SANBI
Biodiversity for Life
South African National Biodiversity Institute

African Biodiversity & Conservation

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Focus and scope

The journal aims to disseminate, to a wide audience, knowledge, information and innovative approaches that promote and enhance the wise use and management of biodiversity in order to sustain the systems and species that support and benefit the people of Africa.

The journal publishes original research findings, as well as reviews, commentaries or perspectives, strategies and short communications. Special focus issues emanating from symposia or conferences that fall within the scope of the journal may also be published.

Authors should contextualise submissions within the framework of the value chain of biodiversity knowledge from its generation, to its application and use. We are especially interested in articles that are written using language and terminology that is accessible to a wide audience.

Specifically, the scope of the journal covers the following areas:

1. Generation of new knowledge that provides a foundation for assessment, planning or management of biodiversity, including new taxonomic discoveries within Africa, from across all Kingdoms of organisms, documenting the abundance, diversity and distribution of genes, species and ecosystems in Africa (including temporal changes in these), and understanding the interactions among components of biodiversity that contribute to the functioning of ecosystems.
2. Assessment of biodiversity, including the status of populations, species and ecosystems, the impacts of threats, harvesting and disturbance or of interventions on populations, species and ecosystems, and the value of the goods and services provided by biodiversity.
3. Innovation in science- or evidence-based decision-making for biodiversity in Africa. This includes the publication of case studies, best practices, tools and plans for the conservation, use and management of biodiversity.
4. Cross-cutting fields specifically developments and innovation in human capital development in the biodiversity sector and innovation in biodiversity information management and dissemination systems and tools for use of biodiversity information.
5. Strategic frameworks that provide guidance and direction for biodiversity research, assessment and management at community, local, national, regional or continental levels, especially those that integrate biodiversity management with local and regional socio-economic systems.

Submissions from authors anywhere in Africa as well as those based outside of Africa are invited if the content relates to African biodiversity.

Peer review process

All manuscripts submitted to *African Biodiversity & Conservation* will be reviewed by experts in the field.

Publication frequency

African Biodiversity & Conservation publishes manuscripts on its website on a rolling basis throughout the year (i.e. as soon as they are ready for publication). A hard copy version of the volume is published at the end of the year.

Manuscript preparation and submission

All articles must be submitted online at https://abcjournal.org/index.php/abc/about/submissions.

Copyright

Copyright on published articles is retained by the author(s).

Distribution

The journal is an online open access publication, available at https://abcjournal.org/index.php/abc/index to read. The hard copy is distributed to those individuals who order a copy from SANBI.

African Biodiversity & Conservation is included in the Directory of Open Access Journals (DOAJ), SciELO SA, Thomson Reuters Web of Science Core Collection, Science Citation Index Expanded, SCIE (previously known as ISI).

Accreditation

The journal meets the criteria of the Department of Higher Education and Training (DoHET). It is therefore accredited and approved by the DoHET for its inclusion in the subsidy system for being a research publication for South Africa.

Reviewer Acknowledgement

In an effort to facilitate the selection of appropriate peer reviewers for African Biodiversity & Conservation, we ask that you take a moment to update your electronic portfolio on http://abcjournal.org for our files, allowing us better access to your areas of interest and expertise, in order to match reviewers with submitted manuscripts.

If you would like to become a reviewer, please visit the journal website and register as a reviewer.

Please do not hesitate to contact us if your require assistance in performing this task.

African Biodiversity & Conservation, Vol. 55.

The editorial team of *African Biodiversity & Conservation* recognises the value and importance of the peer reviewer in the overall publication process – not only in shaping the individual manuscripts, but also in shaping the credibility and reputation of our journal. We are committed to the timely publication of all original, innovative contributions submitted for publication. As such, the identification and selection of reviewers who have expertise and interest in the topics appropriate to each manuscript are essential elements in ensuring a timely, productive peer review process. We would like to take this opportunity to thank all reviewers who participated in shaping this volume of *African Biodiversity & Conservation*. We appreciate the time taken to perform your review(s).

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Adrian Armstrong
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African Biodiversity & Conservation: an open access, free to publish journal for research on African biodiversity and conservation

Authors
*[1,2]Anthony R. Magee
[3,4]John R. Wilson

Affiliations
[1]South African National Biodiversity Institute, Compton Herbarium, Claremont 7735, Cape Town, South Africa.
[2]Department of Botany & Plant Biotechnology, University of Johannesburg, Auckland Park, Johannesburg, South Africa.
[3]South African National Biodiversity Institute, Kirstenbosch Research Centre, Claremont 7735, Cape Town, South Africa.
[4]Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa.
*The authors contributed equally

Corresponding Authors
Anthony Magee; e-mail: a.magee@abcjournal.org
John Wilson; e-mail: j.wilson@abcjournal.org

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In this editorial we provide an overview of the journal *African Biodiversity & Conservation* (*ABC*, www.abcjournal.org/): 'A journal that publishes scientifically robust peer-reviewed studies on African biodiversity and conservation in a manner that is free, accessible and ethical, and that maintains high quality standards throughout'. *ABC* is one of only four ISI-listed platinum open access journals focussing on African biodiversity. The journal is financially supported by, but editorially independent from, the South African National Biodiversity Institute (SANBI). There is no requirement on readers to pay for access nor on authors to pay to publish, although if a research grant provides funds for author page charges, we are keen to establish the principle that SANBI should not subsidise such publications. Unlike many other journals, the production team of *ABC* is in-house, allowing us to ensure that production standards are high.

The scope of the journal is self-explanatory: 1, the research must be directly on African issues; 2, it must be focussed on biodiversity; 3, there should be a link through to conservation management and policy in a broad sense; and finally, 4, the research must be well conducted and noteworthy. We provide various examples of what *ABC* regards as noteworthy and what sorts of submissions are not considered. Parochial articles will be considered if they link to broader lessons or a broader audience, otherwise a local or more discipline-specific journal would be more suited. The aim is to be inclusive; ABC will not chase impact factors. We also evaluate how *ABC* currently addresses the various developing international standards in biodiversity data management and publishing ethics. The journal is indexed in the Directory of Open Access Journals (DOAJ), is listed on the Institute for Scientific Information (ISI) Web of Science, and aims to support FAIR data standards and to meet the principles of Plan S. *ABC* follows a largely traditional model with a growing board of Associate Editors relying on reviewers from Africa and elsewhere to ensure a robust and scientifically rigorous peer-review process. Please get in touch if you are keen to be involved in the journal in whatever capacity. We welcome input, advice, criticism, but most of all noteworthy submissions on African biodiversity and conservation.

Keywords: *Bothalia*, journal, Africa, biodiversity, conservation, free to publish, open access.

The need for a journal on African biodiversity and conservation

Africa is endowed with remarkable natural wealth and an enviably diverse assemblage of ecosystems and habitats. More than a quarter of the world's biodiversity hotspots (9 of the 35 currently recognised) are located in this, the poorest and second most populous continent (IPBES 2018). Cataloguing this tremendous biodiversity is far from complete, especially as biodiversity hotspots likely contain the majority of undescribed species, most of which are likely to be threatened with extinction (Joppa et al. 2011). Sustained maintenance of this rich biodiversity, and the services rendered (at local, regional and global levels) by its varied ecosystems, increasingly need to align with the urgent priorities for economic development and improved human wellbeing (Chapman et al. 2022). It is anticipated that the human population on the continent will quadruple in the next 80 years (United Nations Department of Economic and Social Affairs Population Division 2015) with massive urbanisation (Cartwright 2015), precipitating rapidly expanded pressures on land, aquatic systems and biodiversity. Higher consumption levels will necessitate agricultural development and likely lead to increased hunting pressures (Lambin & Meyfroidt 2011); increased pressure on forests for fuelwood and building material (Fisher 2010); increased pressures on fisheries (Allison et al. 2009); and, with almost 30% of the world's minerals, the pressure for development through mining will be intense. The associated direct and indirect impacts of these pressures on biodiversity will be significant. Complicating these already considerable pressures, Africa is likely to be the continent hardest hit by climate change (IPCC 2014).

Scientific research is an important driver of economic growth and development, and essential if Africa's environmental challenges are to be addressed equitably at appropriate scales. Rapid publication and access to this research is important for African policymakers to make informed science-based decisions that support the region. African scientific production is the fastest growing of any continent (an increase in scientific papers produced of 38.6% between 2012 and 2016), with the number of authors also increasing by 43% over the same period (Duermeijer et al. 2018).

One of the stumbling blocks is ensuring access to information. The global drive for open access scientific publishing, while making scientific literature more accessible, has the potential to limit the publication of research by the Global South due to the cost of open access publishing fees (Table 1; Smith et al. 2021; Kwon 2022) and increase geopolitical knowledge inequality by drowning out the visibility of developing nation research (Demeter & Istratii 2020). The publishing models of scientific journals is generally either pay to access or pay to publish – if research is to be subsidised, it likely only happens when such research aligns with the agendas of journals based outside of Africa, reviewed by institutions outside of Africa, and that will contribute to the reputation of the journal (e.g., through the impact factor). Well-conducted relevant local research is not routinely regarded as important to the wider international scientific community, but such context-specific research should be the foundation of decisions that need to be made on the continent.

Facilitating intra-African collaborations is also vital. Species distributions and how they are impacted by global

Table 1. *African Biodiversity & Conservation* is one of four platinum open access African-based journals publishing on biodiversity across the continent. The following are a list of journals under ISI Web of Science's Journal Citation Index as at mid-2023, filtered using African countries, and manually interpreted to journals that publish research on biodiversity and conservation. The author page charges are the gross figures quoted on websites (i.e., they do not include banking fees, taxes or the cost of exchanging money) for a research article of 16 pages in length published by someone based in South Africa

Title	Scope	Publisher	Publishing model	Author page charges (for open access)
African Biodiversity & Conservation	African biodiversity and conservation	South African National Biodiversity Institute	Platinum Open Access	none
African Entomology	Entomology, particularly in Africa	Entomological Society of Southern Africa	Gold Open Access	ZAR 5 500 (members) ZAR 10 000 (non-members)
African Invertebrates	Taxonomy, systematics, biogeography and palaeontology of Afrotropical invertebrates	Pensoft	Gold Open Access	EUR 300
African Journal of Aquatic Science	Aquatic science, particularly in Africa	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
African Journal of Ecology	Ecology and conservation of African animals and plants	Wiley	Mixed, can select Gold Open Access	USD 3 350 GBP 2 220 EUR 2 780

Table 1. *African Biodiversity & Conservation* is one of four platinum open access African-based journals publishing on biodiversity across the continent. The following are a list of journals under ISI Web of Science's Journal Citation Index as at mid-2023, filtered using African countries, and manually interpreted to journals that publish research on biodiversity and conservation. The author page charges are the gross figures quoted on websites (i.e., they do not include banking fees, taxes or the cost of exchanging money) for a research article of 16 pages in length published by someone based in South Africa (continued)

Title	Scope	Publisher	Publishing model	Author page charges (for open access)
African Journal of Marine Science	Marine science, particularly in Africa	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
African Journal of Range & Forage Science	Management, assessment, monitoring, ecology, conservation, biodiversity and forage science of rangelands and pastures in Africa	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
African Journal of Wildlife Research	Wildlife research in Africa, Arabia and Madagascar	South African Journal of Wildlife Research	Traditional publishing	ZAR 3 200 (local members) USD 320 (non-local members) (double for non-members)
African Zoology	African fauna in terrestrial, freshwater and marine ecosystems	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
Koedoe: African Protected Area Conservation and Science	Conservation of protected areas, particularly in Africa	AOSIS	Gold Open Access	ZAR 19 808
Ostrich	African ornithology	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
Pachyderm	African elephant and African and Asian rhino conservation and management in the wild	International Union for Conservation of Nature and Natural Resources	Platinum Open Access	none
South African Journal of Animal Science	Production of farmed animal species, as well as pertinent aspects of research on aquatic and wildlife species	South African Society for Animal Science	Gold Open Access	ZAR 4 800 (members) ZAR 6 000 (non-members from the Southern African Development Community) USD 800 (everyone else)
South African Journal of Botany	Plant sciences, particularly southern Africa	Elsevier	Mixed, can select Gold Open Access	USD 2 750
South African Journal of Science	General interest science relevant to and for Africa	Academy of Science of South Africa	Platinum Open Access	none
Southern Forests	Forestry: Forest science and management of fast-growing, planted or natural forests in the Southern Hemisphere and the tropics	Taylor & Francis	Mixed, can select Gold Open Access	USD 3 175
Water SA	Water science (including freshwater and estuarine ecology)	South African Water Research Commission	Platinum Open Access	none

change cut across national boundaries. Biological invasions in Africa can be due to introductions to any part of the continent, and so biosecurity is a pan-African issue (Faulkner et al. 2017, 2020). Management decisions therefore can have international consequences. A classical biological control agent released in one country can disperse to other countries, providing significant benefits by reducing plant invasions (Langa et al. 2020) but also potential conflicts (Paterson & Witt 2022). These point to the need for African-wide perspectives rather than solutions from abroad. There are, however, relatively few African-based open access journals that publish biodiversity research (Table 1) and of these only four appear to be both listed on ISI-Web of Science and free to publish and access, i.e., platinum open access. Of these four only *African Biodiversity & Conservation* publishes across the broad scope of biodiversity.

Since the first issue of *African Biodiversity & Conservation* was published in 1922, the scope and title of the journal has expanded. The journal was first published under the name *Bothalia*, as an institutional journal of the then Botanical Research Institute (BRI). The BRI merged with other institutions and eventually in 2004 became part of the newly established South African National Biodiversity Institute (SANBI). *Bothalia* continued to be published by SANBI until 2013 (volume 43). The following year, publication was shifted to the Cape Town based publisher AOSIS under the title *Bothalia, African Biodiversity & Conservation*. In 2020 the journal moved back to being published in-house by SANBI under the title *Bothalia, African Biodiversity & Conservation*. In 2025, the prefix was dropped, and the title updated to *African Biodiversity & Conservation* (*ABC* for short). *ABC* is now an ISI-listed platinum open access journal with dedicated support for journal production from SANBI. We are enormously grateful to Prof. Michelle Hamer, the previous Editor-in-Chief of *ABC*, for pioneering this publishing model. We came on as co-Editors-in-Chief in July 2022, and have since focussed on building on her foundation and codifying how the journal is run.

Until 2014, almost all papers published in the journal were botanical, and the majority included an author based at SANBI. In the years since, and as reflected by the change in title, the scope has broadened to biodiversity, and over the last few years the majority of authors are from outside of SANBI, and increasingly from around the continent (Figure 1).

Based on this we developed a vision for the journal *ABC*:

'A journal that publishes scientifically robust peer-reviewed studies on African biodiversity and conservation in a manner that is free, accessible and ethical, and that maintains high quality standards throughout.'

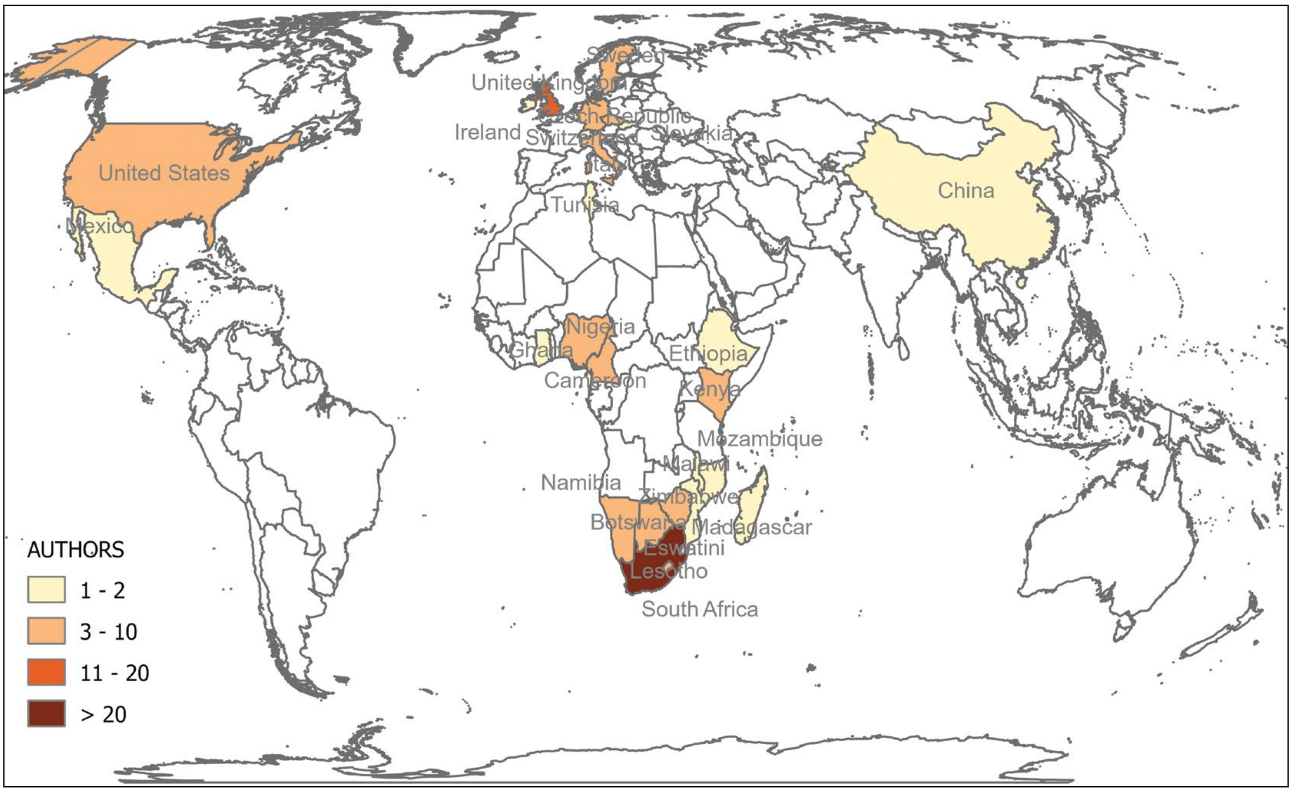

Figure 1. The location of authors of articles in *African Biodiversity & Conservation* 2018 to 2023 (see Supplementary Material for details). Historically the journal (under its previous name *Bothalia*) largely focussed on South African botanical research with some contributions from southern Africa. In the period examined here, 85% of authors have been from Africa (71% from South Africa), from across 15 African countries, with the number of contributions from outside of South Africa increasing.

The scope of ABC

We recognise there is a rich variety of knowledge systems and types of papers; *ABC* will try to be flexible and accommodating, but we take a literal approach to the scope.

1. The research must be directly on African issues

We are keen for submissions from Santo Antao in Cabo Verde in the west to Île Rodrigues in the Indian Ocean to the east, and from Cani Islands in Tunisia to Cape Agulhas in South Africa. This is a rich and varied biogeography. *ABC* does not, however, consider South Africa's sub-Antarctic islands (i.e., the Prince Edward Islands) to be part of Africa, nor any of the Mediterranean islands, except those that form part of African countries (e.g., Tunisia's Galite Islands). As such, we aim to follow the United Nations geoscheme for Africa.

Authors can be based anywhere but the research must be directly on African issues. We welcome papers from those based at African institutions, from the African diaspora and from non-Africans based at non-African institutions (Figure 1).

2. The research must be relevant to biodiversity

We are keen to publish work from genes to ecosystems and across all realms in line with the UN Convention of Biological Diversity (CBD), 1992, Article 2's definition of biological diversity: 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.' We do not believe there is a neat separation between natural, rural and urban, just as people and nature should not be viewed as separate. We have found that the term 'in the wild' can mislead, and *ABC* welcomes studies on urban ecology particularly as Africa rapidly urbanises. However, research on agricultural or production systems would be considered only in the context of how such land-uses or production affect or interact with African biodiversity.

3. Facilitate uptake into conservation policy and management

ABC publishes applied and foundational studies, but we encourage all authors to think about the likely readers and end users of their work. Who would use the results and how? Who might cite it? In describing a new species, identifying a taxon at risk of extinction or reporting a new invasion, it is, we feel, important to consider the implications. Who is affected and how can the information presented feed through to managers and policy-makers? *ABC* does not, at present, specifically have a section on practice and management insights, though we are keen to publish such studies. We are excited by the Kunming-Montreal Global Biodiversity Framework of the CBD, and encourage authors to be explicit as to how their research can help towards the four long-term goals and 23 targets (https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222). We appreciate much work is still needed to develop robust biodiversity indicators to track progress towards such targets (Leadley et al. 2022), and research into making the targets and indicators relevant to the African context is crucial. Often, with a few small tweaks to a manuscript, it is possible to ensure that research is more digestible or more readily incorporated into such processes (see data standards below).

4. The research must be well conducted and noteworthy

ABC publishes research that is scientifically robust and that is clearly and accessibly presented. Our editorial and production teams aim to help, though authors are ultimately responsible for their manuscripts. By noteworthy we mean that research should be of interest to other researchers or conservation practitioners in Africa and not just of local interest to those working in the same field. This is the aspect that is by far the hardest to pin down, and so we have provided specific examples in the last section of this editorial. If the topic of a manuscript is in this scope, *ABC* will try to be flexible in terms of how and what is published.

The ethos of the journal

Open access, free to publish, but still with high-production value

Far too often Africa's natural wealth has been lost to the continent. African taxpayers' money and research grants are still, in some cases, literally going into Swiss bank accounts. None of a recent list of the hundred largest scientific publishing houses in the world are based in Africa (Nishikawa-Pacher 2022), and the top publishers have few if any offices on the continent (See Supplementary Appendix 1).

ABC is different. *ABC* is produced in-house by the South African National Biodiversity Institute (SANBI), Pretoria, South Africa; and offers high-quality scientific editing and production once a paper has been accepted following peer review. As a platinum open access journal, neither authors nor readers pay to publish or access the journal. The journal is indexed in the Directory of Open Access Journals (DOAJ) and aims to meet the principles of Plan S (https://www.coalition-s.org/plan_s_principles/). We are, of course, conscious of cost and sustainability, and want to create a flexible model. *ABC* is not set up to subsidise large international research funders and so, if research funders allocate money to pay for author page charges, then the costs of *ABC* should be covered. We have not worked out the precise model, though the working principle is that no-one needs to pay, but if there is budget for it, then they should.

Trying to meet international data standards

Given the massive increase in our ability to capture data and the urgent need to synthesise such data into information useful for policy-makers and managers, biodiversity informatics is emerging as a distinct discipline [for an overview see Gadelha Jr et al. (2021) and for a perspective from South Africa see MacFadyen et al. (2022) and Parker-Allie et al. (2023)]. We are at the heart of a paradigm shift in scientific practice and impact metrics, where datasets are described and published as data papers, providing recognition for the efforts of data gathering and cleaning. This creates new challenges but also new types of manuscripts. In particular we are looking to have a new category of 'Data Descriptor' publications. Costello et al. (2013) presented a proposed 14-step procedure for such publications, and we will be keen to explore the degree to which *ABC* can adopt this model. We are similarly interested to ensure publications include data workflows where appropriate, so that analyses are truly repeatable and transferrable. We encourage prospective authors to look at proposed best practice for publishing data [e.g., Costello & Wieczorek (2014)]; and at *ABC* we will try to follow FAIR data principles both by encouraging the publication of data underlying papers and also in the way we run the journal (Wilkinson et al. 2016). We aspire for manuscripts to be:

- **Findable** – all articles receive a digital object identifier (doi), and we strongly encourage appropriate metadata to be provided.
- **Accessible** – all papers are published online once accepted and laid out, and papers will be free to access.
- **Interoperable** – we encourage the use of biodiversity data standards (e.g., Darwin Core terms).
- **Reusable** – manuscripts are, by default, published under the Creative Commons Attribution 4.0 International License, meaning that, with appropriate attribution of sources, people are welcome to use and distribute the published work.

We are also keen for authors to follow international best-practices in other areas. For example, for literature reviews and meta-analysis, we would encourage authors to follow the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, for example see O'Dea et al. (2021) for recommendations in ecology and evolutionary biology.

An ethical framework

Accessibility and diversity are core values for the journal. We aim to ensure that the composition of the editorial board is diverse (in terms of gender, ethnicity, career stage and geographical representation) and where possible encourage a similar consideration of diversity in the peer review of manuscripts. In so doing we hope to reduce some of the additional burdens experienced by African scientists as identified by Marincola and Kariuki (2020). To ensure that we maintain the highest standards of publication ethics within the journal, publication policies and core practices will be revised or developed and made available on the journal's webpage as per the guidelines of the Committee on Publication Ethics (COPE). This commitment, in our opinion, will strengthen the scientific rigour of the peer-review process, noting decisions to publish articles will be based solely on the scholarly merit of the research and not the ability to pay.

It is similarly crucial that studies increasingly evaluate issues from various perspectives. Local knowledge systems and indigenous peoples and local communities must be respected and acknowledged. For examples of specific recommendations, see the Cape Town Statement on fostering research integrity through fairness and equity (Horn et al. 2023). We encourage all authors to read and engage with codes of ethical practice for researchers, and we will try and set processes in place to facilitate this. For example, a recent South African statement on ethical research and scholarly publishing practices sets out 12 principles (ASSAf et al. 2019), we believe that *ABC* meets many of these principles in full already, but we recognise that much more can be done (Table 2).

ASSAf and SciELO also recently produced guidelines regarding the ethical use of artificial intelligence (AI) in writing, reviewing and editing scientific publications (ASSAf and SciELO 2024). To summarise, only humans can be considered authors, and if such large language models (LLMs) are used in a substantive way, their use must be declared and cited in either the methods or acknowledgements as appropriate.

So how does ABC work?

