making. A database of relevant information for species can be kept so that it is easy to associate this information with names in a checklist using a relational database or functions in MS Excel or R.

While species checklists are vital for protected area management, they also need to be available for use in national conservation assessments and decision-making. However, many checklists for protected areas are not publicly available. Both iNaturalist and the GBIF provide the ability to upload checklists by protected area staff and scientists. Ideally, once species checklists have been created for protected areas, they should be uploaded to protected area websites, GBIF and iNaturalist. This could enable opportunities for citizen scientists to contribute additional occurrence data and promote the use of checklists for decision-making by protected area authorities who do not read the academic literature.

Conclusion

Way forward

We encourage the use of the GBIF platform and other digital data, the continued collection of preserved specimens in protected areas and the use of standardised approaches for species checklist development, including the use of taxonomic backbones. Improved checklist processes for protected areas can support national biodiversity strategies, reporting obligations and climate adaptation planning. Further research on emerging technologies could offer promising avenues for generating data to support species checklist development processes. Key opportunities include advancing AI-assisted identification to improve the reliability of species detection from BRUV footage, passive acoustic monitoring, and eDNA.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

CRediT authorship contribution

Dian Spear: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualisation, Writing – original draft, Writing – review & editing. Kylen Brown: Data curation, Formal analysis, Investigation, Validation. Nazley Liddle: Data curation, Formal analysis, Investigation, Writing – review & editing. Claire J. Parenzee: Data curation, Formal analysis, Investigation. Nicola J. van Wilgen: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication, and take responsibility for the integrity of its findings.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its references.

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