Full details of how *ABC* works are available on the journal's website (www.abcjournal.org) in particular in the

Table 2. How the editorial team at the journal *African Biodiversity & Conservation* (*ABC*) are addressing the twelve principles from a recent South African declaration on research ethics (ASSAf et al. 2019)

Principle	Current status and proposed actions
1. Responsibility	*ABC* aims to keep abreast of all relevant regulations and tries to maintain academic and research integrity. In terms of addressing unethical practices, *ABC* still needs to develop set procedures, though if there are issues, please raise them either directly with one of the co-Editors-in-Chief (a.magee@abcjournal.org; j.wilson@abcjournal.org) or with the Managing Editor (y.steenkamp@sanbi.org.za). SANBI also has an anonymous whistle-blowing system (sanbi@behonest.co.za).
2. Ethics and integrity	The issues discussed in this table are our attempt as a journal to be open and clear about how *ABC* is trying to be ethical and act with integrity.
3. Methodology and data	Methods will need to be provided in enough detail to allow the research to be repeated. All underlying biodiversity data should be published in an appropriate database unless there is a clear reason not to (e.g., Tulloch et al. 2018). For further details see the section on 'Trying to meet international data standards' (p. 6).
4. Authorship	The corresponding author must confirm all authors have seen the final submitted version and they all agreed to be included as authors. An explicit process to request confirmation from co-authors is not currently in place and is under consideration.
5. Acknowledgement of contributions	*ABC* requires all manuscripts to have an Author Contribution statement. *ABC* has not, as yet, set the Contributor Role Taxonomy (CRediT) as a requirement (Brand et al. 2015), but encourages authors to consider using it (e.g., https://www.elsevier.com/authors/policies-and-guidelines/credit-author-statement).
6. Peer review	*ABC* is committed to rigorous peer review. For further details see the section 'Review model' (p. 7) with details online.
7. Social awareness	*ABC* is committed to ensuring diversity in the composition of the editorial board, as well as the selection of reviewers. Policies for the retraction of articles need to be developed.
8. Conflicts of interest	All manuscripts have a section 'Competing interests' wherein any conflicts are to be clearly stated. *ABC* is committed to ensure there are processes in place to avoid conflicts of interest or to be transparent if conflicts exist or may be perceived. This needs to be formalised.
9. Editorial	If an editor is an author of a manuscript submitted to *ABC*, they are recused from decision-making, and the review process is anonymous. Editorial decisions are, and will continue to be, independent from the host institution (i.e., SANBI). We are committed to establishing an advisory board within the next year that would, for example, review the performance of us as co-Editors-in-Chief and be responsible for guiding the appointment of our successors.
10. Research publishing environment	*ABC* is not for profit. We commit to working with the editorial board and proposed advisory board to develop explicit processes for education and stewardship. Similarly, clear and fair policies and practices need to be developed.
11. Predatory journals and unethical editorial practices	The editorial processes within *ABC* will be guided by those from the Committee on Publication Ethics (COPE; see https://publicationethics.org/ for details).
12. Quality over quantity	*ABC* will not chase impact factors because doing so would mean the journal was being over-selective in what it publishes (cf. Choi et al. in press). *ABC* aims to publish all manuscripts that are within the scope and that are noteworthy. We realise that *ABC* will lose out on publishing important manuscripts that can be more easily published for a fee in open-access journals, but we commit to not taking shortcuts on quality. For further details see the sections on 'The Scope of ABC' (p. 4) and 'What is noteworthy?' (p. 9).

'Information For Authors' section. We highlight a few key aspects below.

Review model

There are lots of exciting emerging publishing models, but *ABC* is committed in the medium term to a traditional model. Each submitted manuscript will be briefly evaluated by the journal team and one of the co-Editor-in-Chiefs to check if it is: within scope, the contribution is original research, not published elsewhere, research techniques are of appropriate standard, written in English, meets ethical considerations and is noteworthy. Submissions need to be of a quality such that potential reviewers will be able to concentrate on the content and not on the presentation. Manuscripts are returned to authors prior to peer review if there are substantive issues that would detract from the peer-review process or rejected if the manuscript is not within the journal's scope. Similarly, it is important that the underlying data are accessible, e.g., they should aim to be tidy where possible (Wickham 2014) (i.e., the physical layout links with its meaning by using a specific structure: a column for each variable, a row for each observation and a table for each type of observational unit). Manuscripts that meet these criteria are then allocated to an Associate Editor who has expertise relevant to the manuscript. The Associate Editor performs a similar but much more detailed evaluation and either rejects, requests pre-review revisions or sends the manuscript out for external peer review.

Peer review at *ABC* involves at least two, ideally three, external reviewers assessing each paper and providing detailed comments and insights. The default model is for single-blind reviews (i.e., authors names are available to reviewers, but reviewers names are not available to authors). If authors specifically request for their names to be withheld from the review process we can try to accommodate, but our experience (at least from South Africa) is that there are only a few people who work on any one topic – it is often readily apparent who the authorship team is, and so double-blind reviewing is illusory. We leave the decision up to reviewers to choose whether to sign a review, but if they do not, then it is assumed that they wish to be anonymous. We have not, as yet, a process whereby manuscript drafts and reviews can be published alongside accepted manuscripts, though this is something we may consider in future.

On receipt of reviews, the Associate Editor then provides feedback to the authors via the journal system. The authors, as appropriate, revise their manuscript, and the process repeats until a final decision is made. A decision can be appealed with the appropriate co-Editor-in-Chief on the basis of procedural or scientific grounds.

Submission system

The journal is managed, from submission, peer review and production, using the Open Journal Systems https://pkp.sfu.ca/ojs/. Supplementary material can be stored online; however, we are very happy if supplementary information, data sets and code are stored on open-access repositories (e.g., Zenodo for data and code on GitHub).

Production

ABC has an in-house production team that provides scientific and copy-editing services and ensures the final documents are appropriately laid out. Articles are published on-line the moment production is complete, with each article assigned a digital object identifier (doi) and page numbers as part of a virtual volume. At the end of each year a physical copy is still produced (divided into issues as necessary). These can be purchased from the SANBI bookshop (bookshop@sanbi.org.za). Physical copies of the journal issues are archived/deposited in various libraries and legal depositories.

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Indexing

The journal is indexed in SciELO SA, SCOPUS, Thomson Reuters Web of Science Core Collection, Science Citation Index Expanded, Directory of Open Access Journals (DOAJ), EBSCO Host and Google Scholar.

Types of papers

The bulk of papers published by *ABC* are 'Research articles and Reviews'. We do not currently separate these papers into different thematic sections (either in the physical volumes or online), though this could be considered if the number of accepted manuscripts increases markedly and such divisions are considered to be useful by the readers and contributors. ABC has four other types of research papers ('Data descriptors', 'Nomenclatural changes', 'New distribution records' and 'Short communications'). It is increasingly important that data are curated and presented in and of themselves. As such *ABC* will start to explicitly publish 'Data descriptors' papers that describe relevant data that are foundational to broader analyses and indicators needed for conservation planning. *ABC* has for many years served as the repository for taxonomic nomenclatural papers in botany in South Africa and will continue to publish 'Nomenclatural changes'. Similarly, the journal will continue to publish 'New distribution records'. Finally we have a 'Short communications' category for papers that don't fit neatly into the other boxes. Sharp and Burrett (2021) provide fascinating insights into the nineteenth century naturalist Emil Holub's work on fungi, including some of his sketches. Such historical notes can serve as important reference points for current research in fascinating ways, and *ABC* will aim to strongly support Sagarin and Pauchard's (2010) call for rigorous observational approaches to ecology.

There are a few other specific categories. 'Editorials', as the name suggests, are opinion pieces by members of the editorial team on issues either directly related to *ABC* (as in this current paper) or on topical issues. Similarly, *ABC* has and will continue to publish 'Commentaries' on topical issues by any contributors. For example, Klopper et al. (2018) provided a report on the outcomes of the Nomenclature Section of the XIXth International Botanical Congress of relevance to South African botanists and mycologists (a report on the 2024 congress is under consideration). Finally, *ABC* will annually publish a list of reviewers under 'Reviewer Acknowledgement'.

ABC has historically published other types of articles, including book reviews. For example, Siebert (2021) reviewed William Bond's (2019) book 'Open Ecosystems: ecology and evolution beyond the forest edge', a fascinating exposition of global grasslands, savannas and shrublands. However, with the move from *Bothalia* to *ABC*, the journal is less about one particular institution or one community of practice and rather about the broader discipline of biodiversity and conservation. *ABC* is not a society-run journal, and as such we found it difficult to justify what to review in terms of books and who to include in the case of obituaries. This is a decision that we will revisit once an advisory board is established.

The current restriction on article length is 8 000 words. We can be flexible on this limit, although, as with all scientific articles, it is desirable that ideas are presented as concisely as necessary. Moreover, as physical copies are still produced, online supplementary material will be preferred for large data sets or discussion on issues not essential for the central narrative of the manuscript.

What is noteworthy?

A potential manuscript will need to carefully demonstrate that the contributions are noteworthy. Given that we do not want to be overly dogmatic, we felt it best to try and define noteworthy through recent *ABC* articles.

Taxonomic papers

We encourage authors to publish new species within a taxonomic revision of a genus or other appropriate infrageneric group. If the taxonomy of the study group is adequate, single species descriptions will be considered, providing the new taxon is placed within the framework of the current taxonomy. Sochorová et al. (2022) described a new fungus – *Pseudoplectania africana* – using morphological, anatomical and phylogenetic data to place the species. This is possibly the first record of the genus in Africa.

Nomenclatural changes

The journal is an outlet for notes to correct, validate and formalise taxonomic nomenclature. These formalised publications are crucial for the rapid updating and correction of taxonomic backbones as nomenclatural issues come to the fore. Manning and Govaerts (2022) demonstrated that the currently recognised name for the African daisy genus *Polydora* Fenzl. ex H. Rob. was superfluous and so illegitimate, as such new combinations for the species needed to be made within the earlier published (and so correct) generic name, *Crystallopollen* Steetz. In order to ensure rapid processing, these manuscripts are reviewed by a dedicated nomenclatural review board. Such a board is in place for botanical nomenclatural papers and additional boards will be instigated to handle other groups.

Distribution records

ABC publishes first records of alien taxa and new distributional records (e.g., range shifts in response to habitat modification or climate change). However, for them to be noteworthy, there needs to be biogeographic novelty. If an alien taxon is already found in neighbouring countries or provinces or states within a country, it is important information, but a local journal is likely preferable; by comparison a first record outside of a species' continent of origin is noteworthy. Such cases should also discuss the potential management or policy implications. Iamonico and El Mokni (2023) record a small population of *Amaranthus crassipes* subsp. *warnockii* (I.M.Johnst.) N.Bayón naturalised within ruderal vegetation in Tunisia, possibly the first such record outside of the plant's native range in North America, noting that the populations might need to be considered for extirpation. Detailed studies and analyses of continent-wide spread would also be noteworthy, especially if linked to mechanistic hypotheses and pathways. Single species distribution models are not noteworthy in and of themselves.

Atlassing and checklists

ABC is keen to ensure that the collection and curation of primary biodiversity data gains the scientific recognition and visibility that it deserves. Fryday (2015) reviewed and updated information on the presence of lichen in South Africa and provided a checklist of 1 750 taxa; and Dayaram et al. (2019) provided details of an update to the vegetation maps of South Africa, Lesotho and eSwatini, adding 47 vegetation types and removing 35 in total affecting around 5% of the whole map. These papers were not specifically flagged as data descriptors / data papers but will likely be categorised as such in future.

Case studies

We agree with Simberloff (2004) that responding to many conservation challenges will require local observational and experimental studies. For such case studies to be noteworthy there should be some explicit consideration of what the context is and why it is important (Catford et al. 2022), and ideally general lessons applicable to other sites or other taxa should be highlighted. For example, Kashe et al. (2022) used the opportunity provided by an international airport in Botswana to provide insight into the ecological consequences of fencing off an area. Case studies that document an eradication or an extinction are noteworthy in and of themselves. For a case study that documents progress towards either to be noteworthy, it would have to provide some general insights relevant to policy and management beyond the individual example (i.e., direct and detailed recommendation of how practices need to change).

People and nature

Conservation is inherently about people and nature, and *ABC* is keen to publish articles about how people interact with nature and why, recognising and respecting the knowledge held by indigenous peoples and local communities. Bello et al. (2019) interviewed traditional medical practitioners and others in the Sudanian savanna of northern Nigeria and developed a list of 169 plant species utilised, of which 43 are used for ethnomedicinal practices. They then conducted local conservation assessments of these taxa to provide recommendations for policy and management. Engaging communities in conservation science takes many forms, including crucially by ensuring there are more eyes on the ground. Deschodt et al. (2021) documented the rediscovery of a taxon thought to be extinct. They found several images of an unusual dung beetle from Madagascar on a citizen science platform (iNaturalist). As the photographs included diagnostic features, they were able to identify the beetles as *Scarabaeus sevoistra*, the only confirmed records of the species for 80 years.

Communities of practice

Understanding relationships between people and institutions is essential if global change challenges are to be effectively met. Jubase et al. (2021) surveyed community groups that are clearing invasive plants in the Western Cape of South Africa, documenting their important contribution to efforts to combat invasions. Davies et al. (2020) reviewed the activities of the CAPE Invasive Alien Animals Working Group, highlighting how the group bridges the science–policy gap and providing important suggestions for how such groups can be made more effective. *ABC* will similarly consider workshop and meeting reports providing there is critical analysis or interpretation of the effectiveness and outcomes of the events held.

Ecosystem processes

Understanding the drivers and mechanisms of global change will be vital if policy makers and managers are to respond effectively. However, understanding such processes often requires rigorous measurements of abiotic and biotic factors, particularly if mechanisms are to be unequivocally ascribed to the observed changes. *ABC* will publish studies that seek to document ecosystem processes, recognising the need to be explicit about potential consequences. Tsheboeng et al. (2020) explored the influence of flooding regimes on plant communities of the Okavango Delta in Botswana. They showed how soil nutrients varied over time and with floods, identifying potential links between flooding, soils and specific plant taxa. They note that water abstraction from the Okavango River Basin needs to carefully consider the quantity and timing of water needed to sustain seasonal floodplain plant communities.

Conservation assessments, monitoring and planning

We support the publication of conservation assessments, in particular to improve the flow of information to decision-makers and managers. However, to be noteworthy, there needs to be more than simply repeating a Red List assessment. Mostert and Mostert (2021) investigated the saprophytic coastal forest floor orchid *Didymoplexis verrucosa* in Zululand, South Africa. After almost a thousand person-hours of searching they found a plant and subsequently a couple of other sightings were noted. Recognising that, ‘Traditional search techniques are inadequate for population monitoring programmes of rare and cryptic species.’, they carefully circumscribed the habitat characteristics of the orchid and used this to develop recommendations for focussed future searches and conservation efforts. Escobar et al. (2021) looked at the species richness and abundance of dung beetles in the Maputo Special Reserve of Mozambique and highlighted the importance of the reserve to conservation in the broader region, particularly given the large patches of sand and dune forest within a natural grassland matrix. *ABC* also welcomes broader taxonomic or regional assessments that look at emerging trends across groups. Van Rooy et al. (2019) produced the first list of lost or threatened bryophytes for Africa, and proposed taxa that should be prioritised for IUCN Red List assessments.

Policy

ABC publishes papers of relevance to regulation and policy, including critiques. Blackmore (2022) reviewed an on-going legal dispute over whether to grant a permit to mine in an area that was, until recently, part of the Mabola Protected Environment in South Africa. Building on this case, Blackmore (2022) argued for an amendment to legislation under which protected areas can be downgraded, downsized and degazetted. *ABC* is keen, as in this case, to ensure that published recommendations are practical, and so encourage authors to consider how a policy would be monitored and effectiveness determined.

Methods

New methods and techniques will be considered if they are clearly and specifically relevant to the African context. Makwela et al. (2016) outlined the potential to use a remotely operated vehicle as a non-destructive measure to investigate the fish fauna of deep reefs off the southern coast of Africa (the central Agulhas Bank). They recorded 35 fish species as compared to 30 species reported by the commercial line fishery over the previous decade. Bertschinger and Lueders (2018), as part of a special issue, reviewed the use of hormone injections to reduce aggressive behaviour in free-roaming 'problem [male elephant] bulls'; again the method is both relevant to Africa and, we believe, noteworthy.

Special issues

ABC publishes special issues with coherent and relevant themes. If you have a proposal, please get in touch. Selier et al. (2018) outlined a special issue on 'Conservation and management of elephant populations on small and medium-sized fenced reserves: Current practices, constraints and recommendations'. Wilson et al. (2017) highlighted a special issue on 'Contributions to the National Status Report on Biological Invasions in South Africa' that fed directly into a national level report published the following year (Van Wilgen & Wilson 2018). Finally the special issue described by Rouget et al. (2016) looked at 'eThekwini Ecosystems' and the Durban Research Action Partnership, exploring how the conservation of threatened ecosystems in an urban biodiversity hotspot in South Africa was being addressed and could be improved. Each of these special issues thus helped establish the state of a particular issue or topic and provided advice as to how things could move forward. By contrast, some publishers send round speculative spam e-mails tempting scientists to edit a special issue on a topic identified by the journal as the most likely to generate income and citations for the journal. Such practices result in papers being published that, to quote a colleague on a list server about science publishing, are 'either banal or venal or, worse yet, both of these'. *ABC* will only focus on special issues where there is a clear reason for why papers are grouped together.

How can I get involved?

We recognise the pressures on everyone's time, but if you get a review request please either accept or reject promptly, and if you do accept, please try to provide a constructive review in good time. For editors of other journals, we welcome collaboration and will endeavour to look to cross-refer out-of-scope articles as appropriate. For authors, please consider *ABC* for your research. We can help with production, and we are committed to sustainably growing the journal. In particular, we are very keen to increase the number of submissions from across the continent (cf. Figure 1). We do not have funds for translation but would be very open to partnerships to address the issue of accessibility and would be keen to publish translated material in languages other than English. If you want to know if a publication might be suitable, please contact us. And if you have comments or criticisms of the journal's vision and proposed approach, please get in touch (the e-mail editorialboard@abcjournal.org will reach both the Managing Editor and the co-Editors-in-Chief).

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A South African perspective on the 2023 IPBES Thematic Assessment Report on Invasive Alien Species and their control

Authors

*J.R.U. Wilson et al.

*Full list of authors and their affiliations are provided at the end of the paper.

Corresponding Author

John Wilson; e-mail: john.wilson2@gmail.com

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Background: Biological invasions are a major threat to biodiversity and sustainable development. A global assessment of biological invasions released in 2023 by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), concluded that while invasions '…cause dramatic and, in some cases, irreversible changes…' they can be '…overcome through a context-specific integrated governance approach'.

Aim: Here we evaluate insights from the IPBES assessment in the context of South Africa and explore how these insights could inform the development of a national policy and strategy to address biological invasions.

Results: Trends and status of biological invasions in South Africa are similar to those seen globally, but there are some distinct local nuances. South Africa has: 1) a long history of invasions with negative impacts caused especially by invasive trees and freshwater fishes, whilst invasive marine invertebrates have transformed large parts of the coastline; 2) a long history of control (biological control was first implemented in 1913) with large-scale, state-run invasive species management programmes currently in place; 3) a comprehensive regulatory system (e.g., there is provision for beneficial invasive species to be used under permits); 4) relatively high levels of awareness and engagement (at least among some stakeholder groups); and 5) a well-connected community of practice.

Discussion: Efforts to limit introductions (intentional or unintentional) are difficult given South Africa's extensive and porous borders and the pressing need to increase trade and travel. Regulatory and implementation efforts aimed at prevention are improving, with the newly established Border Management Authority aiming to integrate biosecurity interventions at ports of entry. Such integrated governance is, we argue, needed more broadly if affected sectors, society groups and stakeholders are to be effectively included in decision-making and management. A more systematic flow of information from observation to action is essential, as is better feedback between research, policy and implementation at all scales. Biological invasions will continue to pose threats, but many of these can be effectively mitigated through focussed interventions. Co-ordinating such interventions in the context of other cross-cutting global change challenges and initiatives is a cost-effective way of protecting and improving livelihoods, human health, quality of life and biodiversity.

Keywords: biological invasions, invasion science, Science-policy interface, the Kunming-Montreal Global Biodiversity Framework (KM-GBF), IPBES IAS Assessment

Introduction

Biological invasions are a global issue with negative impacts on biodiversity and human well-being (Pyšek et al. 2020; Roy et al. 2024; WTO 1998). The introduction and spread of invasive species are facilitated directly and indirectly by different drivers such as the increasing movement of goods and people around the world (Hulme 2021), land- and sea-use change, and climate change (Bellard et al. 2016). Rates of introduction are projected to continue to increase (Seebens et al. 2021). Because biological invasions transcend regional and national boundaries, international collaboration, including the co-ordination of responses and the sharing of insights and expertise, is essential for effective mitigation and management (Faulkner et al. 2020b; IPBES 2023a). Nonetheless, the negative impacts of biological invasions are felt and addressed primarily at local levels, whilst control and regulation efforts are typically decided upon by national jurisdictions (García-de-Lomas & Vilà 2015). Biological invasions are also facilitated by, and impact on, a wide range of sectors (IPBES 2023a), including agriculture (Paini et al. 2016) and human health (Mazza et al. 2014), making co-ordination amongst stakeholders essential. Despite these complexities, managing biological invasions has been shown to be amongst the most cost-effective conservation measures available (Langhammer et al. 2024; Roy et al. 2024).

Global policy is increasingly addressing the challenge of biodiversity loss and associated changes in ecosystem services. The fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD) adopted the Kunming-Montreal Global Biodiversity Framework (KM-GBF) in December 2022. The framework resulted from a four-year consultative and negotiation process and includes 23 action-oriented targets for 2030 and four goals for 2050. Target six (6) focuses on biological invasions and calls on parties to the CBD to:

> 'Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent, by 2030, eradicating or controlling invasive alien species especially in priority sites, such as islands.'
>
> (CBD 2023)

In parallel with activities of the CBD, member states of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) requested a thematic assessment report on biological invasions in 2014. The Thematic Assessment Report on Invasive Alien Species and their Control (hereafter the IPBES IAS Assessment) officially started in 2019 with co-chairs, coordinating lead authors, lead authors, fellows, review editors and contributing authors (Schwindt et al. 2024) ensuring inclusive and diverse views and contributions from across the world, including Indigenous Peoples and local communities (Nuñez et al. 2024). The IPBES guidelines for conducting such an assessment highlight the process as an iterative and collective critical evaluation of the state of knowledge by experts across several chapters, agreed upon in the scoping report (IPBES 2018b). The main findings of each chapter are then summarised in policy relevant key messages, incorporating less technical language, with links to the relevant evidence in the chapters. The Summary for Policymakers (SPM) is then reviewed and negotiated by member states before its approval (IPBES 2023a). The IPBES IAS Assessment was accepted and its summary for policy-makers approved during the 2023 IPBES Plenary in Bonn, Germany. The IPBES IAS Assessment was released on 4 September 2023 (IPBES 2023a).

South Africa made a significant contribution to the IPBES IAS Assessment. The 285 experts listed in the assessment came from 59 countries (Schwindt et al. 2024, Supplementary Table S1), 25 of which (close to 10%) included South Africa as one of their affiliations. Only the UK (39), the USA (35), and Australia (28) had more affiliates (Germany also had 25 listed affiliates). South Africa's significant contribution is not surprising – the country has a long history of being affected by and managing biological invasions and is a global leader in research and capacity building on biological invasions (Van Wilgen et al. 2020a).

South Africa also pioneered the production of national level reports on the status of biological invasions (Wilson et al. 2017). As mandated under the National Environmental Management: Biodiversity Act (Act no. 10 of 2004) and its Alien and Invasive Species Regulations [the NEM:BA A&IS Regulations first promulgated in 2014, and most recently updated in 2020 (Wilson & Kumschick 2024)], triennial reports have been produced, titled *The Status of Biological Invasions and their Management in South Africa in [2017, 2019 and 2022]* (Van Wilgen & Wilson 2018; Zengeya & Wilson 2020; 2023), hereafter 'the South African status report'.

Both the IPBES IAS Assessment and the South African status reports collate information from a broad range of sources and are intended to be policy relevant but not policy prescriptive. Both reports underwent two rounds of open public external review, although the IPBES IAS Assessment underwent an additional round of government review and a formal process for governmental approval at the IPBES Plenary. The major differences between the reports are in terms of structure and scope. The South African status reports are framed around a set of 20 indicators that address biological invasions from the perspective of pathways, species, sites and interventions (McGeoch et al. 2016; Wilson et al. 2018), with a concluding chapter on gaps (both knowledge gaps and gaps in what we are doing to address the problem). The IPBES IAS Assessment had chapters on status and trends, drivers, impacts, management and future options, with knowledge gaps identified within each chapter. The IPBES IAS Assessment does not report on indicators per se, nor does it provide recommendations on which indicators to use. In terms of definitions, the IPBES IAS Assessment (while acknowledging the multi-faceted impacts of biological invasions) defined invasive species purely in terms of those taxa which cause negative impacts on biodiversity. This was because the assessment arises from the CBD and the assessment authors were constrained by the IPBES processes and definitions, including a scoping document agreed by IPBES prior to the assessment starting (IPBES 2018a). No such restrictions are placed on the South African status reports; a biogeographic definition of invasions is preferred (Box 1). Finally, the IPBES IAS Assessment was global whereas the South African status reports are national.

In 2023, South Africa adopted a White Paper on 'the Conservation and Sustainable Use of South Africa's Biodiversity' (Department of Forestry, Fisheries and the Environment 2023). The White Paper addresses invasive species through policy objective 1.4: 'Identify and manage harmful, and potentially harmful, invasive alien species, their potential and existing introduction pathways and biological invasions.' This has created a platform for South Africa's policy and regulations on biological invasions to respond to the KM-GBF, and specifically to implement Target 6 of the KM-GBF at a national level. Notably the focus of this White Paper (and the action paper that is being developed to facilitate it) is on the threat to biodiversity. However, South Africa still has a need for a policy and strategy that addresses all aspects of biological invasions, i.e., beyond the

Box 1. Terminology in biological invasions is fraught, but it need not be if terms are clearly defined

The issue of terminology continues to raise passions. Even at the final plenary of the IPBES IAS Assessment (after four years and three rounds of external review) the distinctions between 'alien species', 'invasive alien species' and 'biological invasions' were contested. This issue was resolved during a special lunch-time session (termed 'Friends of the Chair' that was open to all) a day before the assessment was approved. The outcome reflected a compromise. The term 'invasive alien species' was, for the purpose of the assessment, defined as 'A subset of established alien species that spread and have a negative impact on biodiversity, local ecosystems and species'. It was noted that invasive species might also have negative socio-economic impacts, but the stricture that impact must be on biodiversity was the result of IPBES emanating from the CBD. By contrast the South African status report uses the biogeographical definition for 'invasive alien species', i.e., 'alien species that sustain self-replacing populations over several life cycles, produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction, and have the potential to spread over long distances', on the basis that definitions of impact are often subjective. The relevant South African legislation [i.e., the National Environmental Management: Biodiversity Act of 2004 (NEM:BA)] is more in line with the CBD definition, defining 'invasive alien species' as '…species whose establishment and spread outside of its natural distribution range, threaten ecosystems, habitats or other species or have demonstrable potential to threaten ecosystems, habitats or other species…'.

Three important points arose during the IPBES IAS Assessment and South African status report processes. First, definitions should be written out in full even if they are repeated from elsewhere (Latombe et al. 2019). Second, when referring to the process that needs to be managed, the term 'biological invasions' should be used, as the term is explicit in covering all stages (including interventions at- and pre-border) and all aspects (pathways, species and sites). This means that national strategies address the process 'biological invasions' rather than simply 'invasive alien species' (although for consistency with the CBD and Target 6 of the KM-GBF the later term was preferred for the title of South Africa's draft strategy). Third, and in line with the need to think holistically about the issue, attempts to address biological invasions should: a) consider both socio-economic and environmental impacts and threats, e.g. through the One Health (Ogden et al. 2019) and One Biosecurity concepts (Hulme 2020); and b) consider the interaction between invasions and other global change drivers (Hulme 2022).

Somewhat against the first recommendation a glossary is not included here, noting that the IPBES IAS Assessment, the South African status reports, and the NEM:BA use three slightly different definitions for 'invasive alien species'. The exact definitions of the terms should be read in the context of which of the three sources is being discussed.

Links to definitions

IPBES IAS Assessment: https://www.cbd.int/invasive/terms.shtml; https://www.ipbes.net/glossary-definitions.

NEM:BA: https://www.gov.za/documents/national-environmental-management-biodiversity-act-0 and the various version of the A&IS Regulations https://dx.doi.org/10.5281/zenodo.8160209.

South African status report: http://iasreport.sanbi.org.za/.

threat just to biodiversity. This is a key recommendation of the South African status reports (Zengeya & Wilson 2023). Since 2023, relevant government departments have engaged in developing a National Invasive Species Strategy and Action Plan (NISSAP). Given the launch of the IPBES IAS Assessment and the setting of Target 6 of the KM-GBF, it is an opportune time to reflect on what a policy and national strategy for South Africa should include. This paper aims to assist South Africa to meet its various obligations (international commitments, national imperatives and local needs); and aims to serve as a model for other countries and regions seeking to meet KM-GBF targets. This paper tries to specifically address the following:

- How do statements and proposals in the IPBES IAS Assessment resonate in South Africa?
- Is South Africa addressing the issues raised by the IPBES IAS Assessment?
- What should South Africa do to improve responses to biological invasions (particularly in the context of the proposed national strategy)?

Materials and methods

We undertook a qualitative synthesis based on expert review. We argue this approach is appropriate, if only in that it facilitated discussion, and forced us to be clear on our views and to identify assertions that can be resolved based on evidence and data. Insights were gleaned from the South African status reports, published literature and reports, and from the diverse backgrounds and expertise of us as authors. To capture the perspective of those who were directly involved in relevant processes, invitations to contribute were sent to: all those involved as experts in the IPBES IAS Assessment who listed South Africa as an affiliation (Supplementary Table S1); members of the South African delegation to the tenth session of the IPBES Plenary at which the IPBES IAS Assessment was approved; the chapter lead authors of the latest version of the South African status report (Zengeya & Wilson 2023); and the task team responsible for drafting South Africa's national strategy on biological invasions.

Focussing primarily on the Summary for Policymakers (IPBES 2023a) of the IPBES IAS Assessment (IPBES 2023b), we identified four key elements relevant to South Africa:

- The 22 key messages in the Summary for Policymakers (p. 12–17 of the IPBES IAS Assessment's SPM; see Table 2 and Supplementary Table S2 for the results).
- The six identified management objectives, and eleven management actions (Table SPM.1 in the IPBES IAS Assessment; see Supplementary Table S3 for the results).
- The seven strategic actions, four properties of governance systems that support integration, and the twelve options for strengthening governance (Figure SPM.7 and Table SPM.2 in the IPBES IAS Assessment; see Table 3 for the results).
- The synthesis of knowledge and data gaps (Appendix 2 and Table SPMA.1 in the IPBES IAS Assessment; see Supplementary Table S4 for the results).

In each case we evaluated how these elements resonate for South Africa using a semi-quantitative scale developed for this purpose (Table 1A). Each evaluation was also ascribed one of four levels of confidence as per the IPBES guidelines (IPBES 2018b) (Table 1B).

Throughout the process, we identified recommendations for South Africa's draft national strategy. As noted in the most recent South African status report, the issue of biological invasions on mainland South Africa is significantly different from that on South Africa's sub-Antarctic islands (the Prince Edward Islands, cf. Box 2), with different stakeholders involved. Therefore, we decided to evaluate the Prince Edward Islands separately and plan to conduct a similar exercise at a later stage.

A draft outline was circulated to a core group (those directly involved in the South African status report or leading the draft national strategy) for discussion (January–February 2024). This led to the focus on the five key elements of the IPBES IAS Assessment listed above and how they should be scored. From here, all five elements were shared online with a request for input (March–April 2024). Of the 71 people invited, 36 indicated that they wished to be involved further. Sections of the document were also discussed in person as part of a two-day workshop on drafting the national strategy (March 2024). A further round of online commenting was held (April–May 2024), complemented by four online sessions where each of the five key elements were discussed and edited in plenary (each session was ~ 3 hours with between 11 and 24 participants). Based on these discussions and the emerging insights, a draft of the full manuscript was compiled and posted online for comments and input, with specific tasks allocated (May–June 2024). An online session was held to identify the actions needed to fill in gaps. The manuscript was then completed, circulated for comment in sequence (June–August 2024), with a final version made available for approval by authors (August 2024). To provide a comparison and a less directly biased overview, we invited two Brazilian experts on biological invasions and their management and regulation in the Americas (one of whom acted as a review editor for the IPBES IAS Assessment and the other was a contributing author to the IPBES IAS Assessment, both of whom were on sabbatical in South Africa at the time) to review the draft and provide an external perspective (Box 3).

Table 1. How statements and proposals in the IPBES IAS Assessment were scored in terms of whether they resonate for South Africa

A) A semi-quantitative scale was developed. We did not use a specific elicitation exercise or workshop, but rather discussed responses iteratively. The authors were encouraged to express differences of opinion and provide supporting evidence.

B) The level of confidence was assigned to the degree of resonance as per IPBES guidelines (IPBES 2018b). The level of confidence was based on the views of us as authors and how we perceive the views of other stakeholders in South Africa. For example, if we felt a statement in the IPBES IAS Assessment perfectly captured the situation in South Africa, but the data in support of such an assertion was largely lacking (e.g., there were only a few case studies), the scoring would be 'Completely agree' with a confidence of 'Established but incomplete'.

Table 1A.

Degree of resonance	Description
Completely agree	The experience in South Africa is the same as that outlined in the IPBES IAS Assessment
Largely agree	The experience in South Africa is the same as that outlined in the assessment with a few exceptions (fewer than a quarter of cases)
Somewhat similar	The experience in South Africa is, in many situations, the same as that outlined in the assessment, but there are also many exceptions (in the range a quarter to three-quarters of situations)
Different	The large majority of situations in South Africa are different to that outlined or suggested in the assessment
Not applicable	The topic is not relevant to South Africa

Table 1B.

Level of confidence in the scoring of the degree of resonance	Description
Well established	The quality and quantity of evidence is robust and there is a high level of agreement
Established but incomplete	The quality and quantity of evidence is low, but there is a high level of agreement
Unresolved	The quality and quantity of evidence is high, but there is a low level of agreement
Inconclusive	The quality and quantity of evidence is low and there is a low level of agreement
Not applicable	There is no resonance with which to be confident about

Results

The key messages

Most of the 22 key messages of the IPBES IAS Assessment resonated strongly with what we perceive the situation in South Africa to be – 14 were scored as 'completely agree', five as 'largely agree', two were 'somewhat similar', and one was 'different' (Table 2). The differences from the global assessment are that: 1) South Africa has shown significant progress with managing and regulating biological invasions (e.g., Wilson & Kumschick 2024) (cf. key message A5); 2) the available evidence does not suggest that rates of introduction have increased drastically over the past few decades (Faulkner 2023) (cf. key message B2); and 3) there are few examples of successful nationwide eradications to date (Davies et al. 2020b; Wilson et al. 2013) (cf. key message C3). Despite a system in place to regularly report on biological invasions in the country (Zengeya & Wilson 2023) and a recent comprehensive academic review (Van Wilgen et al. 2020a), the evidence base was scored as low in many cases (6 key messages scored as 'inconclusive'; 11 as 'established but incomplete'; only 5 as 'well established'). Notably, no key messages were scored as 'unresolved'. We feel that there is, with a few exceptions (Zengeya et al. 2017), general agreement among all stakeholders on the need for interventions in situations where the quality and quantity of evidence of impacts or threats is high.

Managing biological invasions

There were more differences between how we scored the objectives and actions for managing biological invasions in South Africa and how these were scored in the IPBES IAS Assessment (Table S3):

1. While prevention efforts have improved recently with the integration of biosecurity functions at ports of entry into the Border Management Authority, South Africa's geographical position means that prevention is inherently more challenging than on islands or for countries with borders that are fewer, shorter or that align with major biogeographical breaks (e.g., mountain ranges). South Africa has a substantial land border (4 862 km) that it shares with six other nations (Faulkner et al. 2017).
2. Physical methods of control were scored as being relatively ineffective in the IPBES IAS Assessment but are routinely and sometimes effectively used in South Africa (Van Wilgen et al. 2023a). Much of the physical control in South Africa might be considered

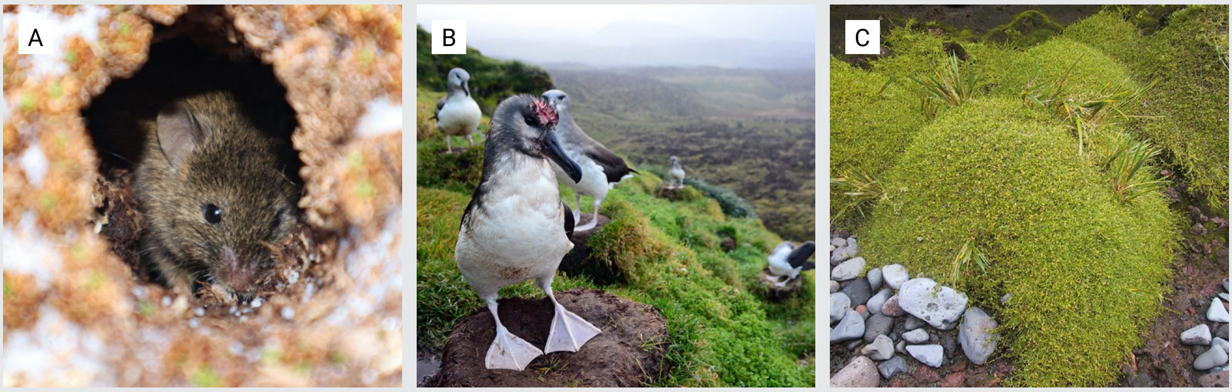
Box 2. South African islands and invasions

Islands are particularly threatened by biological invasions. The IPBES IAS Assessment states: 'On islands, invasive alien species are a major cause of biodiversity loss' (background message A3) and 'Eradication has been successful and cost effective for some invasive alien species, especially when their populations are small and slow-spreading in isolated ecosystems such as islands' (background message C19). South Africa has few inshore and freshwater islands but possesses two sub-Antarctic islands (Prince Edward Island and Marion Island, collectively called the Prince Edward Islands or PEIs).

The PEIs were declared a Special Nature Reserve in 1995 (De Villiers & Cooper 2008). Tourism is prohibited, with the PEIs set aside for conservation and science. Nonetheless alien species have been, and continue to be, introduced, albeit all invasive species were introduced before 1995, after which strict biosecurity measures were introduced (Department of Environmental Affairs 2010). The PEIs have only one regular access point – a government-owned research vessel transports people, food and cargo to and from the island once a year (Greve et al. 2017). About 80 people at a time can stay on Marion Island, and Prince Edward is visited no more than once every four years by a maximum of 10 people (Department of Environmental Affairs 2010) [by comparison there were > 3 million international arrivals at South African airports in 2022 (Faulkner 2023)]. The intentional introduction of taxa to the PEIs, as well as the importation of fresh produce, is prohibited. Clothes and cargo are checked for propagules prior to and upon landing at the islands. The pathways for the introduction of alien species are therefore very limited [there are only ten potentially active pathways], and most pathways are effectively managed. However, despite clear biosecurity guidelines and enforcement, introductions continue, highlighting that more can still be done. For example, systematically recording all detections and identifying them to species level could assist with pinpointing breaches in biosecurity (Fernández Winzer et al. 2025).

Approximately 45 alien species are currently present on the PEIs, with 25 considered invasive. These include invertebrates, plants, a mammal and a fungus, with no alien birds, reptiles, amphibians or marine taxa detected to date (Greve et al. 2020). The house mouse (*Mus musculus*) causes the most detrimental impacts (Box 2 Figure 1) (Greve et al. 2017), and an eradication plan is being developed (https://mousefreemarion.org/). Feral cats have already been eradicated from Marion Island (Bester et al. 2002). Thirteen species are regulated and require management on the PEIs; however, not all are being managed, and some unregulated species are being controlled. Close communication and collaboration among researchers and managers will likely do much to assist such control efforts.

Given how distinct the issue of biological invasions is on the PEIs when compared to the rest of South Africa, it is recommended that regulation and management be tailored to the specific needs of the PEIs (Fernández Winzer et al. 2023; Wilson & Kumschick 2024). This should perhaps be reflected as a separate subgoal or discrete set of actions in the national strategy, with most day-to-day decisions informed by the PEIs Management Plan itself. See Fernández Winzer et al. (2025) for a recent review of invasions on the islands, including most of the information herein.



Box 2 Figure 1. Two invasive species with harmful impacts on the Prince Edward Islands: A, the house mouse (*Mus musculus*) has caused a 'Massive' impact, damaging native flora like this *Azorella selago* cushion (into which the mouse has burrowed), and preying upon invertebrates and birdlife, like this Grey-headed Albatross (B). Birds on these islands did not evolve with predators and do not defend themselves when attacked; C, the invasive plant *Sagina procumbens* (light green) dominates some areas of Marion Island, in this case overgrowing the native grass *Polypogon magellanicus*. Photographs: A, Stefan Schoombie; B, Ben Dilley; C, Peter le Roux.

Box 3. South Africa as a model for invasive species management and governance –perspectives from Brazilian experts on biological invasions

South Africa has been a reference for Brazilian researchers, practitioners and policymakers in terms of relevant scientific production, construction and implementation of public policies, and management of invasive species. Although Brazil and South Africa have similarities in some aspects of historical colonisation and exploitation, past and current socioeconomic problems and environmental conditions; the success of South Africa in addressing biological invasions is likely due to different factors, with one that stands out. In simple terms, it seems that the 'knowing-doing' gap is less in South Africa than in Brazil.

In South Africa, cooperative programmes in the 1970s and 80s brought together academics, government officials, researchers and managers (Huntley 1987); these were expanded upon by long-term programmes established by the democratic government in the late 1990s onwards, such as Working for Water, Working for Wetlands and Working on Fire. The connection between the urgent need of management of biological invasions for the availability of natural resources that are fundamental for human well-being was crucial for the understanding of the threats posed by invasive species to nature and human livelihoods. Those programmes also provided vast environmental and social benefits, including the clearing of thousands of hectares invaded by alien trees based on the creation of jobs for disadvantaged people (Van Wilgen & Wannenburgh 2016) and poverty alleviation. Therefore, public awareness about invasive species and the engagement of South African citizens in management activities (e.g., volunteer groups) is more prominent than in other countries, especially in the Fynbos Biome in the Western Cape (Jubase et al. 2021).

The Brazil Ministry of Environment published the second National Invasive Alien Species Strategy in 2018, the result of collaborative construction by governmental, research and civil society organisations. However, no central coordination has been established, so despite the willingness of many to contribute, only a few agenda items have moved forward with funding from a Global Environmental Facility project targeting the conservation of endangered species. A national list was compiled but is not officially published; the layout of an early detection, rapid response programme was conceived, but not implemented; and other valuable information was made available by the government, but there is no work towards the fulfilment of the Kunming-Montreal Global Biodiversity Framework (KM-GBF). A few of the 26 Brazilian states have advanced with the publication of official lists, regulations and management, though mostly only for protected areas. Restrictions on the use of herbicides to control invasive species hinders the efficiency of work done in natural areas, while there is great need for the use of additional techniques such as biological control, so far only developed for agriculture, and the use of aerial spraying from helicopters for areas of high risk to people. Brazil has committed to restore 12 million hectares of land by 2030, but restoration initiatives cannot make progress due to the difficulty in managing invasive African grasses without proper chemical control. Therefore, South Africa provides important learning opportunities for Brazil, and much of the work in progress can be quite inspirational in terms of proving that it is possible to achieve significant results for biodiversity and human well-being. Also, the collaboration between scientists and policymakers is unique and remarkable, a key factor for the prevention of new introductions and to mitigate negative impacts by invasive species, as set in Target 6 of the KM-GBF. For a recent assessment of biological invasions in Brazil see Dechoum et al. (2024); and for a call for more collaboration between the countries on biological invasions see Measey et al. (2019).

'integrated' control by others (e.g., cut-stump herbicides are often used when clearing invasive trees to prevent resprouting), but labour costs are often lower, and there are some long-term and well-established initiatives in place to address multiple socio-economic objectives, e.g., the Working for Water Programme (Van Wilgen et al. 1998; Van Wilgen et al. 2022a).

3. Possibly for some of the same reasons that physical control is relatively successful, we scored ecosystem restoration as easier in South Africa than globally (Table S3).
4. Finally, and perhaps most noticeably, there is a great deal of uncertainty in South Africa in terms of the effectiveness of most interventions. Efficacy is rarely measured. Without a feedback loop between the outcomes of interventions and decision-makers, adaptive management is not possible, and the goal of reducing biological invasions might not be met. The exception to this is that biological control interventions are often well researched, understood and highly effective.

Strategies and governance

In terms of strategies and governance, we strongly concur with a key conclusion of the IPBES IAS Assessment (key message D) – integrated governance should be improved at all levels (Table 3). Greater collaboration and coordination is needed: with neighbouring countries, across disciplines, among and between local, provincial and national government departments, and with various stakeholder groups. The recent establishment of South Africa's Border Management Authority that integrates biosecurity for animals, plants, the environment and humans with the regulation of the movement of people at ports of entry under a single command, is a notable step forward in this regard.

Whilst it will be difficult to achieve, greater flexibility is needed to ensure that management decisions are made at the most appropriate level and that proactive interventions are incentivised. A focused long-term approach that empowers relevant institutions to implement the measures necessary for the control and management of biological invasions would ensure critical decisions can be made timeously. It would also ensure interventions can adapt to changing threats and respond to successes and failures. This would require flexibility in decision-making. At the same time, much of what South Africa is doing needs to be systematised, i.e., interventions and analyses should be repeatable, and progress and successes should be tracked and shared. Monitoring of outcomes in terms of the status of invasions and feedback loops are needed to ensure that management can respond to what is happening on the ground (Ntshotsho et al. 2015). Several specific initiatives have been proposed to improve integrated governance including: stakeholder mapping, a legal review and meetings and fora to increase collaboration between all stakeholders as part of an active community of practice; with some collaborative governance programmes having been initiated (e.g., Angelstam et al. 2017; Canavan et al. 2021; Foxcroft & McGeoch 2011; Ivey et al. 2024). We also need to consider integrated governance from the perspective of the regulated community and how to leverage support (e.g., through integrated corporate governance, companies could reflect their contributions towards prevention and management of biological invasions).

Gaps

We found it generally difficult to apply the scoring used in the IPBES IAS Assessment to evaluate how addressing a gap would improve management and understanding (Table S4). Some gaps at a global level (e.g., comparatively incomplete inventories of invasive alien species in Africa and Central Asia) were not as applicable to South Africa (South Africa has relatively good inventories when compared with many countries around the world). Many of the identified actions to fill gaps (e.g., the need for systems to track the effectiveness of interventions) have already been identified as part of the South African status reports (e.g., Wilson et al. 2023) and are under consideration in the draft national strategy. There also appears to be a need to integrate global and national needs. Nonetheless, the process helped us develop some specific actions that should be considered (e.g., the need to support general surveys of alien invertebrates and microorganisms, the need to promote transdisciplinary work and draw more on integrative social-ecological systems thinking and the need for actions to improve participation of communities in decision-making). Finally, there are a range of valuable South African specific databases and knowledge products (e.g., on research, policy, compliance and enforcement and management best practice). Consolidating such information so it is findable, accessible, inter-operable and reusable (i.e., FAIR; Wilkinson et al. 2016) as well as better co-ordination between the various organisations that collect and curate data will be essential if governance is to be integrated (Table 3).

Discussion

South Africa is a significant contributor to global knowledge and policy on biological invasions (Pinto et al. 2022; Van Wilgen et al. 2020a) and many authors affiliated to South Africa were involved in the IPBES IAS Assessment (Table S1). As such, it is not surprising that, in our opinion, much of the IPBES IAS Assessment resonated strongly with South African issues and priorities. Going through the exercise of comparing the IPBES IAS Assessment with the situation in South Africa provided a useful cross-check for developing South Africa's national strategy and action plan. It also: served to strengthen our view that certain actions are key to improving how biological invasions are understood and addressed (through integrated governance in particular); highlighted where South Africa differs from other countries (Box 3); and helped us identify actions that need to be prioritised (e.g., continued funding for biological control and research across different taxa and realms, and a move towards more adaptive management). We discuss these below.

Invasive trees, invasive freshwater fishes and a substantially modified coastline

In South Africa, invasive trees (Richardson et al. 2020b) and invasive freshwater fishes (Weyl et al. 2020) are particularly problematic and rocky parts of the western and southern coastlines have been substantially modified by marine invasive species (Robinson et al. 2020; Figure 1, 2). Relative to elsewhere in the world, South Africa (especially the mainland) is much less affected by invasive vertebrates (Measey et al. 2020), and no offshore marine invaders have been recorded to date (Zengeya & Wilson 2023). There are also relatively few examples of highly damaging terrestrial arthropod invasions (Janion-Scheepers & Griffiths 2020) and plant pathogens, although the recent invasion of the polyphagous shot-hole borer (*Euwallacea fornicatus*) along with its fungal symbiont *Fusarium*

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation

The key messages are taken verbatim from the IPBES IAS Assessment (IPBES 2023a). The resonance for South Africa (RSA) was evaluated as per Table 1, combining both our evaluation of the degree of resonance and our confidence in that evaluation. The focus is on mainland South Africa and the immediate offshore environment (including islands); cf. Box 2. The corresponding paragraphs for each key message in the IPBES IAS Assessment are further broken down in Table S2.

Key message	Resonance for RSA	Rationale	RSA references
A1. People and nature are threatened by invasive alien species in all regions of Earth	Largely agree (established but incomplete)	While the key message is appropriate at a global scale, as in other regions in the world, at local scales in South Africa there are sites where there are few, if any, invasions. Most remote sites are not heavily invaded, and no invasive off-shore marine taxa have been recorded to date (although such sites are not well sampled).	Zengeya et al. (2023a)
A2. Invasive alien species cause dramatic and, in some cases, irreversible changes to biodiversity and ecosystems, resulting in adverse and complex outcomes across all regions of Earth, including local and global species extinctions	Largely agree (established but incomplete)	Significant changes to ecosystem functions caused by invasive species have been observed in many parts of South Africa. The evidence of impacts on extinctions are less clear, although invasive species have been implicated in the extinction of seven plant species and some population extirpations have been recorded. Observed impacts are of greater magnitude in some environments than others.	Skowno et al. (2019); Van der Colff et al. (2023); Van Wilgen et al. (2022b)
A3. The economy, food security, water security and human health are profoundly and negatively affected by invasive alien species	Completely agree (established but incomplete)	Economy: the monetary cost of the damage caused has been estimated at ZAR 52.7 billion between 1960 and 2023 (in 2022 values). Food security: there are substantial negative impacts on agriculture through imported pests and diseases (though not systematically estimated). An estimate of the negative impacts on rangeland and grazing activities at the scale of South Africa has been made. Water security: invasive plants have caused substantial reductions in water flows with important consequences. For example, it was estimated that if there had been no invasive trees in the water catchment of the City of Cape Town, day zero during the 2015–2018 drought would have been delayed by 60 days. Human health: biological invasions have various negative impacts on human health, but information has not been well consolidated to date. More research is needed. Fire: there has been a notable increase in fire intensity caused by invasive plants. Tree invasions have often exacerbated recent fires (e.g., the devastating fire in 2017 in the Garden Route). Note: This key message is not intended to downplay the positive impacts that can accrue from invasive species – it is important to consider positive and negative impacts separately before they are compared.	De Wit et al. (2001); Kraaij et al. (2018); Le Maitre et al. (2016); Le Maitre & Gorgens (2003); McCulloch-Jones et al. (2024); O'Connor & Van Wilgen (2020); Wise et al. (2012)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
A4. Invasive alien species can add to marginalisation and inequity, including, in some contexts, gender- and age-differentiated impacts	Completely agree (inconclusive)	The impact on rural communities has been explicitly evaluated in some studies with indications that it can have significant negative impacts. But gender- and age-differentiated impacts have rarely been assessed. Rural communities often adapt to invasions or co-opt invasive species (e.g., for firewood and the medicinal trade). Such adaptation would likely reduce marginalisation, but the overall impact is not known, and so the confidence level is scored as inconclusive. More research is needed.	Ngorima & Shackleton (2019); Ruwanza & Thondhlana (2022); Yessoufou et al. (2021, 2022)
A5. Overall, policies and their implementation have been insufficient in managing biological invasions and preventing and controlling invasive alien species	Somewhat similar (established but incomplete)	South African regulations addressing biological invasions date back to 1861. Comprehensive regulations were promulgated in 2014 and revised in 2016 and 2020. They are being implemented although more evaluations of their effectiveness are needed. The quality of the regulatory framework was scored as 'partially adequate' by the South African status report. The 'Conservation and Sustainable Use of South Africa's Biodiversity' White Paper addresses part of the issue of biological invasions, though impacts on agriculture and health are not part of its remit. A strategy for implementing the regulations is being developed. The resources for effective implementation or ensuring compliance are inadequate. Overall, there is a need for better integration of policies (e.g., those on animal pests and diseases with those on biological invasions), noting the current lack of an overarching policy.	Lukey & Hall (2020); Van Wilgen et al. (2022a, 2023a), Wilson & Kumschick (2024)
B1. Many human activities facilitate the transport, introduction, establishment and spread of invasive alien species	Completely agree (well established)	This has been and is still true for South Africa.	Faulkner et al. (2016), Faulkner (2023)
B2. The threats from invasive alien species are increasing markedly in all regions of Earth, with the current unparalleled high rate of introductions predicted to rise even higher in the future	Different (inconclusive)	In South Africa, pathways, particularly those relating to intentional introductions, are much better regulated than in the past and arguably than in other countries. There have not been dramatic recent increases compared to historical introductions for many pathways (e.g., trees for forestry and freshwater fishes for angling); though information on unintentional introductions and illegal deliberate introductions is not available and will be difficult to obtain. Without better estimates of search effort, it is difficult to be confident in estimates of introduction rates (hence scored as inconclusive). The data that are available suggest similar rates over the past few decades. There has been a long history of introductions to the country resulting in invasions. This arguably has led to relatively high levels of awareness and appreciation of invasions in policy and industry sectors; and many potential invaders have already been introduced.	Faulkner (2023)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
B3. The ongoing amplification of drivers of change in nature may substantially increase the number of invasive alien species and their impacts in the future	Completely agree (inconclusive)	Expect similar mechanisms will operate in South Africa, though there is a very high level of uncertainty and some drivers are likely to be much more important in (or even unique to) the African context.	Van Wilgen et al. (2023b)
B4. The magnitude of the future threat from invasive alien species is difficult to predict because of complex interactions and feedback among direct and indirect drivers of change in nature	Completely agree (inconclusive)	Expect similar complexities, particularly given the diversity of environmental, socio-economic and climatic conditions seen in South Africa; and uncertainty particularly around future rainfall. There have been few explicit studies though. Estimates of invasion debt have shown the potential for problems.	Rouget et al. (2016); Shackleton et al. (2020); Van Wilgen et al. (2020a, 2020); Wilson et al. (2020)
C1. The number and impacts of invasive alien species can be reduced through management of biological invasions	Largely agree (established but incomplete)	South Africa has management structures in place across the different stages of invasion. However, the funding does not match the scale of the problem, and thus it has not been possible to get on top of all invasions. There is evidence that: invasions can be controlled at local scales; impacts have been reduced through classical biological control for some species; water flows have been improved by removing pines, wattles and eucalypts; and there is an increasing understanding of the negative impacts. However, for most invasive species and invaded sites, invasions continue to grow. Saying that, some impacts might be difficult or impossible to reduce even with management, and often the effectiveness of management is not measured in terms of impact reduction, so data are not available in many cases.	Coetzee et al. (2021); Henderson & Wilson (2017); Hill et al. (2020); Le Maitre et al. (2020); Paterson et al. (2021); Van Wilgen et al. (2022a, 2022b)
C2. Prevention and preparedness are the most cost-effective options and thus crucial for managing the threats from invasive alien species	Largely agree (established but incomplete)	With significant land borders, South Africa relies on biosecurity of neighbouring countries. In some cases, it will be very difficult to prevent accidental introductions (or natural spread) without severely affecting trade. In this sense prevention is not always feasible (and so not cost effective). An assessment of the returns of investment of funding prevention and preparedness for South Africa would be very useful. Inspections are occurring at the border; however, there is insufficient staff capacity to cover all goods and modes of transport. Efforts are being made to improve this through risk-based inspections at ports of entry. Furthermore, efforts are being made to manage pathways such as the breakbulk cargo. Efforts have been made to develop a national watchlist, though a formal watchlist has not been adopted to date. No approved contingency plans for environmental threats are available. Deliberate legal introductions are being addressed. All new imports require a formal application supported by a risk analysis.	Faulkner et al. (2017); Faulkner (2023); Kumschick et al. (2020); Wilson et al. (2013)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
		Plant pests are regulated in terms of the Agricultural Pests Act no. 36 of 1983 and Control Measures R.110 of 27 January 1984, with the aim of providing for measures by which agricultural pests may be prevented and combated; and for matters connected therewith. The South African Emergency Plant Pest Response Plan (SAEPPRP) provides guidelines for an efficient and timely reaction to the identification, mitigation and detection of an emergency plant pest incursion in South Africa. During a plant pest emergency, this protects and maintains production and business continuity in unaffected areas, prevents the establishment and spread before the pest population becomes established, and facilitates efficient and timely communication between local, national and international government agencies, academia and professionals in the plant industry. Given the massive volumes of data generated, pest detection techniques are critical to pest early warning systems. The implementation of awareness campaign programmes is essential for detection of incursions and for securing community members' and role actors' cooperation during pest control efforts.	
C3. Eradication has been successful, especially for small and slow-spreading populations of invasive alien species in isolated ecosystems	Somewhat similar (well established)	There has been only one documented nationwide eradication on the mainland [that of the Mediterranean snail (*Otala punctata*) in 1989] though several attempts are ongoing. Nationwide coordinated efforts were initiated in 2008 and there are currently around 42 eradication attempts. Numerous eradication targets have been brought down to 'low levels' some of which may already have been eradicated (e.g., *Sporobolus alterniflorus*) and the extirpation of some populations has been declared for various sites. However, protocols to formally declare eradication have not yet been established. Given variations in life histories we suspect some widespread conspicuous invaders will be easier to eradicate than small populations of other invaders. Various taxa have been eradicated (or at least extirpated) from in-shore islands (e.g., rabbits from Robben Island).	Davies et al. (2020b); Herbert & Sirgel (2001); Riddin et al. (2016); Wilson et al. (2013)
C4. Containment and control can be an effective option for invasive alien species that cannot be eradicated for various reasons from terrestrial and closed water systems, but most attempts in marine and connected water systems have been largely ineffective	Largely agree (established but incomplete)	In contrast to the IPBES statement there have been some notable successes with classical biological control containing and controlling invasive aquatic species in connected water systems. There have been some successes in extirpating invasive fishes in discrete catchment sections. There has been no successful management of invasive species in marine ecosystems. Various techniques have been used to manage agricultural insect pests. Sterile Insect Technique (SIT) is mostly used, establishing areas of low pest prevalence (ALPP) or pest-free areas (PFA). This requires effective communication, coordination and active participation from the farmers and stakeholders in the target area. In South Africa, FruitFly Africa (FFA) is an SIT company that works in collaboration with stakeholders such as HORTGRO (pome- and stone-fruit), Canning Fruit Producers Association, Raisins SA, South African Table Grape Industry, Agricultural Research Council and the Department of Agriculture (DoA).	Davies et al. (2020b); Hill & Coetzee (2017)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
C5. The recovery of ecosystem functions and nature's contributions to people can be achieved through adaptive management, including ecosystem restoration in terrestrial and closed water systems	Completely agree (established but incomplete)	There have been a few notable cases of successful restoration following clearing of extensive stands of invasive plants. However, projects to clear invasive plants typically do not include dedicated ecosystem restoration – systems are left to restore passively. For some invasions this seems to be sufficient and systems show significant recovery even after long periods of invasions (e.g., pine invasions). In other cases, abiotic thresholds have been crossed requiring active restoration (e.g., wattle invasions). The success of restoration thus depends on the context, including the nature of the invasions and the timing and type of interventions. Investments in ecosystem restoration have increased over time. However, barriers to restoration remain unaddressed in many instances (including re-invasion, secondary invasions and soil legacy effects). There is a need to scale-up restoration efforts with investments made to match the problem. Restoration projects could also do more to align with international standards and guidelines and best practice. Tracking of progress through monitoring is essential and national reporting should be emphasised and streamlined.	Holmes et al. (2020); Nsikani et al. (2018)
C6. Engagement and collaboration with stakeholders and Indigenous Peoples and local communities improve outcomes of management actions for biological invasions	Completely agree (inconclusive)	There is a broad consensus that engagement is crucial for management to be effective. However, as few studies have explicitly evaluated the impact of such engagements in South Africa, the evidence is weak. Sometimes communities have adapted, and invasive species have become important commodities (e.g., fruits of cacti) and part of the local culture. Attempting to shift such practices would require an offer of alternatives but is not always practical or desirable. It is important to identify situations where invasive species can be a (net) benefit if managed (i.e., invasives are well contained in agricultural areas and controlled effectively outside designated growing areas). Similarly, it is important to identify when and where conflicts are likely (e.g., if benefits cannot be preserved without undue threat to the broader environment).	Shackleton et al. (2007, 2011); Zengeya et al. (2017)
D1. Through a complementary set of strategic actions, integrated governance can limit the global problem of invasive alien species throughout the biological invasion process and at local, national and regional scales	Completely agree (established but incomplete)	There have been few specific analyses of the importance of governance or the value of integrated governance in South Africa, although we as authors were unanimous that a lack of co-ordination limits the effectiveness with which biological invasions are managed. The Border Management Authority is a potential example of integrated governance (in this case co-ordinating preventative actions at ports of entry). The BMA was established in 2020 and became operational in 2023, and so monitoring of progress is needed to confirm its value. There are some other examples of integration (e.g., intergovernmental meetings on biocontrol releases and the Risk Analysis Review Committee) but the impact of these has not been evaluated and in most cases different organisations have different mandates. South Africa does not yet have a formally adopted strategy, but one is in development. This will help to formalise what is happening and to assist with co-ordination. There are also regional initiatives through the Southern African Development Community (SADC). The White Paper on Biodiversity includes biological invasions, but there is no overarching policy (i.e., guidelines or principles that guide decision-making) specifically on biological invasions. Such a policy would help move integrated governance forward.	Van Wilgen et al. (2023a); Wilson & Kumschick (2024)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
D2. The threat of invasive alien species could be reduced with closer collaboration and coordination across sectors and countries to support the management of biological invasions	Completely agree (well established)	Closer coordination across countries is particularly important for South Africa as it shares a 4 862 km long land border with six countries (Botswana 1 840 km, Lesotho 909 km, Mozambique 491 km, Namibia 967 km, Eswatini 430 km, Zimbabwe 225 km), with 71 official ports of entry. There are sector specific co-ordination actions in some cases, such as the forestry industry (Forest Invasive Species Network for Africa) and citrus industry. However, roles and responsibilities are not always clear. The control of biological invasions relies on other sectors for whom invasions are seen as a minor issue (e.g., the Departments of Health and Transport). Cross-cutting approaches offer promise (e.g., One Biosecurity and One Health) but are not widely implemented yet. International co-ordination is outlined in various multilateral agreements (e.g., the International Plant Protection Convention and World Trade Organization Agreements) but co-ordination at the national level is less clear. Collaboration with private landowners is key as biological invasions occur on public and private land. There is a need to provide guidance on best practice to achieve this. There is also a need to harmonise regulations (e.g., the issuing of permits under the Agricultural Pest Act and the NEM:BA A&IS Regulations).	Faulkner et al. (2017, 2020b); Faulkner (2023)
D3. The Kunming-Montreal Global Biodiversity Framework provides an opportunity for national governments to develop or update aspirational, ambitious and realistic approaches to prevent and control invasive alien species	Completely agree (inconclusive)	The Kunming-Montreal Global Biodiversity Framework (KM-GBF) is influencing the development of the national strategy and how the South African status reports are structured. The KM-GBF also forms the basis for setting up local, national and regional targets. There is an important opportunity for funding via the Global Biodiversity Framework Fund specifically on biological invasions, this would be useful to stimulate greater subregional collaboration.	Zengeya & Wilson (2023)
D4. Preventing and controlling invasive alien species can strengthen the effectiveness of policies designed to respond to other threats to biodiversity and contribute to achieving several Sustainable Development Goals	Completely agree (established but incomplete)	The interaction between biological invasions and other drivers of change (such as climate change) are well recognised in South Africa. Strategic interventions that tackle biological invasions are occurring through projects following the principle of Ecosystem-based Disaster Risk Reduction (Eco-DRR). These projects are designed to help communities to adapt to the impacts of climate change (e.g., drought, fire and floods) and sustain human livelihoods (including through policy development and the involvement of the private sector).	Graziosi et al. (2020); Paini et al. (2016); Sileshi et al. (2019)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
		Achieving Sustainable Development Goals requires coordination of relevant pieces of legislation in South Africa when responding to invasive species [e.g., including the Agricultural Pests Act, 1983 (Act no. 36 of 1983) and its associated regulations, namely, Control Measures R.110 of 27 January 1984 as amended, Regulations R.111 of 27 January 1984 as amended, Government Notice R.1013 of 26 May 1989 as amended]. The Agricultural Pests Act mandates the National Plant Protection Organisation of South Africa to regulate plants, plant products and other regulated articles when imported into South Africa. The Fertilizers, Farm Feeds, Agricultural Remedies, and Stock Remedies Act of 1947 (Act no. 36 of 1947) governs the registration of pest control operators, sterilising facilities, agricultural remedies, farm feeds and stock remedies. The importation, sale, purchase, disposal and use of farm feeds, fertilisers, agricultural and stock remedies are all governed by this Act. Additionally, it allows for pest registration in emergencies such as detection of new pests or diseases.	
D5. Open and interoperable information systems will improve the coordination and effectiveness of the management of biological invasions, within and across countries	Completely agree (well established)	There are multiple organisations in South Africa that work across different mandates and collect different types of data. Initiatives are in place to develop interoperable and open information systems (e.g., a list of alien species linked to the South African status reports). We still need data pipelines and workflows to go from observation to action. Many records on alien species in the country have been digitised, but more still needs to be done. The South African status report has started working on several of these, e.g., permits issued and information on regulated alien species are available. Notable information systems include the Southern African Plant Invaders Atlas (SAPIA) and the government's Water Information Management System (WIMS). SAPIA was valuable for a wide range of stakeholders who were interested in managing invasive plants, but information was held in a proprietary format and not readily accessible. Increasingly iNaturalist is providing similar functions. WIMS provides valuable information on management actions, but the information can be very hard for external people to use (i.e., lacking in interoperability).	Kraaij et al. (2017); MacFadyen et al. (2022); McConnachie et al. (2012); Van Wilgen et al. (2023a), Wilson (2024); Wilson & Kumschick (2024); Zengeya et al. (2023b)
D6. Public awareness, commitment and engagement, and capacity building, are crucial for the prevention and control of invasive alien species	Completely agree (established but incomplete for public awareness; well-established capacity building)	Public awareness, commitment and engagement: there are lots of initiatives (e.g., through the Working for Water programme, Weed Buster Week) but these are not systematically monitored so it is difficult to judge their effectiveness. The awareness of some key sectors (nurseries) has been shown in some instances to be low, and in other sectors (pet trade) where there is awareness, there is disagreement with management. If activities are linked more closely to outcomes, the efficacy of interventions will likely improve.	Byrne et al. (2020); Davies et al. (2020a); Jubase et al. (2021); Novoa et al. (2017); Potgieter et al. (2024); Shivambu et al. (2022); Weaver et al. (2021)

Table 2. The 22 key messages from the IPBES IAS Assessment and how the authors felt they resonate with the South African situation* (continued)

Key message	Resonance for RSA	Rationale	RSA references
		The National Invasive Alien Species Awareness & Advocacy Support Project developed a toolkit that can be built upon. iNaturalist has facilitated and engaged people to help monitor biological invasions in the country. Hack groups have assisted with in-field control, these are very active groups often locally based and run (e.g., 'Friends of …' groups and Botanical Societies). The work is not always well co-ordinated, and data could potentially be productively shared and activities tracked. However, a careful balance must be struck between bureaucracy and motivating volunteers. Capacity-building: student projects can assist with detecting and managing biological invasions. Biological invasions are included in the school curriculum and various outreach initiatives have been set up.	
D7. There is compelling evidence for immediate and sustained action to manage biological invasions and mitigate the negative impacts of invasive alien species	Completely agree (well established)	South Africa has well over a century of experience of the impacts of biological invasions, of research into understanding them, and of using various management techniques to alleviate the impacts. The challenge remains to continue to engage with government and civic society to ensure immediate and sustained actions continue to be funded and resourced.	Van Wilgen et al. (2020c)

euwallaceae seems set to change this (De Wit et al. 2022; Paap et al. 2018). Despite some no invasions [e.g., rinderpest, Van Helden et al. (2020)], information on invasive pests and pathogens of animals has not been as well collated into databases on invasions as it has been in other regions globally.

There has been some success in using teams of people to clear invasive trees (Fill et al. 2017; McConnachie et al. 2016), and in extirpating freshwater fishes in isolated water bodies (Weyl et al. 2014). There has also been substantial success in using biological control to manage invasive cacti, some trees and shrubs, and floating aquatic plants (Coetzee et al. 2021; Impson et al. 2021; Paterson et al. 2021). However, the ubiquitous and connected nature of the marine environment means that there is little that can be done in coastal settings once invaders have established, and so the focus must be on vigilance and pathway management to prevent incursions.

Relatively high levels of awareness and engagement?

During our discussions, we disagreed about the levels of general awareness around biological invasions in South Africa. Shackleton et al. (2020) argued that, '*certain sectors of society are more knowledgeable regarding invasions, such as elites, and those living in rural areas who are likely to be more in contact with invasions and their impacts*'. However, absolute levels of knowledge are often low, e.g., Coka et al. (2024) found that 23% of rural villagers in the Eastern Cape (former Transkei region) knew *Acacia dealbata* was an invasive species. Studies that have monitored awareness come to differing conclusions (Cronin et al. 2017; Shackleton et al. 2015a), but from our experiences, stories about biological invasions appear regularly in newspapers and online; and some studies indicate both government officials and the public are often aware of invasive species and their impacts (Byrne et al. 2020). In discussions with international colleagues who are experts in biological invasions, levels of awareness are less than in New Zealand but greater than in much of the Americas (Box 3), Asia and other African countries. There is also broad agreement among researchers, practitioners and policy-makers as to the desirability of raising awareness about impacts and management (Van Wilgen et al. 2020a). What is clear is that efforts to raise awareness (amongst the public or specific stakeholders) have rarely been monitored in terms of their outcomes. This topic deserves much more focussed research effort so that the intended outcomes are specified and progress tracked. Systematic interdisciplinary research and monitoring (including through collaborations with social scientists and economists) could profoundly improve our understanding of the perceptions of stakeholders and facilitate management (Novoa et al. 2018), e.g., by ensuring awareness activities are tailored to particular stakeholders.

Figure 1. Biological invasions are a significant threat to biodiversity and sustainable development in South Africa. A, South Africa has had a long-history of the introduction and invasion of cacti, but classical biological control has been used to effectively control invasions for over a century (Kaplan et al. 2017; Paterson et al. 2021). The image is of *Cylindropuntia fulgida* (boxing-glove cactus) invading in the Northern Cape, a species that has been a recent target for successful biological control (Klein et al. 2020); B, substantial sections of the South African coastline have been transformed by the invasive mussel, *Mytilus galloprovincialis*; currently there are no control options to address existing marine invasions and so prevention is the only current option to limit future marine invasions (Robinson et al. 2020); C, a farm labourer clearing *Neltuma* spp. (prosopis) trees in the Northern Cape; this helps to reduce spread and impacts from invasions with the wood later used on the farm or sold for fuelwood to help cover control costs (Shackleton et al. 2014, 2015b); D, pines (*Pinus* spp.) are among the most damaging invasive species severely impacting water run-off, but they also provide shade in recreational areas and are still important forestry species in South Africa; various methods have been developed to address these conflicts of interest, with the goal of limiting negative impacts while preserving benefits where possible (Van Wilgen & Richardson 2012; Zengeya et al. 2017); the picture shows historically planted pines on the slopes of Table Mountain; E, workers from the Working for Water (WfW) Programme clearing invasive shrubs in the Table Mountain National Park; the South African government has invested significant resources to control invasions through job creation (WfW in particular) (Van Wilgen & Wannenburgh 2016); while there is evidence of significant reductions in invasions in some cases, better monitoring of outcomes is needed to ensure management is effective in meeting both the social and environmental goals of the programme (Van Wilgen et al. 2022a). Photos: A, T. Xivuri; B, D, T. Robinson; C, R. Shackleton; E, B.W. van Wilgen.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context

The recommendations are from key message D25 (Figure SPM.7) and key message D28 (Table SPM.2) of the SPM of the IPBES IAS Assessment (IPBES 2023a), a current prognosis is detailed, and some key actions for a proposed national strategy identified. The focus is on mainland South Africa and the immediate offshore environment (cf. Box 2).

Table 3A.

Recommended strategic action	Current status	Proposed actions for a national strategy
1. Enhance coordination and collaboration across international and regional mechanisms	South Africa actively contributes to many multilateral environmental agreements it is party to [e.g., IPBES and as part of the Regional Plant Protection Organisation (RPPO)]. The SADC Secretariat has flagged the need for a regional approach on biological invasions (including through the SADC Biodiversity Strategy), noting existing substantial collaboration in science and for biocontrol between SADC and other African countries. There are several industry specific partnerships between African countries to monitor alien species (e.g., the Forest Invasive Species Network for Africa for forestry pests; and the SADC Plant Protection Technical Committee). Notably, the SADC Seed Centre, with technical assistance from the SADC Seed Committee and National Plant Protection Organizations (NPPOs), helps member states: document current policies and how they affect seed exchange; organise technical reviews to improve standards and procedures; ensure new initiatives comply with regional and international agreements; design and support initiatives to garner political support for rationalising and harmonising regulations; help establish databases to provide links to important documents and current national regulations; help with the issuance of permits (including the quantity of seed involved) and to resolve disputes; and keep informed about important issues through the SADC Food Agriculture and Natural Resources (FANR) website and other channels. The SADC Seed Centre closely collaborates with the NPPOs and facilitates the holding of regional meetings to discuss the following topics: the creation and revision of phytosanitary guidelines and procedures for seed; the identification and recommendation of more effective methodologies for use in the phytosanitary system(s) for seed; and the creation of techniques for technical support and monitoring of the existing system(s).	Several proposed actions were codified in Figure 5 of Faulkner et al. (2017), these are built on below: Facilitate the Border Management Authority to collaborate with neighbouring countries on compliance & enforcement / border control issues. Encourage joint symposia and researcher and student exchanges (including attending already established scientific meetings). Establish flagship projects (based on shared invasive species) as models for regional collaboration. Incentivise collaboration with other biodiverse countries in Africa and beyond. Share technology and approaches leading to the development of international agreements over biosecurity requirements.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3A. (continued)

Recommended strategic action	Current status	Proposed actions for a national strategy
2. Develop and adopt effective and achievable national implementation strategies	A National Invasive Species Strategy and Action Plan (NISSAP) is under review by South African governmental structures (October 2025), and due to go for public consultation and approval in 2026.. There is provision for all regulated taxa to have national plans developed (a few drafted but not formally approved). Biological invasions are highlighted in other implementation strategies (e.g., the Biodiversity and Ecosystems Sector Climate Change Response Strategy). The White Paper on Biodiversity sets out intentions for the environment sector (noting that some actions are captured here, e.g., on pathways, but not elsewhere). A Plant Health Bill is in draft (replacing the Agricultural Pest Act).	Identify and outline responsibilities for each proposed action in the NISSAP, detailing indicative time-lines and resources and specifying how progress will be monitored. Identify people/bodies with responsibilities and mandates to co-ordinate and separately oversee the activities of the NISSAP. Draft, approve and implement national management plans for priority taxa. Cross-check that NISSAP covers aspects identified in the White Paper. Ensure implementation strategies and working groups focus on specific targets and co-ordinate across responsible agencies (e.g., One Health, as a broad concept).
3. Share efforts, commitments and understanding of the specific roles of all actors	Mandates are set out in legislation emanating from the Constitution (national, provincial and municipal government departments and entities); and international commitments are set out in the CBD and multilateral environmental agreements. The responsibility for the management and regulation of biological invasions sits sometimes with a government department, but it is a minor issue for that department [e.g., Transport (hull fouling) and Health (invasive wasps)]. In other cases, there might be no champion, expertise or continuity. A newly created intra-departmental Alien and Invasive Species Forum was established by the DFFE to facilitate integrated governance and is to cover all issues of biological invasions. The intention is for it become interdepartmental. In terms of interaction with scientists, there were Management and Research Partnership meetings (MAREP) organised by the DFFE as part of Working for Water, but these have not happened for at least the last decade. The National Symposium on Biological Invasions is one mechanism. NGOs are very active and work closely with communities. Traditional landowners similarly play vital roles. There are some examples of structures for such roles (e.g., the uMzimvubu partnership in the Eastern Cape). In contrast, in some cases the roles have not been clear or there have been overlaps between mandates.	Expand the forum on biological invasions to include other entities (although with the focus specifically on the issue of biological invasions). Set up a broader inter-agency One Biosecurity Forum to address animal, environmental, human and plant health issues. Map mandates and roles onto activities. Facilitate working groups, communities of practice and steering groups.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3A. (continued)

Recommended strategic action	Current status	Proposed actions for a national strategy
	There have been steering committees formed on detection of new threats and working groups on various taxa or invasions. Annual co-ordination meetings are held on biological control.	
4. Improve policy coherence	There is no cross-cutting policy on biological invasions that talks to all the different elements of the issue. A White Paper on Biodiversity is in place (but this only covers the remit of DFFE). The Inter-Governmental Relations Act is also in place but has not been implemented with regard to biological invasions. The Biodiversity Lekgotla (linked to the Kunming-Montreal Global Biodiversity Framework) introduced the idea of a Biodiversity Indaba for policy coherence.	Conduct a legal review of the regulatory framework (aimed at repealing, replacing, filling gaps or aligning). Establish and utilise mechanisms to interact with SADC partners.
5. Engage broadly across governmental sectors, industry, the scientific community, Indigenous Peoples and local communities, and the wider public	There are various initiatives to raise awareness (e.g., roadshows), but it is not always clear whose responsibility it is to engage (particularly across sectors). All legislative changes, however, involve discussions with stakeholders and include formal processes for public comment. Some studies have estimated levels of engagement, but these have been piecemeal and with varying results. Without a systematic evaluation it is difficult to be sure of the current status. It is also not clear what level of awareness would be desirable.	Map stakeholders to identify who should be targeted, for what reason and how. Review awareness raising activities to learn from existing cases across the country. Develop mechanisms to promote stakeholder engagement and collaboration (Novoa et al. 2018). Set up systems for the co-design and co-implementation of management. Acknowledge and address conflicts and power dynamics among stakeholders, including through a better understanding of different value systems and conflicts (Mukwada et al. 2016). Incentivise social scientists to work on biological invasions. Develop and implement a biosecurity awareness campaign targeting stakeholders who produce and trade in products based on alien species and those involved in pathways that facilitate accidental introductions.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3A. (continued)

Recommended strategic action	Current status	Proposed actions for a national strategy
6. Support, fund and mobilise resources for innovation, research and environmentally sound technology	There is a long history of research and technology development in South Africa but this is somewhat under threat due to declining funding. A national centre of research excellence of biological invasions received direct government support up until 2023 (becoming funded by a specific university thereafter). Primary research on biocontrol was previously well supported but governmental funds have been reduced and delayed.	Develop a technical tertiary qualification (that allows for part-time study) on the management of biological invasions. Develop a series of short courses teaching relevant skills. Fund and support research and capacity building. Build/develop more public-private partnerships. Identify and develop novel funding mechanisms (e.g., crowd sourcing and tax incentives).
7. Support information systems, infrastructures and data sharing	The South African status report is one mechanism to consolidate data, but there are continuing issues of data access, awareness and data curation. For example, South Africa's list of alien species exists only as a static database produced triennially, risk analyses are produced but not in public domain yet, the digitisation of historical paper records is not complete, the mapping of invasions is partial and not consolidated, and records on inputs (e.g., money spent) are not accessible or in an interoperable format. Data-sharing agreements are lacking between organs of state. This is exacerbated by a lack of cooperative governance, with poor alignment of mandates and poor communication.	Provide training on data management. Move to on-line dashboards for species lists. Develop workflows and data pipelines. Publication of risk analyses in support of changes to regulatory lists. Develop consistent maps of presence of alien species across freshwater, marine and terrestrial systems to facilitate application of regulatory measures.

Table 3B.

Recommended property	Current status	Proposed actions for a national strategy
1. Robust institutions that maintain performance through sustained investment and commitment	South Africa has several strong well-established and robust governmental institutions, public entities and public universities with many civic societies and organisations. However, it seems probable that the fiscus will continue to decline. The DFFE is the lead organisation for many activities (under NEM:BA) but funding is typically on three-year cycles, with little guarantee of continuity.	Explore the role of private actors to assist with funding, keeping issues of sustainability in mind. Look critically at options to extract value from control operations (e.g., value addition and value chain, biomass harvesting). Explore other financing mechanisms (payment for ecosystems services and tax incentives)

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3B. (continued)

Recommended property	Current status	Proposed actions for a national strategy
	The Department of Agriculture (DoA), the Department of Science and Innovation (DSI), and Innovation Africa @ University of Pretoria have partnered to create the National Biosecurity Hub. A fundamental component of the STI Decadal Plan 2021–2031 and the White Paper on Science, Technology, and Innovation (2019–2020), the Hub contributes to the research, development and innovation necessary to revitalise the agricultural sector. To protect the country from newly emerging sanitary and phytosanitary (SPS) threats that compromise food security, the establishment, upkeep and financing of a strong national biosecurity system also fosters trade partner confidence, which expands market access and creates jobs throughout the value chain.	
2. Responsive governance that adapts to different and changing contexts	There is provision for emergency changes to the NEM:BA A&IS Regulations to be made, but none have been implemented to date. Emergency plant pest response plans are, however, in place and have been implemented. In general, the situation is typified by decisions being made at a very high level (for example director generals are held financially responsible for most issues); with implementation further delayed by unsuitable supporting bureaucratic functions (e.g., supply chain management). In most cases contracts are fixed and inflexible. There is also typically inadequate monitoring of outcomes. As a result, it is very hard for government or their implementing agents to do adaptive management. Governance is mostly reactive rather than proactive.	Investigate ways of devolving decision-making to lower and local levels (e.g., clear aliens in response to fires at a local level). Develop emergency response plans both for agricultural issues and threats to other sectors (e.g., biodiversity). Outline co-ordination mechanisms for emergency response plans including all affected sectors. Establish regular active general surveillance. Monitor outcomes and develop feedback loops to ensure management can respond to what is happening on the ground. Develop and prioritise watch lists for surveillance activities.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3B. (continued)

Recommended property	Current status	Proposed actions for a national strategy
3. Effective implementation that results in the achievement of goals and targets	Current goals and targets for management are not clearly specified and so the progress to address biological invasions is unclear. Similarly, a lack of monitoring of outcomes means progress cannot be tracked. Monitoring focuses on inputs (and in a few cases outputs, e.g., area cleared). By contrast, the goals and targets of biocontrol are specified, and high efficacy has been demonstrated in some cases. For bureaucratic reasons, eradication attempts are often based on the same clearing approach as for widespread invaders, more flexibility is needed. Some protected areas have been evaluated and some control has been shown to be effective. Exercises have been undertaken to prioritise management interventions but these have rarely been acted upon.	Set priorities and goals. Develop a clear monitoring framework. Establish and implement reporting mechanisms. Align goals and mandates between institutions. Link different clearing approaches (best practice) to activities and goals. Establish and implement medium to longer term plans.
4. Equitable and inclusive governance that is fair to all people, communities, and institutions affected by and responsible for the problem	The processes of public government are in place, with mechanisms for three levels of governance and consultation. The system has, at least on paper, all these properties (though in consequence decision-making can be slow). There are several good examples of partnerships (e.g., the uMzimvubu partnership in the Eastern Cape). The NEM:BA A&IS Regulations try to uphold the various rights enshrined in the Constitution by balancing commercial needs vs local community or individual needs. For example, exemptions are specified and provision for permits can be made.	Establish risk management measures and processes to evaluate them so risks are reduced without unduly limiting people's rights. Setup consultation processes (e.g., stakeholder forums and information groups) with specific timelines to ensure decisions are reached. Routinely run stakeholder identification exercises to ensure affected parties become participants in decision-making. Measure the positive impacts both of invasions and interventions and evaluate against costs. Explore options to ensure communities benefit in situations where the risk is minimised and mitigate the risks outside of those cases.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3C.

Recommended option	Proposed actions for a national strategy
Coordination and resourcing 1. Enhance multilateral coordination and collaboration to support the integrated governance of biological invasions	*This is defined here at an international level noting there were differing views on what 'multilateral' means in this context* Support the development and implementation of a regional biological invasions strategy and action plan (this is a CBD COP decision and outcome of SADC joint session held June 2023 / ministerial joint session of ministers of natural resource management, wildlife and tourism). Identify taxa that occur across national borders, engage relevant departments/units from affected countries, co-develop a strategy to manage each taxon, explore means of funding and implement an agreed-upon strategy using relevant tools and monitoring arrangements. Specifically establish joint research and control projects within SADC and working groups on shared issues including classical biological control. Identify specific funding proposals. Identify potential points of conflict across different multilateral agreements. Consider options to integrate management of biological invasions with other global change drivers, by considering land degradation and different perspectives (e.g., under UNFCCC and CBD, ocean acidification and carbon markets). Interact and where possible align with international efforts guided by IPBES, IPCC and others on biological invasions. Explore whether the ideas specified in the sections below should also be done at an international level.
Coordination and resourcing 2. Engage broadly across affected and responsible parties	Stakeholder mapping (e.g., plot amount of interest vs amount of influence, and network analysis) at different scales. Build public-private partnerships (e.g., the Greater Cape Town Water Fund) Incorporate local/indigenous knowledge, perspectives and rights in the strategy development (cf. Box 4). Where feasible and relevant, translate communication material into the most appropriate languages. Develop protocols to ensure consent of use of knowledge or access to land. Identify and address the need for working groups on particular taxa or issues. There are existing working groups for specific taxa in the country; however, not all taxa are covered. There may be a need to increase the number of working groups to cover more taxa and strengthen existing ones by bringing more organisations on board. Share management plans and pool funding, e.g., implementing agencies could share their management plans, review them together, explore opportunities for working together on pathways, species or sites of interest, and allow for pooling of funding where possible. Create a platform for private landowners that are interested in managing invasions on their property to enhance collaboration and/or provide guidance on best practice.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3C. (continued)

Recommended option	Proposed actions for a national strategy
	Continue with existing outreach activities and roadshows to explain the NEM:BA A&IS Regulations. Conduct targeted engagements with the public to develop a sense of shared responsibility, with clearly defined roles and responsibilities.
Coordination and resourcing 3. Build capacity to enable strategic actions	Explore options for funding to build on existing expertise. The South African government has previously provided significant resources, but the fiscus is declining. It is vital to ensure the continuity of core funding if other funding sources are to be leveraged. Set up relevant postgraduate courses (e.g., on risk analysis, biocontrol). Set up specific training courses for technical skills (e.g., herbicide application). Fund postgraduate degrees. Identify and implement novel funding sources to promote control (e.g., debt for nature swaps, public-private partnerships, crowdsourcing).
Policy 4. Share efforts, commitments and understanding of the specific roles of all	Develop a policy on all aspects of biological invasions (going beyond the White Paper on Biodiversity). Ensure the NISSAP has a broad interdepartmental support process for developing, reviewing and implementing the strategy. Conduct awareness raising activities (e.g., roadshows and information sessions) to clarify what needs to be done by whom.
Policy 5. Strengthen compatibility of relevant regulatory instruments	Undertake a legal review and based on that rationalise regulatory instruments. Enforce legislation by building capacity for compliance monitoring by the Border Management Authority, and administrative and criminal enforcement by Environmental Management Inspectors. Review the list of invasive species informed by current science.
Policy 6. Use national strategy and planning for invasive alien species to achieve policy implementation	Finalise the development of the NISSAP and integrate action items identified into the Annual Performance Plans of relevant departments/units.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3C. (continued)

Recommended option	Proposed actions for a national strategy
Policy 7. Support, fund and mobilise resources for innovation, research and environmentally sound technology	Increase the integration of biological invasions and their management in the National Development Plan so that it is seen as a potential driver of economic development.
	Identify and implement novel funding sources to promote control (e.g., debt for nature swaps, public-private partnerships, crowdsourcing).
	Fund the Centre for Invasion Biology, the Centre for Biological Control, and consider other inter-institutional research-based agencies that can support the achievement of the national strategy.
	Build public-private partnerships (e.g., the Greater Cape Town Water Fund).
	Explore options to use biological invasions as a demonstration to highlight the application of a technology (e.g., remote sensing, gene drive).
	Consider investment platforms and market incentives/mechanisms, being careful to avoid perverse incentives.
Policy 8. Support information systems, infrastructures and open and equitable access to information on invasive alien species	Develop, update, collate and curate factsheets on pathways of introduction and spread, alien species and invaded sites.
	Maintain a central information clearing website and email circular (e.g., through www.invasives.org.za).
	Encourage open-access publishing by relevant journals and include funding for publications in grants as needed.
	Develop an integrated biosecurity data system that is accessible and interoperable.
	Use the South African status reports to link with data provision systems.
Research, information and technology 9. Invest in information systems for invasive alien species for information-sharing within and across countries	*Within country*
	Set up an information portal where details regarding research, policy, compliance and enforcement can be sourced (similar to a clearing house mechanism).
	Integrate the South African list of alien species with the Global Register of Introduced and Invasive Species.
	Across countries
	Develop and share generic protocols for data on biological invasions and work with neighbouring countries and other collaborators to facilitate such processes.

Table 3. Reflections by the authors on how the: A. seven strategic actions, B. four properties and C. 12 options to strengthen efforts to address biological invasions proposed in the IPBES IAS Assessment are or could be adopted in the South African context (continued)

Table 3C. (continued)

Recommended option	Proposed actions for a national strategy
Research, information and technology 10. Maintain up-to-date information on necessary and enabling indicators	Develop, document (e.g., using factsheets), regularly review and update biological invasion indicators as part of the South African status reports.
	Ensure indicators used in South Africa are compatible with indicators used for reporting to multilateral environmental agreements (e.g., the CBD).
	Move from a triennial national report to on-line dashboard of status (with broader reports roughly every decade).
	Develop data pipelines and workflows so that it is easy to move from observation to action.
Research, information and technology 11. Monitor policy and management effectiveness and resourcing levels	Use case studies/systems to develop and test different systematic monitoring approaches.
	Develop best management practice guidelines and run workshops to share techniques across groups. Regularly review and update guidelines based on field experiences.
	Develop pathways, species and site-based management plans to allow for monitoring of effectiveness.
Research, information and technology 12. Develop new solutions through research and technology	Undertake research responding to current trends relevant to prevention and management of biological invasions.
	Fund environmental management focused start-ups.
	Scan other environmental management literature.
	Move from technology and tools to application (e.g., gene drive, herbicides, remote sensing and eDNA).
	Support initiatives that promote innovation and product development in the field of biological invasions (e.g., innovation expositions).
	Look for opportunities for piggy-backing on techniques developed elsewhere.
	Systematically incorporate future thinking tools (e.g., environmental scanning, driver mapping, horizon scanning and scenario planning) into strategies and action plans.

A key cross-cutting issue for the IPBES IAS Assessment (referred to in four of the 22 key messages) is the importance of 'Indigenous Peoples and local communities' (IPLC) and 'Indigenous and Local Knowledge' (ILK). The roles of IPLCs and the value of ILK was felt to be very important in the South African context, but the terminology used locally sometimes differs from that used by the IPBES. It will be important to keep the sentiment without forcing the use of a specific framework and terms (Box 4).

A vibrant community of practice

Arguably South Africa's community of invasion scientists, managers and practitioners is neither too small that major issues are not addressed nor too large that they cannot regularly meet as a group. There is a sufficient diversity of practitioners with some turnover of both scientific and managerial staff so that there is institutional memory and willingness to continue group discussions over long periods of time (e.g., Davies et al. 2020a). This community of practice hits a Goldilocks zone, small enough to be intimate, connected, collaborative and continue over time without too much irrelevant bureaucracy, but not so small that it relies on a few individuals (Foxcroft et al. 2020).

South Africa is well placed in terms of specific governmental institutions that focus on directed applied research and coordination (e.g., the Agricultural Research Council, the Council for Scientific and Industrial Research and the South African National Biodiversity Institute). The government department in charge of fundamental research values applied research, and the departments in charge of environmental affairs and agriculture recognise the importance of foundational research, providing support to scientists through research grants and postgraduates through various bursary schemes.

Invasion science, as a discipline, allows for training in a real-world problem that cuts across different sectors and in which a tangible difference can be made by individual students. For almost two decades (2004–2022), the South African government funded a world-leading institute with the aim of conducting research, education and training, coordinating networking, information brokerage and service provision relating to biological invasions (the Centre for Invasion Biology, Richardson et al. 2020a). Similarly, a research centre dedicated to biological control research, training and implementation has provided vital support to managers across the country (the Centre for Biological Control, Byrne et al. 2020). Ensuring such initiatives continue will be crucial if the national strategy is to be effective.

Various methods are used to increase interactions, including joint attendance and participation in voluntary fora and conference series where researchers and managers are regularly exposed to each other's challenges (Foxcroft et al. 2020). There is an annual National Symposium on Biological Invasions that regularly has an attendance of over one hundred delegates including researchers, academics and policy- and decision-makers from various government departments. Government officials are also encouraged to attend training [e.g., short courses in biological control and risk analysis have been developed and led by academics and staff of research institutions (Byrne et al. 2020; Wilson & Kumschick 2024)] or to register for post-graduate qualifications. Other initiatives that have been in place are management and research planning fora. Some have run their course, but others have been ongoing for many years, including working groups on cacti, grasses and invasive animals (Davies et al. 2020a; Kaplan et al. 2017; Visser et al. 2017).

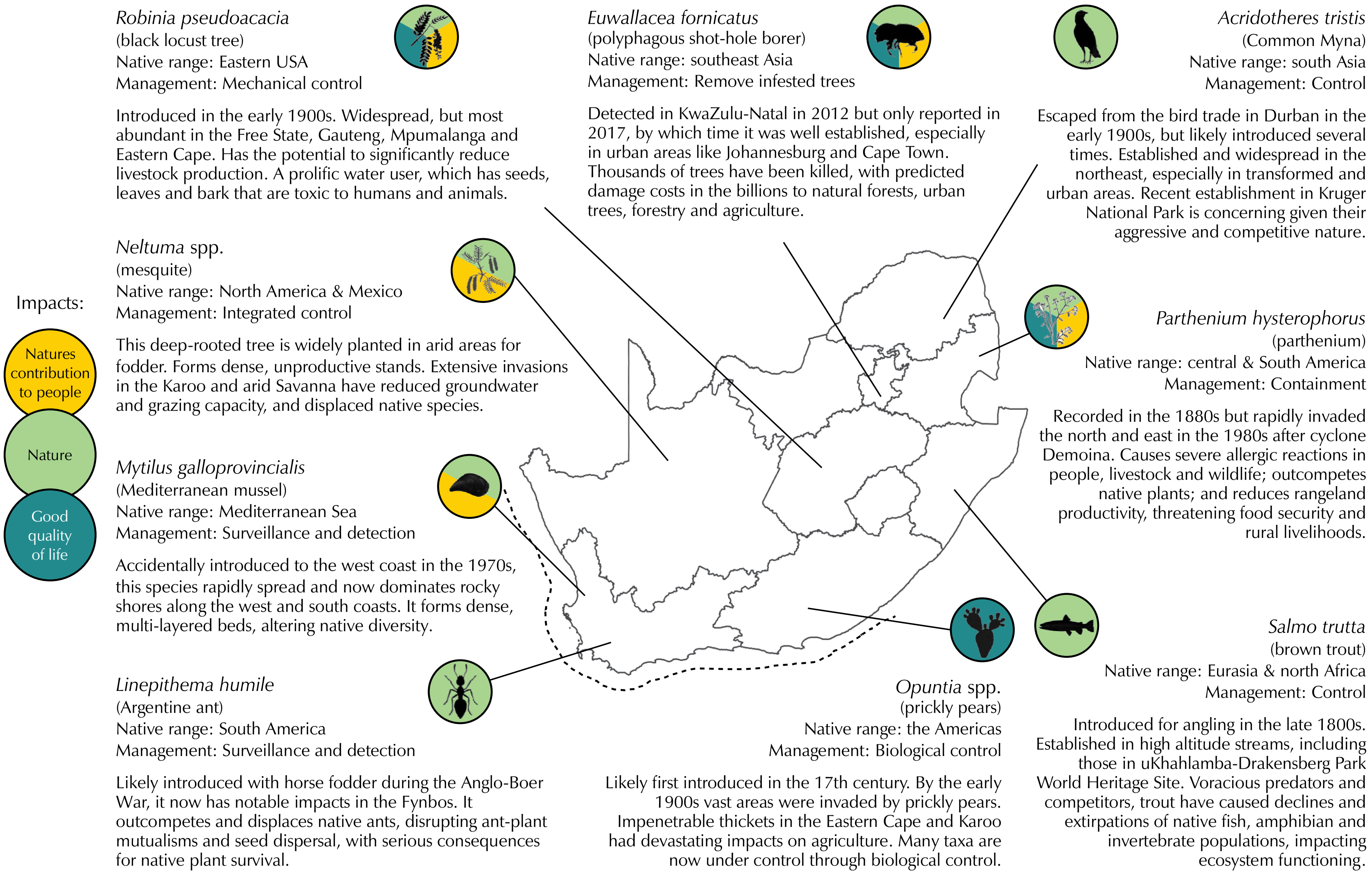
A substantial existing knowledge base but one that can be rapidly expanded

Biological invasions have been reasonably well-documented in protected areas (Van Wilgen & Herbst 2017), as well as across the whole country for plants (Henderson & Wilson 2017). There has also been a growing use of citizen science platforms (e.g., iNaturalist) to facilitate monitoring and reporting in South Africa (Potgieter et al. 2024; Zengeya & Wilson 2023). There is still a need, however, for inventories of cultivated aliens and cultivated areas (this was notably outside the scope of the IPBES IAS Assessment). Angling, arboreta, botanical gardens, horticulture, the pet trade and zoos often use alien taxa and information on these need to be incorporated into our thinking (Cheek et al. 2022; Glen 2002; Vezi et al. 2024; Wondafrash et al. 2021). Pathway-specific risk assessments and management plans are also needed.

Importantly, there is still much to be gained from more interdisciplinary and transdisciplinary research – much of the research on biological invasions is still driven by a core group of ecologists (Abrahams et al. 2019). For example, arguably social and gender issues as outlined in the IPBES approach are not adequately addressed [though studies have looked at the value of overt targets for gender and the need to consider social redress in interventions (Hough & Prozesky 2012, 2013; Sadan 2005; Van Koppen et al. 2011)]. It will be important to ensure the proposed national strategy elicits contributions from the social sciences and incorporates discourses from different perspectives.

Integrated governance

We agree strongly with the plea in the IPBES IAS Assessment for more focus on integrated governance. For example, provincial legislation on keeping pets differs



Robinia pseudoacacia
(black locust tree)
Native range: Eastern USA
Management: Mechanical control

Introduced in the early 1900s. Widespread, but most abundant in the Free State, Gauteng, Mpumalanga and Eastern Cape. Has the potential to significantly reduce livestock production. A prolific water user, which has seeds, leaves and bark that are toxic to humans and animals.

Neltuma spp.
(mesquite)
Native range: North America & Mexico
Management: Integrated control

This deep-rooted tree is widely planted in arid areas for fodder. Forms dense, unproductive stands. Extensive invasions in the Karoo and arid Savanna have reduced groundwater and grazing capacity, and displaced native species.

Mytilus galloprovincialis
(Mediterranean mussel)
Native range: Mediterranean Sea
Management: Surveillance and detection

Accidentally introduced to the west coast in the 1970s, this species rapidly spread and now dominates rocky shores along the west and south coasts. It forms dense, multi-layered beds, altering native diversity.

Linepithema humile
(Argentine ant)
Native range: South America
Management: Surveillance and detection

Likely introduced with horse fodder during the Anglo-Boer War, it now has notable impacts in the Fynbos. It outcompetes and displaces native ants, disrupting ant-plant mutualisms and seed dispersal, with serious consequences for native plant survival.

Euwallacea fornicatus
(polyphagous shot-hole borer)
Native range: southeast Asia
Management: Remove infested trees

Detected in KwaZulu-Natal in 2012 but only reported in 2017, by which time it was well established, especially in urban areas like Johannesburg and Cape Town. Thousands of trees have been killed, with predicted damage costs in the billions to natural forests, urban trees, forestry and agriculture.

Opuntia spp.
(prickly pears)
Native range: the Americas
Management: Biological control

Likely first introduced in the 17th century. By the early 1900s vast areas were invaded by prickly pears. Impenetrable thickets in the Eastern Cape and Karoo had devastating impacts on agriculture. Many taxa are now under control through biological control.

Acridotheres tristis
(Common Myna)
Native range: south Asia
Management: Control

Escaped from the bird trade in Durban in the early 1900s, but likely introduced several times. Established and widespread in the northeast, especially in transformed and urban areas. Recent establishment in Kruger National Park is concerning given their aggressive and competitive nature.

Parthenium hysterophorus
(parthenium)
Native range: central & South America
Management: Containment

Recorded in the 1880s but rapidly invaded the north and east in the 1980s after cyclone Demoina. Causes severe allergic reactions in people, livestock and wildlife; outcompetes native plants; and reduces rangeland productivity, threatening food security and rural livelihoods.

Salmo trutta
(brown trout)
Native range: Eurasia & north Africa
Management: Control

Introduced for angling in the late 1800s. Established in high altitude streams, including those in uKhahlamba-Drakensberg Park World Heritage Site. Voracious predators and competitors, trout have caused declines and extirpations of native fish, amphibian and invertebrate populations, impacting ecosystem functioning.

Figure 2. Selected damaging invasions across South Africa. The nomenclature is as per the species list of the South African status reports. The affected sectors are indicated by colours: yellow is on nature's contribution to people; green is on nature; and teal is on good quality of life [cf. Figures SPM.2 and SPM.3 in IPBES (2023a)].

throughout the country with some provinces allowing many alien pets, while others ban most (Nelufule et al. 2020). We often have the tools, frameworks and knowledge necessary to address biological invasions, and in many cases these have been adapted specifically to the South African context. We argue for a greater focus on how we implement. Improvements to project management (e.g., supply chain management) could greatly increase the effectiveness of control projects funded by the government. It will be important to focus management on where and when it is needed most, and ensure monitoring is sufficient to allow for management to be adaptive.

Humans are both the cause of and solution to biological invasions. Effective management requires co-ordination across different mandates, sectors (e.g., agriculture, health and transport) and scales (local to national). Several promising cross-cutting approaches have been identified with links to biological invasions, including One Health (Ogden et al. 2019) and One Biosecurity (Hulme 2020). The challenge (in particular for the national strategy) is to improve coordination while limiting bureaucracy to that which is needed. We believe there is room both for a forum dedicated to biological invasions (for those who work directly on the issue) and for a broader inter-agency One Biosecurity Commission (that brings together those working on animal, environmental, human and plant health; cf. the Presidential Climate Commission https://www.climatecommission.org.za/ established in Sep. 2020).

Box 4. Indigenous and Local Knowledge (ILK) and Indigenous Peoples and local communities (IPLCs) terminology in the South African context

In the parlance of IPBES, Indigenous and Local Knowledge (ILK) refers to ‘knowledge and know-how accumulated across generations, which guide human societies in their innumerable interactions with their surrounding environment’. The collective term for stakeholders that hold and provide ILK are Indigenous Peoples and local communities (IPLCs). IPLCs are, ‘typically, ethnic groups who are descended from and identify with the original inhabitants of a given region, in contrast to groups that have settled, occupied or colonized the area more recently’ (IPBES 2022). Using ILK and other forms of knowledge, IPLCs have shaped the ecologies, conservation initiatives and resource economies of vast regions of the world – IPLC either control, use, manage or co-administer an estimated ~38 million km^2 or 25–28% of the world’s land area (McElwee et al. 2020). Crucially these lands are less invaded than other areas, potentially due to active custodianship by IPLCs (Seebens et al. 2024).

In 2004 South Africa adopted an indigenous knowledge systems policy, with the then Department of Science and Technology as the custodian. Terms such as Indigenous Knowledge Systems (IKS) and Traditional Knowledge (TK) are widely used to refer to the knowledge, skills, practices and technologies developed by indigenous and local communities (often in practice synonymous with the term ‘rural communities’). The literature in South Africa also recognises groupings such as indigenous communities, local communities, traditional communities and traditional knowledge holders. The aim is to include those who have a distinct cultural identity and a deep connection to their ancestral lands, including those that have lived in a particular area for a long period of time with their own knowledge systems and practices related to the natural environment. These terms are often used in policies, legislation and academic discourse in South Africa to recognise and respect the role of ILK in biodiversity conservation and sustainable development.

Several instruments exist currently to protect the input of IKS and TK such as NEM:BA, the indigenous knowledge systems policy and Protection, Promotion, Development, and Management of Indigenous Knowledge Act (IK Act, 2019), drawing on methods such as stakeholder engagements, public participation processes and citizen science. As examples, IKS are engaged through Community-Based Natural Resource Management (CBNRM) programmes as intervention points to assist with management of invasive species. Similarly, rural livelihoods affected by the impact of invasive species on ecosystem services, such as grazing or water supplies (Yapi et al. 2018), are best understood by engaging with the community. IKS contribute to local development, however traditional knowledge holders are often excluded from decision-making processes. IKS should be seen as a natural resource which guides decisions and informs how land is used, e.g., by farmers and agricultural households.

In summary, while the concepts of ILK and IPLC, as defined by IPBES, are recognised and contribute to biodiversity conservation and management in South Africa, given the diversity of definitions and associated groups, care should be taken to ensure that all stakeholders are represented and to avoid the misinterpretation and misalignment of information. As argued elsewhere in this paper, IPBES concepts and definitions should, we believe, be interpreted and adapted to the local context if they are to be of most value.

Biological invasions do not respect administrative borders, and all agreed on the need for greater collaboration with neighbouring countries, the Southern African Development Community (SADC) and Africa more generally. It will be vital for Africa to share experiences and collectively address biological invasions (Faulkner et al. 2017), particular in light of the African Continental Free Trade Area that was established in 2019 (Faulkner et al. 2020a).

Resourcing and where to from here

The amount of resources invested to address biological invasions in South Africa is substantial but declining (McCulloch-Jones et al. 2024; Van Wilgen et al. 2022a).

There is a specific and substantial value proposition in preventing and controlling biological invasions. This needs to be made more strongly. A greater investment of resources in proactive management would do much to limit future biological invasions (McCulloch-Jones et al. 2024) especially in the context of environmental biosecurity (Early et al. 2016). Substantial returns on investment have, however, also been made by treating existing widespread invasions, especially through clearing trees in water source areas (McConnachie et al. 2012; Stafford et al. 2019) and classical biological control (McConnachie et al. 2003; Van Wilgen & De Lange 2011). Since 2022, national government funding for biocontrol has not been forthcoming even though South Africa has a long and successful history of research and implementation in this area (Hill et al. 2020). This suggests the need to both improve how the case for safe and effective biological control is made to the South African government and to diversify funding options, for example, with more public-private partnerships (Ivey et al. 2024; Martin et al. 2018). We advocate strongly that funds to improve human health, agricultural productivity and food security, livelihoods and the economy can be highly effective if invested in addressing biological invasions.

There are, as always, challenges that could severely limit management options in future. A ban on herbicides would remove essential tools for control (integrated control linking mechanical removal with chemical control is imperative for many invasive trees); the push for commercialisation has the potential to open up new introduction pathways; and perverse incentives to address climate change through afforestation using alien species has led to widespread damaging invasions (Bond et al. 2019).

During our discussions, and as flagged by many parties during consultations, much more integration and collaboration with neighbouring countries are urgently needed if biological invasions are to be effectively addressed. Although South Africa was well represented in the IPBES IAS Assessment, several concerns were expressed at the IPBES plenary (during which the assessment was approved) pertaining to data gaps and low representation of experts from developing countries. South Africa’s draft national strategy recognises this. Opportunities for funding through the Global Biodiversity Framework Fund and various international initiatives could provide valuable sources of seed funding to facilitate greater integration of efforts within SADC and Africa more broadly.

This paper is a selected view by a selected group in response to a particular initiative (the IPBES IAS Assessment). The South African status report provided background information but was not explicitly reviewed here. This paper also does not explicitly review the historical context [for a broad review of biological invasions in South Africa see Van Wilgen et al. (2020a)]. Key sectors from South Africa did not contribute to the IPBES IAS Assessment (and so were not included as authors of this paper), in particular microbiologists, fungal biologists and human health specialists; a more diverse range of viewpoints would be extremely valuable. A much broader analysis using a range of tools from futures thinking (including environmental scanning, driver mapping, horizon scanning and scenario planning) would also provide significant insights for the national strategy and action plan (Hulme 2025). Nonetheless, we believe this paper provides an important perspective linking international best practice and insights (the IPBES IAS Assessment) to national needs (the draft national strategy).

Conclusion

The IPBES IAS Assessment is a landmark report at the science-policy interface on biological invasions that, we argue, provides guidance for South Africa to deal with biological invasions. The IPBES IAS Assessment provides compelling evidence of the need for immediate and urgent control of invasive species, serving as a baseline to monitor progress towards Target 6 of the Kunming-Montreal Global Biodiversity Framework. Nonetheless, given the focus of the IPBES IAS Assessment (global and holistic), the key messages and gaps will likely not wholly resonate for any specific country. We encourage readers in South Africa and other countries to go beyond the key messages from the IPBES IAS Assessment and contextualise and scrutinise the findings based on what is important for their region or country. This opinion paper hopefully provides insights both for how South Africa can contribute to the implementation of CBD Article 8h and to Target 6 of the KM-GBF, what South Africa’s national strategy should include, and, ultimately, how South Africa can be protected from the harm caused by biological invasions for the benefit of the environment and human well-being.

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Competing interests

Most of the authors are involved in management and research on biological invasions in South Africa. Several of the authors contributed to the IPBES IAS Assessment (see legend to Table S1).

Authors' contributions

Conceptualisation (JRUW, KTF, LFW, EJMcC-J, SM, BWvW, TAZ); project administration (JRUW); visualisation [CC (Figure 1); EJMcC-J, KTF, RB (Figure 2)]; writing – original draft [JRUW, KTF, LFW, EJMcC-J, SM, DMR, TBR, SK, NT, FT, SJR, BWvW, TAZ; JRUW (Box 1); KTF, LFW, MG, PClR (Box 2); MSD, SRZ (Box 3); RB, SJR (Box 4)]; writing – review and editing (all). All authors have read and agreed to the published version of the manuscript.

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Full list of authors and affiliations

Authors

[1,2]J.R.U. Wilson
[1,3]K.T. Faulkner
[1,2]L. Fernández Winzer
[1,2,3]E.J. McCulloch-Jones
[2]B.W. van Wilgen
[2,4]R. Blanchard
[5,6]C. Carbutt
[7]M.S. Dechoum
[2,8]L.C. Foxcroft
[9]M. Greve
[10,11,12]C. Hui
[13]P. Ivey
[14]B. Kgope
[1,2]S. Kumschick
[9]P.C. le Roux
[14]T.S. Masehela
[2,15]J. Measey[†]
[1]S. Miza
[14]T. Mogapi
[14]F. Mpikanisi
[16]L. Mulaudzi
[17]K. Nelukalo
[17]L. Nnzeru
[1,18]M.M. Nsikani
[19]Z. Pattison
[20,21]S.J. Rahlao
[2]D.M. Richardson
[2]T.B. Robinson
[2,22]R.T. Shackleton
[23]F. Tererai
[23]N. Tshidada
[24]P.P. Tshikhudo
[25]I. Tshivhandekano
[26]K. Wanjau
[27]S.R. Ziller
[1,28]T.A. Zengeya

Affiliations

[1]Kirstenbosch Research Centre, South African National Biodiversity Institute, Cape Town, South Africa.
[2]Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Stellenbosch, South Africa.
[3]Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa.
[4]Fynbos Node, South African Environmental Observation Network, Observatory 7925, South Africa.
[5]Scientific Services, Ezemvelo KwaZulu-Natal Wildlife, Cascades 3202, South Africa.
[6]School of Life Sciences, University of KwaZulu-Natal, Scottsville 3209, South Africa.
[7]Departamento de Ecologia e Zoologia, Centro de Ciências Biológicas, Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil.
[8]Scientific Services, South African National Parks, Skukuza, South Africa.
[9]Department of Plant and Soil Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa.
[10]Centre for Invasion Biology, Department of Mathematical Sciences, Stellenbosch University, Stellenbosch 7602, South Africa.
[11]Biodiversity Informatics Unit, African Institute for Mathematical Sciences, Cape Town 7945, South Africa.
[12]National Institute for Theoretical and Computational Sciences (NITheCS), Stellenbosch 7602, South Africa.
[13]Centre for Biological Control, Department of Zoology & Entomology, Rhodes University, Makhanda, South Africa.
[14]Biodiversity Risk Management, Biosafety and Alien Invasive Species, Department of Forestry, Fisheries and the Environment, Environment House, 473 Steve Biko Road, Pretoria, South Africa.
[15]Centre for Invasion Biology, Institute for Biodiversity, Yunnan University, Kunming, China.
[16]Agricultural Research Council-GC, 114 Chris Hani Drive, Potchefstroom 2531, South Africa.
[17]Biodiversity Risk Management, Issuing Authority, Department of Forestry, Fisheries and Environment, 14 Loop Street, Cape Town, South Africa.
[18]Centre for Invasion Biology, Department of Conservation Ecology and Entomology, Stellenbosch University, Stellenbosch, South Africa.
[19]Faculty of Natural Sciences, Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, Scotland.
[20]Oceanographic Research Institute, Durban, South Africa.
[21]School of Life Sciences, University of KwaZulu-Natal, Durban, South Africa.
[22]Swiss Federal Institute for Forest, Snow and Landscape Research, WSL, Zürcherstrasse 111, CH-8903, Birmensdorf, Switzerland.
[23]Pretoria National Botanical Gardens, South African National Biodiversity Institute, Pretoria, South Africa.
[24]Pest Risk Analysis Division, Directorate Plant Health, Department of Agriculture, South Africa.
[25]Biosecurity Compliance, Oceans, Coasts and Biosecurity Compliance, Department of Forestry, Fisheries and the Environment, Environment House, 473 Steve Biko Road, Pretoria, South Africa.
[26]Border Management Authority, South Africa.
[27]Instituto Hórus de Desenvolvimento e Conservação Ambiental, Florianópolis, Santa Catarina, Brazil.
[28]Centre for Invasion Biology, Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa.

Supplementary Material

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Table S1. IPBES IAS Assessment experts and countries of affiliation

Table S2. The key message paragraphs from the IPBES IAS Assessment and the corresponding South African situation

Table S3. Objectives and actions for managing biological invasions with details of the South African situation

Table S4. Knowledge and data gaps identified in the IPBES IAS Assessment in the context of South Africa

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Rust fungi (Pucciniales) of southern Africa

Author
[1,2]A.R. Wood

Affiliations
[1]ARC-Plant Health Protection, Private Bag X5017, Stellenbosch 7599, South Africa.
[2]Discipline of Plant Pathology, School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, P.O. Box X1, Pietermaritzburg 3209, South Africa.

Corresponding Author
A.R. Wood; e-mail: WoodA@arc.agric.za

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The last comprehensive checklist of rust fungi (Pucciniales; Basidiomycota) of southern Africa was published in 1950 by Ethel Mary Doidge, and included 468 species. An updated listing is provided here, including all published records of rust fungi from Angola, Botswana, Eswatini (formerly Swaziland), Lesotho, Mozambique, Namibia, South Africa and Zimbabwe, and their recorded hosts. A total of 631 taxa of rust fungi are recorded, on 1 355 host plant taxa. *Sphaerophragmium senegaliae* A.R.Wood, *Maravalia neomimusops* A.R.Wood and *Aecidium afrocanthii* A.R.Wood are newly described. New combinations made are *Milesina silvae-knysnae* (R.Berndt) A.R.Wood and *Elateraecium celastrineae* (Cooke & Massee) A.R.Wood. *Endophyllum austroafricanum* (Henn.) A.R.Wood represents a new combination and has been raised to species level. *Endophyllum rhamni-prinoides* (Thüm.) A.R.Wood (currently known as *Endophyllum macowanii* Pole-Evans) and *Endophyllum conyzae-scabridae* A.R.Wood (currently known as *Endophyllum macowanianum* (Thüm.) A.R.Wood) are new names provided for species with illegitimate names.

Keywords: southern Africa, biodiversity, Basidiomycota, Pucciniomycetes, neomycetes, biotrophic fungi, indigenous fungi.

Introduction

The rust fungi (Basidiomycota, Pucciniomycetes, Pucciniales) are a diverse group of environmentally and economically important biotrophic plant pathogenic fungi (Aime et al. 2018). The last comprehensive checklist of rust fungi of southern Africa, which included all known records from southern Angola, Botswana, Eswatini (formerly Swaziland) Lesotho, Mozambique, Namibia, South Africa and Zimbabwe, and all recorded host plants, was by Ethel Mary Doidge (Doidge 1950) in *Bothalia*. Since then, Berndt (2008a) provided a checklist of the rust fungi from South Africa, Botswana and Namibia (but without host records). Doidge (1950) listed 468 species of rust fungi, while Berndt (2008a) recorded 546, and McTaggart et al. (2017) recorded 572. Both these latter lists included various species names that are considered to be synonyms according to Species Fungorum (http://www.speciesfungorum.org), and they did not include all species recorded from the region. In the list provided here, there are 631 taxa of rust fungi recorded from southern Africa, from 1 355 host plant taxa. The list includes 78 species considered to be alien (neomycetes), either as naturalised pathogens of introduced plants (crops and weeds), or invasive pathogens and attacking plants indigenous to the region. Also included are four species that have been deliberately introduced for the biological control of alien invasive plants. The current list aims to provide a comprehensive record of all rust fungi recorded in southern Africa up to the end of 2023, providing the first comprehensive updated listing since Doidge (1950), together with a comprehensive host list and a guide to the literature concerning the rust fungi included.

In compiling her list, Doidge drew on many sources (including literature and herbarium specimens), as well as her own comprehensive taxonomic investigations (Doidge 1927, 1928, 1939, 1941, 1948a, 1948b) of southern African rust fungi. One of the sources she drew on was Hopkins (1938), a similar checklist for Zimbabwe. Since Doidge (1950), many changes in nomenclature, as well as to generic and family concepts of the rust fungi, have occurred. In addition, there are a substantial number of new distribution records and new species recorded from the region. This checklist was compiled from published records as a means of summarising current knowledge on the taxonomy and biodiversity of the region's rust fungi. No attempt has been made to verify the published identity of the rust fungi or host plant species, however, all publications cited do list specimens examined, allowing for subsequent corrections to be included. Angola was included because Doidge (1950) included species recorded by Hennings (1903). All records found for Angola were also included here for completeness.

Of all the countries included in this checklist, only the rust funga in South Africa and Zimbabwe are relatively well known, with 526 and 169 species, respectively. Only one rust fungus is recorded from Lesotho, 6 each from Botswana and Eswatini, 39 from Angola, 36 from Mozambique and 68 from Namibia. South Africa's and Zimbabwe's fungal flora are the best known because there is a history of active mycologists and plant pathologists in these countries. Both countries also have a long history of producing plant disease lists, namely those of Doidge (1924), Doidge and Bottomley (1931), Doidge et al. (1953), Gorter (1977, 1981, 1982) and Crous et al. (2000) in South Africa; and Hopkins (1938, 1950), Whiteside (1966), Rothwell (1983) and Masuka et al. (1998) in Zimbabwe. These lists were consulted but are not cited unless they are the sole record of a species occurring in the region. Because these lists do not provide details of the specimens used to make the record, any changes in taxonomy can't be followed. Literature that provides taxonomic and specimen details was preferred as the source for species recorded here. Another shortfall of these lists of South African plant diseases, is that they do not give a comprehensive listing of pathogens of indigenous plants. This results from decisions made about which host plants to include in Doidge and Bottomley (1931), only indigenous plants considered at that time to be of economic importance (timber, fodder, medicinal, poisonous or ornamental) were included, and therefore many pathogens recorded from other plant species were excluded. These excluded records mostly continued to be excluded in all publications up to and including Crous et al. (2000).

Doidge (1950) gives a comprehensive historical account of the mycological exploration of the region, including the rust fungi. Halvor Gjærum has since then made a notable contribution to the knowledge of rust fungi indigenous to the region (see the various publications under his name), with the description of 15 new species and a further 27 previously unrecorded species from southern Africa. Mechthilde Mennicken (Mennicken & Oberwinkler 2004, Mennicken et al. 2003, 2005a, 2005b, 2005c) and Reinhard Berndt (Berndt 2007, 2008a, 2008b, 2009, 2010, 2020, Berndt & Uhlman 2006, Berndt & Wood 2012, Berndt et al. 2008, Ritschel et al. 2007) and their co-workers, significantly increased the knowledge of rust fungi in the west of the region. Together they described 51 new species and recorded an additional 33 from Namibia and South Africa. As a result, the number of rust fungi known from Namibia increased from 16 to 68. More distribution records and new species remain to be found as many areas remain poorly collected. In particular, Mozambique and Angola should yield many more records.

The circumscription of rust families and genera have a convoluted history; however, a degree of order was brought to rust taxonomy by Cummins and Hiratsuka (1983, 2003) whose taxonomic scheme was based on the morphology of teliospores and spermogonia. Subsequently, it has been shown that various of their families and genera are polyphyletic (Aime 2006, Aime et al. 2017, 2018), and a new taxonomic scheme has been proposed (Aime & McTaggart 2021) based on phylogenetic data and morphology. This latest taxonomy has been followed in the current list.

Methods

Old and new literature was searched for records of rust fungi occurring in southern Africa. Farr and Rossman (2024) (initially http://nt.ars-grin.gov/fungaldatabases/, now https://fungi.ars.usda.gov/) was a useful source of distribution data about various species included. Old literature was sourced from the CyberLiber web page in CyberTruffle (http://www.cybertruffle.org.uk/eng/index.htm), the Biodiversity Heritage Library (http://www.biodiversitylibrary.org/), and JSTOR (https://www.jstor.org).

This checklist consists of two parts (Supplement 1 and 2). The first is a list of all rust fungi recorded from southern Africa, and the second a list of all their host plants, recorded in alphabetical order according to family, genus and species. The entries in Supplement 1 are presented in the order: rust species and authority, [synonyms published after Doidge (1950), refer to this publication for older synonyms], family of host plant(s), genus/genera of host plant(s), references, distribution and spore stages recorded (based on their morphology). Rust species occurring on plants not indigenous to southern Africa (alien, including crop plants and naturalised alien plants) are indicated by 'A' appearing at the beginning of the entries, and are in purple. The authorities are according to Index Fungorum (http://www.speciesfungorum.org), which is also a useful resource to check the current status of many species.

Doidge (1950) served as the starting point of this checklist, her list was copied and then all changes to nomenclature and new records published subsequent to that work are listed, with the page number of the specific record. Spore stages present for each species were determined from the references listed. Additionally, for widespread species, details were obtained from Arthur (1962) and Wilson and Henderson (1966). Where available, literature on various aspects of the biology of the species is included. For listings of earlier literature and synonyms, Doidge (1950) should be consulted, however, for completeness an attempt was made to include all published names with type specimens collected in southern Africa. Abbreviations indicating distribution are: A = Angola, B = Botswana, L = Lesotho, M = Mozambique, N = Namibia, SA = South Africa, SZ = Eswatini (formerly Swaziland), and Z = Zimbabwe. The type of pustule (spore) morphology is indicated with the notation of O, I, II, III and X for spermogonia, aecia (aeciospores), uredinia (urediniospores), telia (teliospores) and mesospores (this last in *Puccinia* only), respectively. In a few cases where uredinia associated with spermogonia differ to those not associated, this is denoted by I^{II}, $\mathrm{II}^{\mathrm{II}}$. Endocyclic species are denoted with $\mathrm{I}^{\mathrm{III}}$. Autoecious species are indicated with all known spore types within one set of parentheses e.g., (O, I, II, III), and heteroecious species are indicated by using two sets of parentheses e.g., (O, I) (II, III). For heteroecious species, the name of the aecial stage (gametothallus) is given in brackets, as well as an entry similar to the above, after the end of the entry on the telial stage (sporothallus). Additional notes are given after the species entry.

In Supplement 2, the host entries are listed in the order: plant family, plant species and authority, rust species, reference(s). Host plants not indigenous (alien) to southern Africa are indicated by '*' at the beginning of the entry. The taxonomy of the host plants was initially according to Germishuizen and Meyer (2003), though where possible more recent synonyms have been applied. The Plant List (http://www.theplantlist.org/) and more recently WorldFloraOnline (http://www.worldfloraonline.org/) were useful resources to verify plant names and authorities, as well as to find current names for some of those used in the older literature. Note that the plant taxonomy used follows that according to WorldFloraOnline and not the names as used in Plants of southern Africa (https://posa.sanbi.org/sanbi/Explore). Some host names may therefore differ to the name commonly used currently in South African literature. Only one resource of those available was chosen to ensure consistency. Host plant family names are according to the Angiosperm Phylogeny Group (APG IV) (2016), Stevens (2001 onwards) and WorldFloraOnline (http://www.worldfloraonline.org/).

Results

A total of 631 rust taxa occur in southern Africa, including 550 species indigenous to the region, and a further 78 that have been accidentally or deliberately introduced (Figure 1–3). Three unidentified species (in *Puccinia* and *Uredo*) have also been listed, possibly representing new taxa. These represent a total of 47 genera, with representatives in 5 suborders and 10 families recognised in Aime and McTaggart (2021).

The generic limits for various rust genera are still not certain as phylogenetic data from their type species are not yet available, therefore species have only been reasigned where DNA sequence data is available to confirm their generic placement. As far as possible, various species of *Uredo* and *Aecidium* have been assigned to suborders based on morphology or DNA sequence data. It is likely that new genera will be described in the future to accommodate various species that are currently of uncertain placement.

Compared to Doidge (1950), many more genera are recognised and the number of species recognised within many genera has increased (Table 1), particularly in *Hemileia*, *Phakopsora sensu lato*, *Ravenelia sensu lato*, *Endophyllum*, *Puccinia* and *Uromyces*. Despite many species of *Uredo* being assigned to teleomorph species, the total number recognised (35) is similar to that in Doidge (1950) (40) due to more species being recorded. The only genus with a reduction in species recognised is *Aecidium* (93 to 76), mainly due to a number being recognised as endocyclic (a total of 9 species in this list compared to one in Doidge, 1950), as well as a few that have been linked to their sporothallus.

The rust fungi of southern Africa have been recorded on a total of 1 355 host plant taxa in 84 families, including both indigenous and alien plants. The host families with the greatest number of host species are the Asteraceae, Poaceae and Fabaceae accounting for almost 40% (Table 2) as is common for rust funga elsewhere. More unusually, the Iridaceae and Rubiaceae include many host species (Table 2). Many host species have only been identified to genus level, and occasionally some only to a family, due to generic limit changes in plant taxonomy. Recollecting these rust fungi and identifying their host plants is required.

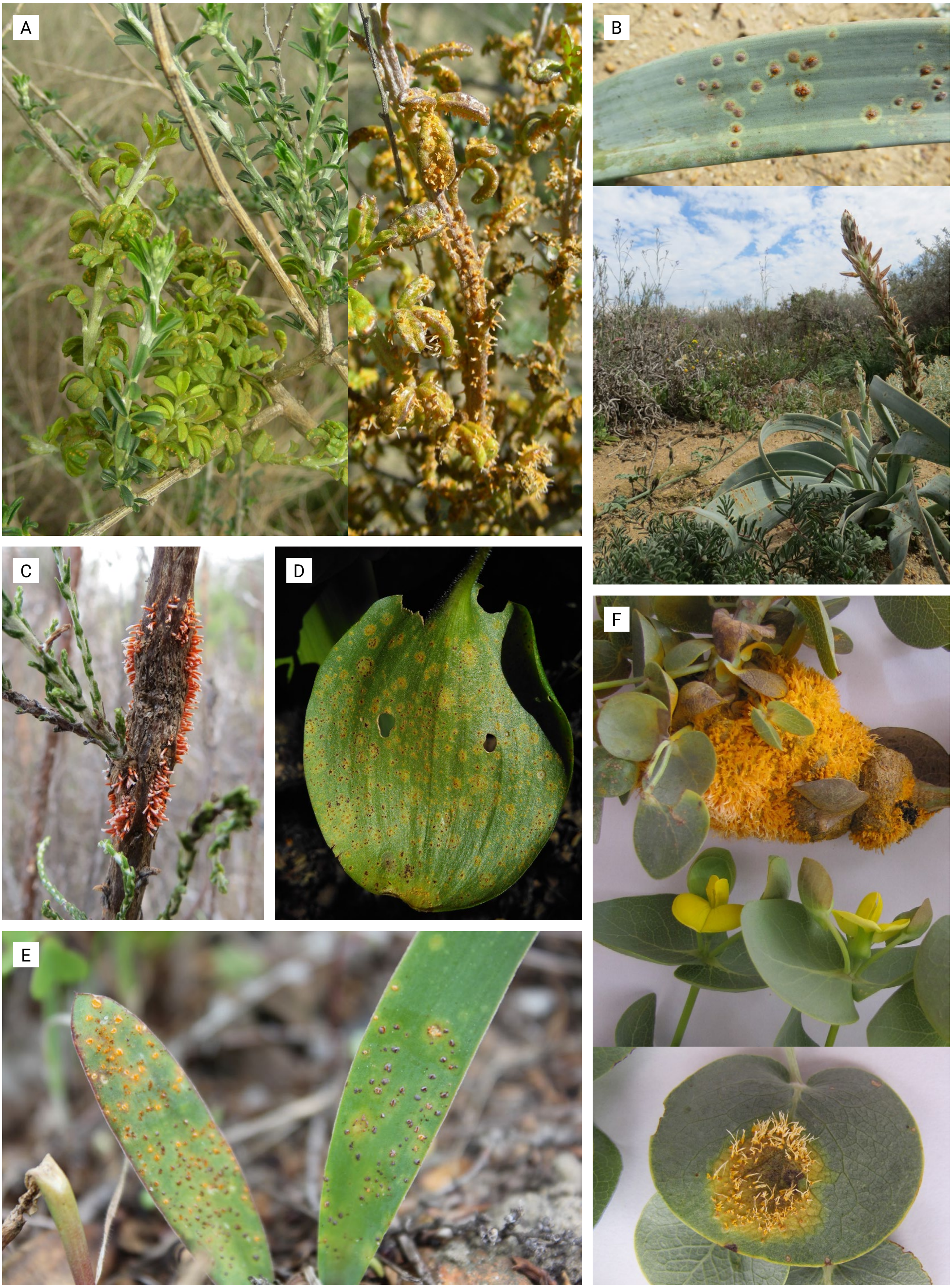

Figure 1. Examples of rust fungi indigenous to southern Africa: A, witches' broom with aecia of *Aecidium wiborgiae* on *Wiborgia obcordata*; B, uredinia of *Puccinia polycampta* on leaves of *Trachyandra falcata*; C, aecidioid-telia of *Endophyllum elytropappi* on galled stems of *Elytropappus rhinocerotis*; D, spermogonia, aecia, uredinia and telia of *Uromyces eriospermi* on abaxial leaf of *Eriospermum* sp.; E, uredinia and telia of *Uromyces lachenaliae* on *Lachenalia unifolia*; F, stem gall and leaf pustule of aecia of *Aecidium resinicola* on *Rafnia amplexicaulis*.

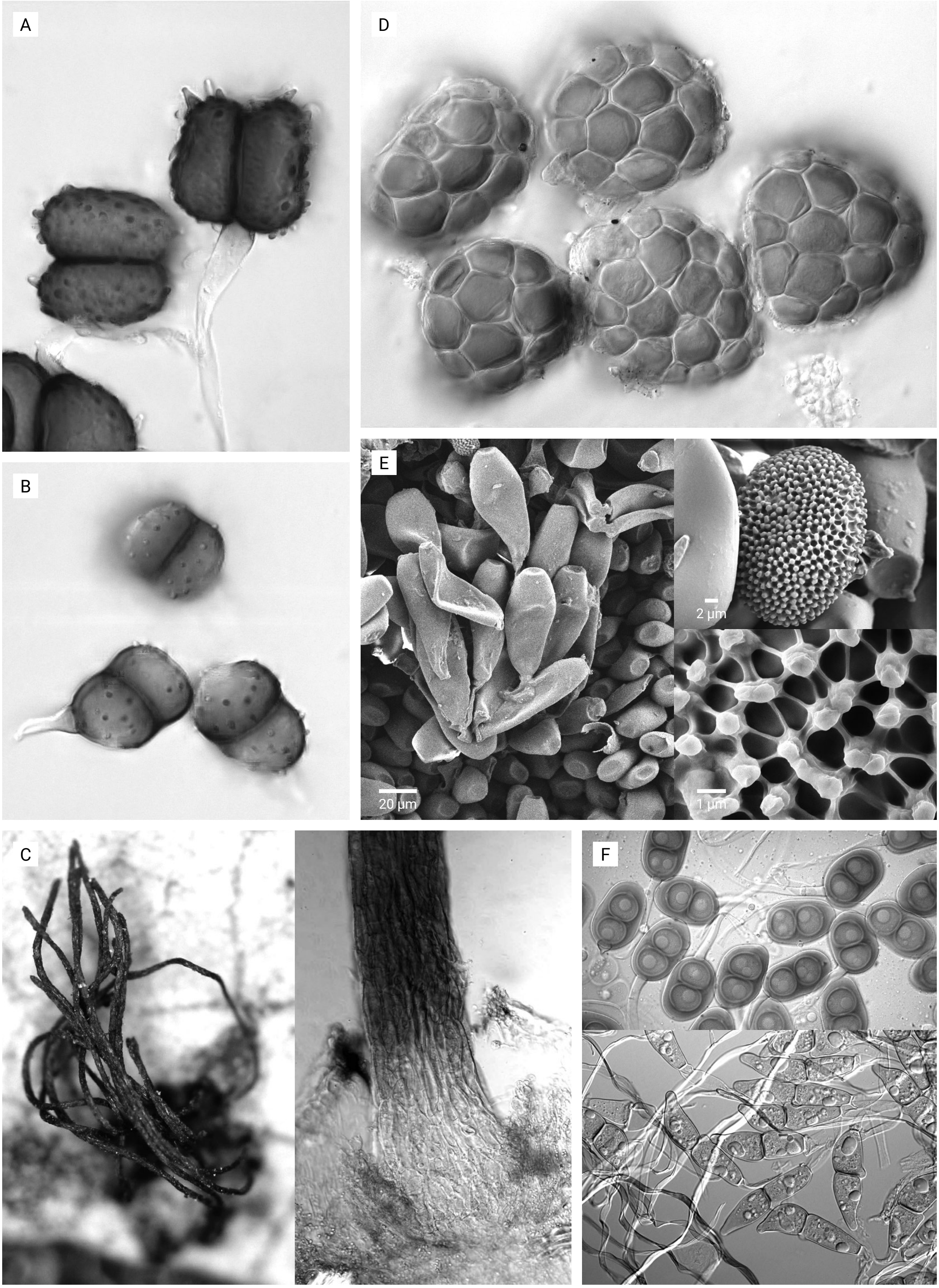

Figure 2. Teliospores of various genera of rust fungi from southern Africa: A, *Diorchidium woodii*; B, *Puccorchidium popowiae*; C, telial horns of *Crossopsora gilgiana* (left) and cross-section of base of horn in telium (right); D, *Cephalotelium macowanianum*; E, *Maravalia mimusops* teliospores in a telium, urediniospore (top right) and detail of ornamentation of urediniospore (bottom right); F, *Puccinia* cf. *asparagi* on top and *Puccinia berkheyaephila* on bottom.

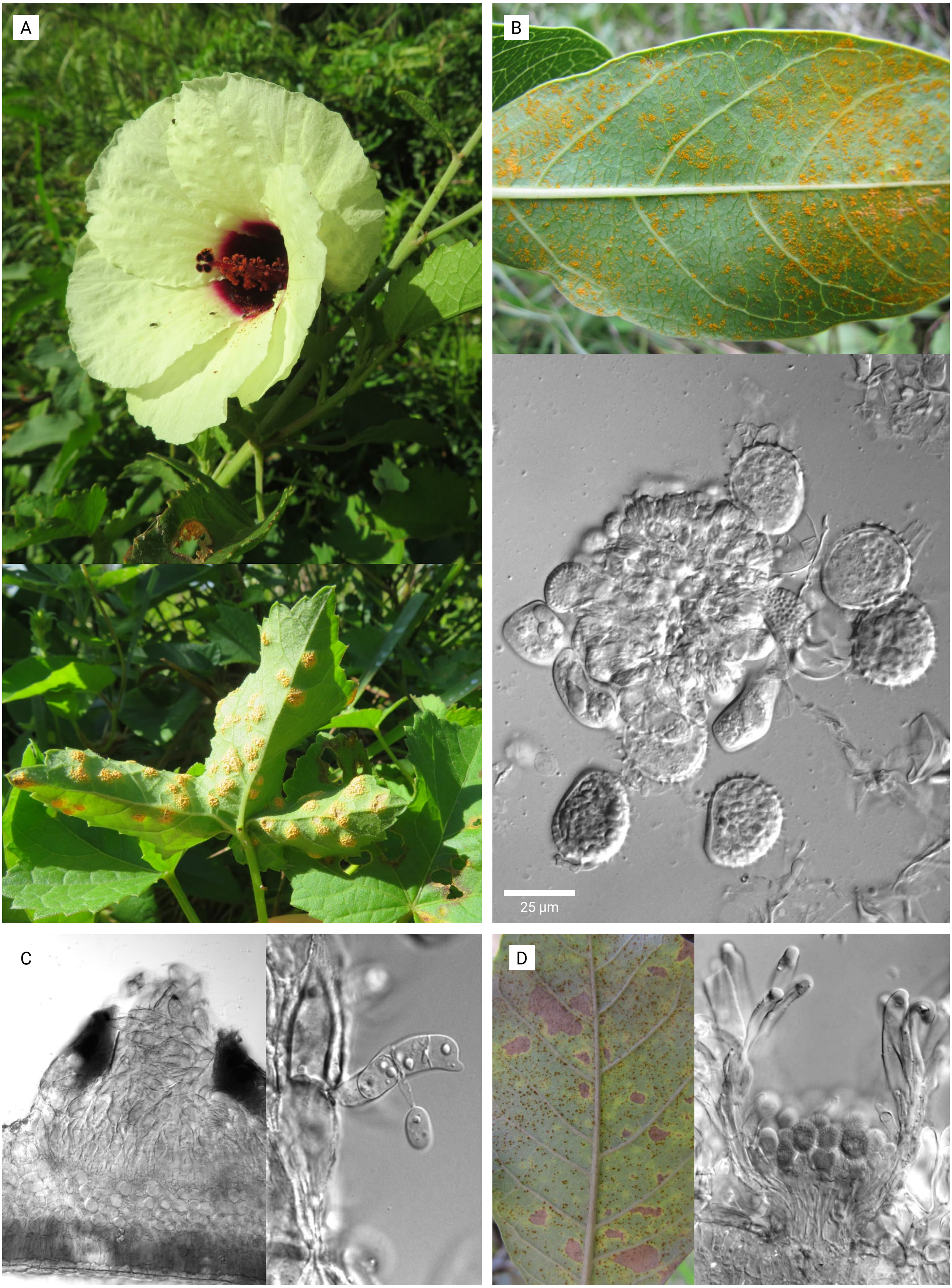

Figure 3. Examples of rust fungi indigenous to southern Africa: A, aecidioid-telia of *Endophyllum mpenjatiense* on its host plant *Hibiscus calyphyllus*; B, suprastomatal uredinia of *Hemileia woodii* on *Vangueria bowkeri* (top) and a uredinium with sporogenous cells and urediniospores of *Hemileia wakefieldii* (bottom) (top view of whole uredinium with spores around the edges); C, cross-section through a telium of *Skierka robusta* (left) and teliospores of which one has germinated producing a metabasidum with one basidiospore (right); D, uredinia of *Crossopsora brachylaenae* on *Brachylaena rotundata* (left) and cross-section through a uredinium (right).

Table 1. Comparison between genera and number of species of the rust fungi (Pucciniales) recognised in Doidge (1950) and in this checklist. Genera without a footnote are unassigned with undetermined affinities

Doidge (1950)		This checklist	
Aecidium	93	*Aecidium*[a]	81
		'Aecidium'[b]	4
		Angiopsora[a]	2
		Angusia[b]	1
		Austropuccinia[a]	1
		Bubakia[b]	2
Caeoma	2	*Cephalotelium*[b]	5
Cerotelium	1	*Cerotelium*[b]	1
Coleosporium	3	*Coleosporium*[c]	4
Cronartium	2	*Crossopsora*[a]	7
		Cumminsina	1
		Cystotelium[b]	1
		Didymopsorella	1
		Dietelia[a]	1
Diorchidium	2	*Diorchidium*[b]	2
		Elateraecium[d]	2
Endophyllum	1	*Endophyllum*[a]	9
Hamaspora	1	*Hamaspora*[a]	1
Hemileia	6	*Hemileia*[d]	12
Kuehneola	1	*Kuehneola*[a]	1
		Macuropyxis[a]	1
		Maravalia[b]	2
Masseeëlla	1	*Masseeëlla*[b]	1
Melampsora	5	*Melampsora*[c]	10
Milesina	2	*Milesina*[c]	4
		Miyagia[a]	1
		Neoravanelia[b]	1
		Newinia[b]	1
		Phakopsora[b]	8
		'Phakopsora'[a]	3
Phragmidium	1	*Phragmidium*[a]	2
Puccinia	158	*Puccinia*[a]	247 (+1)[e]
Pucciniastrum	1	*Pucciniastrum*[c]	2
Pucciniosira	1	*Pucciniosira*[a]	2
		Puccorchidium[a]	1
		Quasipucciniastrum[c]	1
Ravenelia	22	*Ravenelia s.l.*[b]	31
Schroeteriaster	2		
Skierka	1	*Skierka*[f]	1
Sphaerophragmium	2	*Sphaerophragmium*[a]	4
		Spumula[b]	1
		Stomatisora[a]	1
		Trachyspora[a]	1
		Tranzschelia[b]	1
Uredinopsis	1	*Uredinopsis*[c]	1
Uredo	40	*Uredo*[a]	37 (+2)[e]
		'Uredo'[d]	1
		'Uredo'[b]	3
		'Uredo'	2
		Uredopeltis[b]	6
Uromyces	89	*Uromyces*[a]	104
		Uromycladium[b]	3
Uropyxis	2	*Uropyxis*[b]	1

[a]Genera included in the Uredinineae. [b]Genera included in the Raveneliineae. [c]Genera included in the Melampsorineae. [d]Genera included in the Mikronegeriineae. [e]Number of unidentified species recorded in southern Africa. [f]Genera included in the Skierkineae.

Table 2. The fifteen plant families with the greatest number of species recorded as host plants (both indigenous and alien) of the southern African rust fungi

	Host family	Number of host taxa
1	Asteraceae	195
2	Poaceae	176
3	Fabaceae	169
4	Iridaceae	96
5	Asparagaceae	67
6	Rubiaceae	54
7	Cyperaceae	41
8	Lamiaceae	35
9	Euphorbiaceae	32
10	Xanthorrhoeaceae	29
11	Malvaceae	27
12	Acanthaceae	23
13	Aizoaceae	24
14	Geraniaceae	21
15	Rosaceae	21

Taxonomy

New species

1. **Sphaerophragmium senegaliae**

A.R.Wood, sp. nov.

HOLOTYPE: SOUTH AFRICA, **KwaZulu-Natal**: Hluhluwe-iMfolozi Park, Hilltop camp, on *Senegalia brevispica* (Harms) Seigler & Ebinger (Fabaceae), 25 Jul. 2018, *A.R. Wood 988* (PREM 63114); GenBank: 28S = OQ215083

MycoBank: MB 836557.

Description

Spermogonia and aecia not observed. *Uredinia* scattered on pinnules, tiny, 0.1–0.2 mm, erumpent, surrounded by paraphyses which barely extend beyond torn epidermis. *Urediniospores* produced on pedicels, ellipsoid, oval, obovoid to pyriform, 28–45 × 15–20 μm (mean 36.3 × 17.4 μm), light brown, 2 equatorial germ pores (often 1 distinct and 1 indistinct), wall sparsely echinulate, spines 1–3 μm (mean 2.6 μm) apart, walls 1–2 μm thick, apex slightly thickened 3–5 μm thick. *Paraphyses* more or less curved, cylindrical or slightly clavate, 1 septate, united basally, 35–65 × 10–15 μm, walls 4–6 μm thick but frequently no lumen present as entire width thickened. *Teliospores* produced in uredinia, becoming dominant; spherical, dark brown, 6–9 cells, typically 8 cells, 37–52 × 33–48 μm (mean 45.8 × 40.8 μm), walls on outer cell surfaces 2–3 μm, internal cell walls 1–2 μm, 24–42 tri- to sexfurcate projections per spore (with 2 or 3 primary branches each with 1, 2 or 3 hooks on these branches), 5–16(–20) μm long (mean 11.4 μm), pedicel persistent, up to 80 μm long, 6–8 μm wide, wall 1 μm thick. Figure 4A–4F.

Etymology

Named for the genus of the host plant, *Senegalia*.

Diagnosis

Similar to *Sphaerophragmium dalbergiae* but distinguished by different host, larger urediniospores and longer teliospore projections.

Notes

Using the morphological key to species in Monoson (1974), this specimen keys to *S. dalbergiae* Dietel, and to *S. fimbriatum* Mains in Lohsomboon et al. (1994). It differs from the former species by larger urediniospores with thickened apices and distinct germ pores, and longer teliospore projections, and from the latter by larger and more thickened paraphyses, urediniospores with less thickened apices and only 2 distinct germ pores, and the teliospores with longer projections. The combination of urediniospores and teliospores present in the same paraphysate pustules, urediniospores with 2 germ pores and thickened apices, teliospores with ~8 cells and projections up to 16 μm long and 3– to 6–furcate, is unique in the genus (Monoson 1974, Lohsomboon et al. 1994). A sequence (OQ215083) of the nuclear large subunit (28S) region of the ribosomal DNA repeat has been published (Wood & Aime 2024).

2. **Maravalia neomimusops**

A.R.Wood, sp. nov.

= *Uromyces mimusops* Cooke fide Doidge (1927), Bothalia 2(1a): 15, pro parte.

HOLOTYPE: SOUTH AFRICA, **North West**: Paaskraal, Magaliesberg, on *Mimusops zeyheri* Sond. (Sapotaceae), 31 Oct. 1998, *S. Neser* (PREM 56225, II + III);

MycoBank: MB 836558.

Description

Spermogonia and aecia not observed. *Uredinia* hypophyllous, single 0.25–1.0 mm or several forming a ring to 2 mm diam., dark brown, subepidermal, erumpent, aparaphysate, densely packed with hyphal elements that are interpreted as spore initials and pedicels originating from columnar sporogenous cells each with many initials. *Urediniospores* globose to ellipsoid, usually flattened on opposite sides so that they are bilaterally symmetrical, apex rounded, base rounded or attenuate, 27–45 × 20–28 μm; wall bilaminate, inner wall golden-brown, smooth, 2–3(–5) μm, outer wall hyaline, reticulate verrucose, with smooth area (or verrucae reduced in size) in centre of flattened sides, 1–2 μm; germ pores 1 or 2, consistent in number for individual collections, indistinguishable if not in median view. *Teliospores* produced in uredinia apparently from same spore initials as urediniospores, leptosporic, clavate, apex rounded, base gradually attenuate, light yellow-brown, (45–)50–65(–83) × 17–30 μm, large apical germ pore, wall 1.0–1.5 μm thickening to 2–3 μm around the germ pore. Figure 5A–K.

Etymology

Previously confused with *Maravalia mimusops*, hence the ‘new species of *Maravalia* on *Mimusops*’.

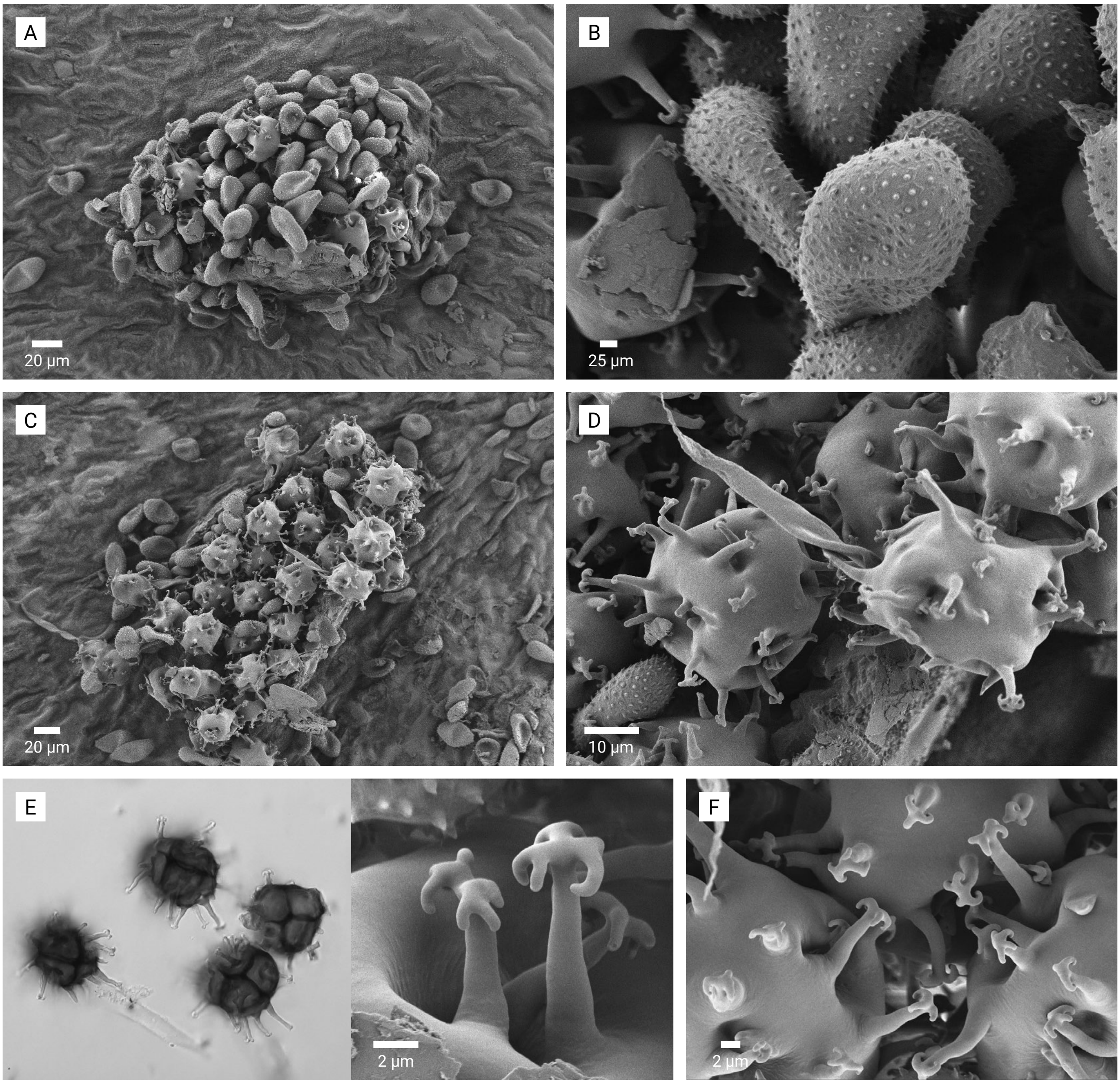

Figure 4. *Sphaerophragmium senegaliae*, A, uredinium; B, urediniospores; C, telium; D, teliospores; E, teliospores (left), showing detail of projections (right); F, teliospore projections.

Diagnosis

Similar to *Maravalia mimusops* but differs in smaller pustules and urediniospores with 2 basal germ pores.

Specimens examined

SOUTH AFRICA, **North West**: De Kroon, Brits, on *Mimusops zeyheri*, 12 Feb. 1926, Malherbe (PREM 12807, II only); Kloof, Rustenburg, on *Mimusops zeyheri*, 27 Oct. 1928, L. *Kresfedder* (PREM 23629, II + few III); Kromrivier, 9 miles [14 km] from Buffelspoort, on *Mimusops zeyheri*, 14 Dec. 1938, *E.M. Doidge & A.M. Bottomley* (PREM 32740, II only); Zilkatsnek, Magaliesberg, on *Mimusops zeyheri*, 18 Nov. 1953, *A. Meeuse* (PREM 40673, II only); Easter Kloof, Magaliesberg, on *Mimusops zeyheri*, 30 Aug. 2010, *A.R. Wood 786* (PREM 63121, II + few III). **Gauteng**: Klein Wonderboom, Magaliesberg, Pretoria, on *Mimusops zeyheri*, 20 Apr. 1932, *H.O.D. Mogg 12425* (PREM 26367, II only). **Limpopo**: University of Limpopo, Ga-Mankoeng, E of Polokwane, on *Mimusops zeyheri*, 7 Mar. 2019, *M. Shadrack* (PREM 63201, II only); University of Limpopo, Ga-Mankoeng, E of Polokwane, on *Mimusops zeyheri*, 8 Jun. 2019, *M. Shadrack* (PREM 63203, II only).

Notes

Maravalia mimusops (Cooke) Y.Ono (from Africa) and *M. aulica* (Syd.) Y.Ono (from India), both on species of *Mimusops* (Sapotaceae), are the only species currently

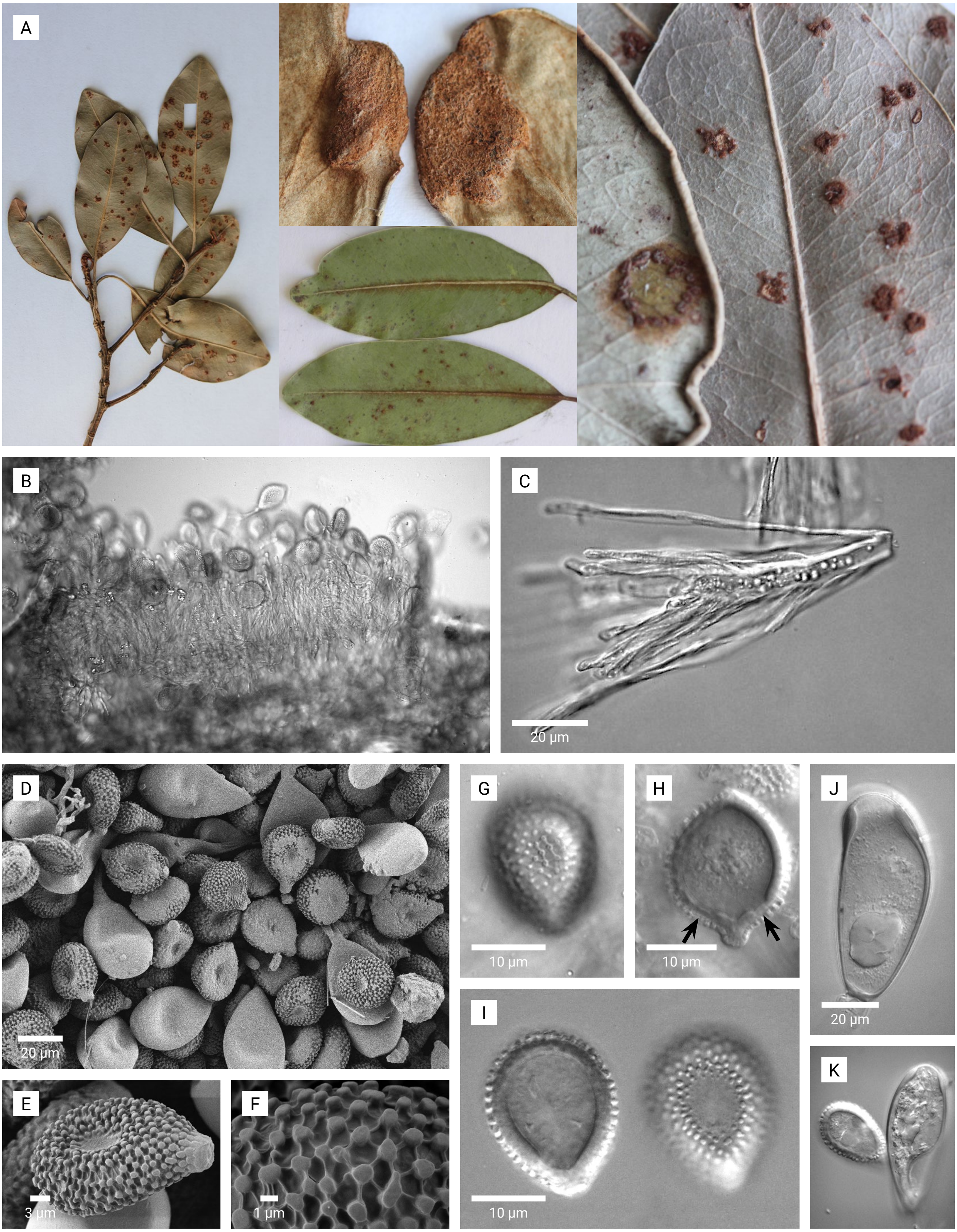

Figure 5. *Maravalia neomimusops*, A, habit on *Mimusops zeyheri*, left showing holotype with uredinia in which teliospores were found, middle with uredinia and for comparison insert showing large group of uredinia (uredinioid-aecia) of *S. mimusops* on hypotrophic areas on *Mimusops afra*, right comparison of size between *M. mimusops* on *Mimusops afra* (leaf on left) and *M. neomimusops* on *Mimusops zeyheri*; B, cross-section through uredinium showing densely packed pedicels; C, hyphal sporogenous cell with numerous thin pedicels attached along sides and apex; D, uredinium with scattered teliospores; E, urediniospore with equatorial smooth area; F, detail of reticulate verrucose ornamentation of urediniospore; G, surface view of urediniospore showing ornamentation; H, median view of urediniospore showing two germ pores (arrows); I, urediniospore in median and surface view showing equatorial smooth area; J, teliospore showing large apical germ pore; K, comparison of size of teliospore and urediniospore.

recognised within *Maravalia* to have urediniospores with a bilaminate wall and verrucose ornamentation (Cummins 1950, Ono 1984). They are distinguished by the urediniospores being verrucose with one germ pore in the former, and striately verrucose with two germ pores in the latter (Cummins 1950). All collections made in southern Africa have been considered until now to be *M. mimusops* (Doidge 1927, 1950, Cummins 1950, Ono 1984). Although morphologically very similar, there are consistent differences between collections from South Africa made on *Mimusops afra* E.Mey. ex A.DC. (note corrected orthography of the name following Art. 61.6, Turland et al. 2025) and those on *Mimusops zeyheri* Sond. On *Mimusops afra*, spermogonia are present with amphiphyllous uredinia (uredinoid aecia) of which many occur on slightly hypotrophic areas up to 2 cm wide, other hypophyllous pustules occur on round discoloured spots with the pustules forming one to several rings 2–6 mm wide. These latter pustules may have either both urediniospores and teliospores, or exclusively teliospores. The urediniospores have only one germ pore and no smooth area (though Ono, 1984, states there is one near the hilum). On *Mimusops zeyheri*, no spermogonia have been observed, all uredinia are hypophyllous and smaller (up to 2 mm wide), and teliospores infrequently produced (none were found in most specimens observed). The urediniospores had either 1 or 2 germ pores, more commonly the latter, and two equatorial smooth areas. The urediniospore dimensions are similar on both host species, but those on *Mimusops zeyheri* tend to be shorter and rounder (27–45 × 20–28 µm (n = 40) vs. 35–46 × 20–26 µm (n = 20) (30–43 × 16–25 µm in Cummins 1950) on *Mimusops afra*; average length 34.0 ± standard error (s.e). 0.63 µm vs. 40.4 ± s.e. 0.64; average length: width ratio 1:1.42 ± s.e. 0.034 vs. 1:1.78 ± s.e. 0.044). Because these differences are consistent, those on *Mimusops zeyheri* are here described as a new species, *Maravalia neomimusops*. The holotype (PREM 56225) was selected as it is the only specimen with teliospores in any number.

Maravalia aulica is similar to this new species, both having small uredinia and specimens are frequently without telia. Both have two germ pores in the urediniospores (Cummins 1950, Ono 1984). However, this species has spermogonia and the urediniospores (uredinoid aeciospores) are striately verrucose with a single bald patch towards the base (Ono 1984) (no spermogonia and two equatorial bald patches in *M. neomimusops*). All three species have teliospores that are morphologically almost identical and can’t be readily distinguished.

Doidge (1927) stated there are 2 or 3 germ pores per urediniospore in *M. mimusops*, whereas Cummins (1950) and Ono (1984) stated there is only one. This discrepancy may be explained by the fact that Doidge used specimens from both *Mimusops afra* and *Mimusops zeyheri* for her description. Thus, her description of urediniospores may have been influenced by those from *Mimusops zeyheri* (PREM12807), which is here recognised as a distinct species usually having two germ pores though in some specimens only one occurs. It was observed that germ pores were easily distinguishable only when they were in cross-section in median view on the sides of the spores, thus it would be hard to distinguish whether a spore had one or three germ pores. It is possible that those collections, such as the holotype, which were observed to have only one distinct germ pore, may have had three. Alternatively, Doidge (1927) may have come to the wrong conclusion. Specimens of *M. mimusops* (on *Mimusops afra*) examined were found to have only one germ pore, confirming the observations of Cummins (1950) and Ono (1984).

3. **Aecidium afrocanthii**

A.R.Wood, sp. nov.

HOLOTYPE: SOUTH AFRICA, **Eastern Cape**: Grahamstown Municipal Nature Reserve, S of Grahamstown, on *Afrocanthium mundianum* (Cham. & Schltdl.) Lantz (Rubiaceae), 27 Jan. 2000, *A.R. Wood 166A* (PREM 63113).

MycoBank: MB 836559.

Description

Spermogonia, uredinia and telia not observed. *Aecia* aecidium-like, yellow, single to small groups (1–4), occasionally groups coalesce to form larger groups, not on leaf spots, usually on abaxial leaf surface occasionally on adaxial surface, subepidermal, often deep-seated within leaf mesophyll, cupulate, peridium not extending beyond leaf epidermis, 150–280 µm diam. *Peridial cells* irregular angulate rhomboid, 16–29 × 14–26 µm, side wall 2–4 µm thick, inner wall coarsely verrucose to ridged, 3–5 µm thick, outer wall smooth to weakly verrucose, 1–2 µm thick. *Aeciospores* angular globose, 16–20(–28) × 14–20 µm, wall verrucose on upper portion grading to finely verrucose on lower portion, the verrucae not evenly sized, wall uniformly 1 µm thick. Figure 6A–C.

Etymology

Named for the genus of the host plant, *Afrocanthium*.

Diagnosis

Differs from other African species on Rubiaceae by no spermogonia, aecia single to small groups (1–4) and not protruding beyond leaf epidermis so that infections are inconspicuous, aeciospore wall uniformly 1 µm thick.

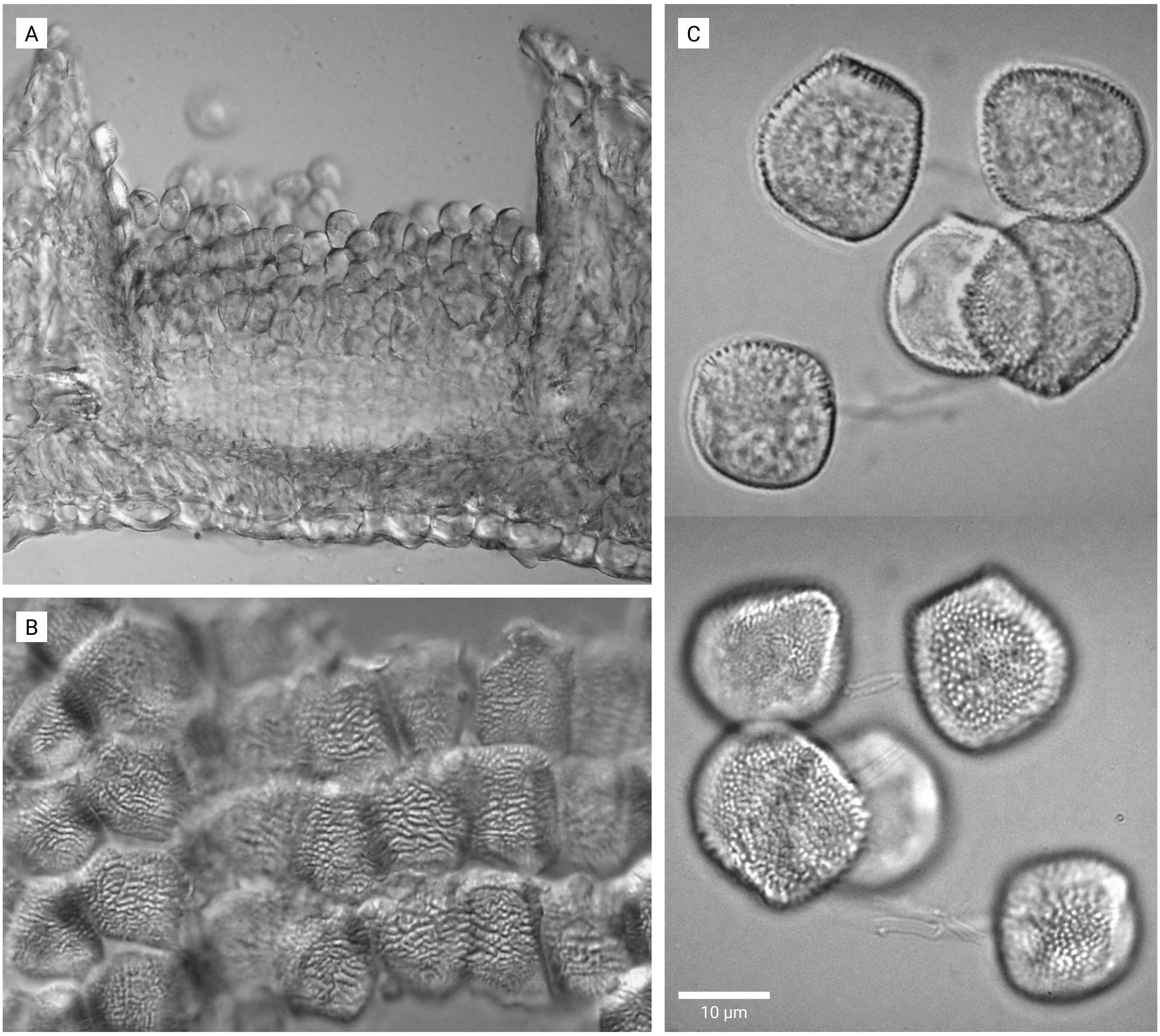

Figure 6. *Aecidium afrocanthii*, A, cross-section through a deep-seated aecidium showing catenulate production of aeciospores and the bounding peridium that typically does not extend beyond the leaf epidermis; B, peridial cells; C, median and surface views of aeciospores.

Specimens examined

SOUTH AFRICA, **Western Cape**: Garden Route National Park, Goudveld Forest Station, Knysna, on *A. mundianum*, 6 Jul. 2000, *A.R. Wood 195* (PREM 63142); Garden Route National Park, Wilderness, on *A. mundianum*, 20 Feb. 2002, *A.R. Wood 364* (PREM 63145); Newlands Forest, Cape Town, on *A. mundianum*, 23 Jul. 2009, *A.R. Wood 757* (PREM 63155); Fynbos Retreat, Gansbaai, on *A. mundianum*, 20 Feb. 2016, *A.R. Wood 967* (PREM 63165, GenBank: 28S = OQ214983, 18S = OQ215127, CO3 = OR789143).

Notes

This species differs from *Aecidium plectroniae* Cooke (considered to be the aecial stage of *Puccinia versicolor* Dietel & Holw.), which occurs on the same host, by the lack of spermogonia, aeciospore apex not thickened and its inconspicuous habit (*A. plectroniae* produces circles of aecia surrounding spermogonia, on leaf spots up to 1 cm diam., and aeciospore apices thickened to 5 *µ*m). *Aecidium baumianum* Henn., also occurring on the same host, is largely identical to *A. plectroniae* except spermogonia are not recorded, and therefore also differs from this new species by thickened aeciospore apices and habit. A total of 13 *Aecidium* species have been described from Africa on hosts in the Rubiaceae, but none have the combination of characters given in the diagnosis. A sequence of the nuclear large subunit (28S) region (OQ214983) and small subunit (18S) region (OQ215127) of the ribosomal DNA repeat, and the cytochrome c oxidase subunit 3 (CO3) (OR789143) of the mitochondrial DNA have been published (Wood & Aime 2024).

New combinations

1. **Elateraecium celastrineae** *(Cooke & Massee) A.R.Wood, comb. nov.*, *Uredo celastrineae* Cooke & Massee, Grevillea 17 (no. 83): 70 (1889).

TYPES: SOUTH AFRICA, **KwaZulu-Natal**, Durban, on *Salacia kraussii* (Harv.) Harv. (Celastraceae), Oct. 1888, *J.M. Wood 4028* [K (M) 147679, holo.; PREM 359 and 991, iso.].

MycoBank: MB 836560.

Description

Spermogonia scattered or forming concentric circles in large chlorotic spots up to 3 cm diam., subepidermal, flask-shaped, deep seated within leaf cortex, 100–175 μm wide, 200–274 μm high. *Aecia* erumpent, hypophyllous, blistering most of the leaf surface, epidermis remaining intact for long periods, contents appearing as a bright orange (when fresh) to light yellow (old specimens) fluffy mass due to presence of elaters. *Peridial cells* loosely connected, globose, 19–25 × 15–21 μm; wall 2 μm thick, very finely verruculose, verruculae ± 1 μm apart. *Elaters* modified persistent hyphae, thin walled, hyaline, irregularly branched, with simple septa, varying in width 4–8 μm. *Aeciospores* fusiform, 40–66 × 14–20 μm; wall granular-verrucose, 2 μm thick. Figure 7A–7E.

Specimens examined

SOUTH AFRICA, **KwaZulu-Natal:** Durban, on *Salacia kraussii* (Harv.) Harv. (Celastraceae), Oct. 1888, *J.M. Wood 4028* (holotype K(M) 147679, isotypes PREM

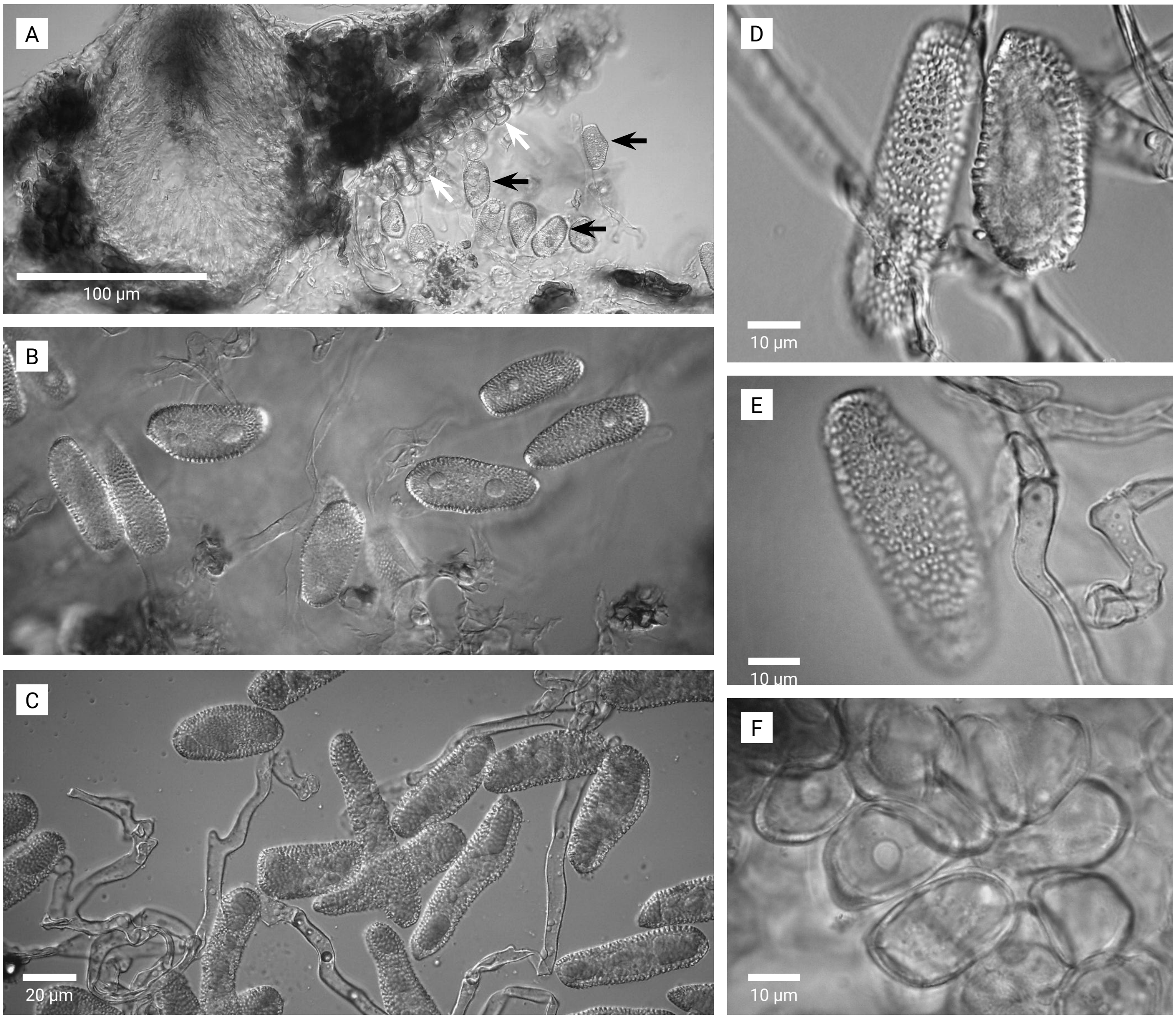

Figure 7. *Elateraecium celastrineae*, A, cross-section through deep-seated spermogonium and edge of an aecium showing peridial cells (white arrow) and aeciospores (black arrow); B, aeciospores; C, aeciospores and elaters; D, aeciospores showing coarse verrucose ornamentation; E, aeciospore showing ornamentation and septate elaters; F, peridial cells.

359 and 991); St Lucia, on *S. kraussii*, 19 Mar. 2020, *A.R. Wood 1073* (PREM 63115).

Notes

Sydow and Sydow (1924) considered that the urediniospores as originally described in Cooke (1889) were in fact peridial cells, and described in addition structures they interpreted as aeciospores. They were thus correct in interpreting the life stage of this rust as aecial not uredinial, but otherwise their interpretation is incorrect, the structures they thought were peridial cells are the aeciospores, and what they assumed were aeciospores are in fact the peridial cells. Doidge (1927) regarded this species as 'insufficiently known', noting that the material in PREM was 'practically destroyed by insects and is quite unfit for study'. She, like the Sydows before her, did not recognise the nature of this rust fungus. The old material is in fact in very good condition, with aeciospores and elaters present in large quantities. This species has been recently collected again, the first new record in 132 years.

This is the second species of *Elateraecium* known from South Africa, the other being *E. natalense* Gjærum & D.A.Reid (Gjærum and Reid 1983), on *Salacia leptoclada* Tul., distinguished by smaller aecia. *Elateraecium callianthum* (Syd.) Gjærum & D.A.Reid is described from *Salacia senegalensis* (Lam.) DC. in Sierra Leone. So far, the telial stage (Hiratsukamyces-like) has not been found for any of the African species.

2. **Endophyllum austroafricanum** *(Henn.) A.R.Wood stat. & comb. nov.*, *Aecidium mikaniae* Henn. f. *austroafricanum* Henn., Bot. Jahrb. 38: 105 (1907) (as 'austroafricana').

TYPE: TANZANIA, **Amani**: East Usambara Mountains, Sept. 1903, *Eichelbaum 104*, (B, holo., not seen, likely destroyed in World War II). MycoBank: MB 836561.

Description

Spermogonia not produced, aecia and uredinia not observed. *Telia* aecidium-like, numerous on small swellings on stems or petioles, or few in a cluster on lower leaf surfaces without any hypertrophy. *Teliospores* aecidioid, catenulate, ellipsoid, ovoid or angular-spherical, 17–24 × 14–20 µm; wall finely and densely verruculose, with several refractive granules 2–4 µm diam., wall 1 µm thick; germinating to form a thin-walled 3-celled metabasidium with two basidiospores produced on sterigmata from the two distal cells, basidiospores thin walled, ovoid, 13–17 × 8–10 µm. Otherwise as for *Aecidium mikaniae* Henn. Figure 8.

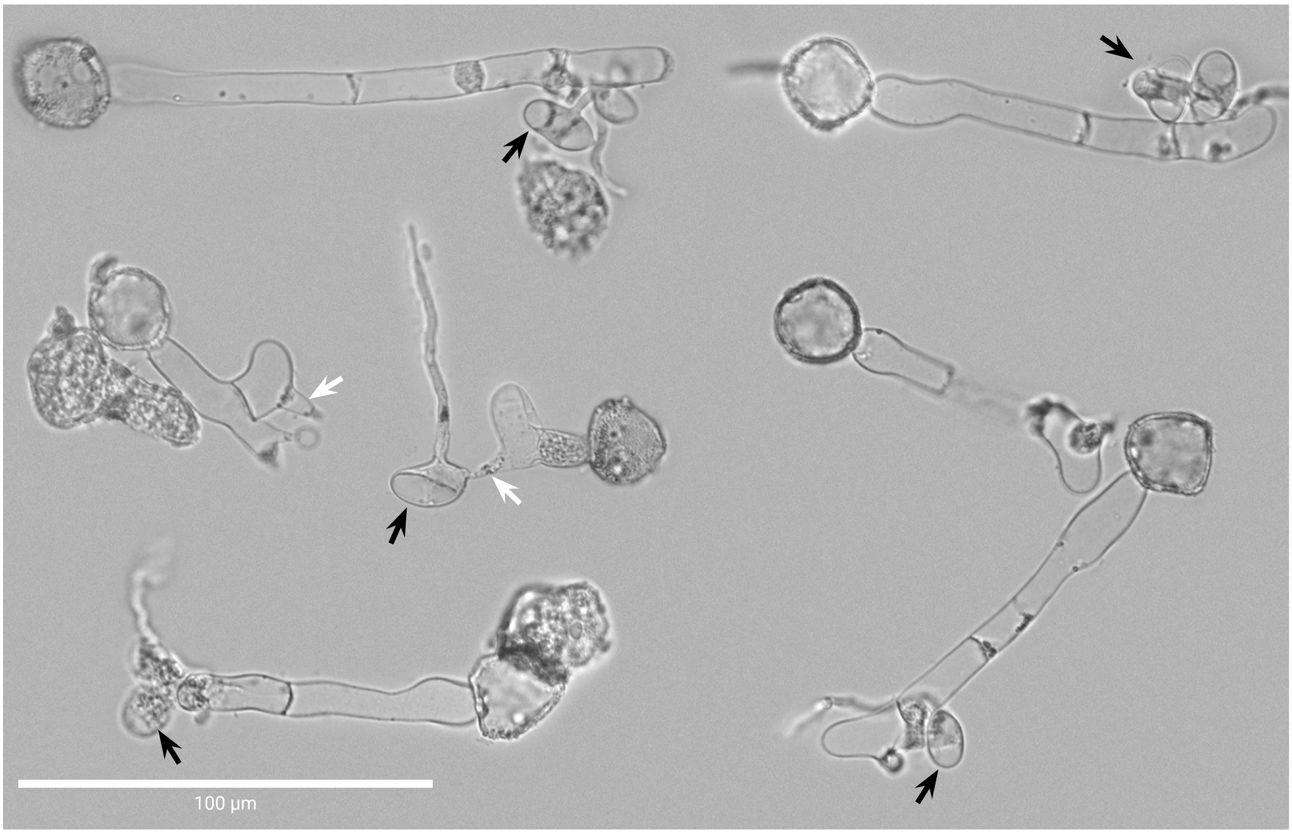

Figure 8. Germinated aecidioid-teliospores of *Endophyllum austroafricana* showing 1–3-celled metabasida, sterigmata (white arrows) and basidiospores (black arrows).

Specimen examined

SOUTH AFRICA, **KwaZulu-Natal**: Hilton, on *Mikania capensis* DC. (Asteraceae), 16 Jun. 2009, *A.R. Wood 756* (PREM 62322).

Notes

Hennings (1907) stated that this form of *Aecidium mikaniae* differed from the nominal form, which occurs in South America, only in having slightly larger spores. The nominal form is now considered to be the gametothallus of *Puccinia mikaniae* H.S.Jacks. & Holw. (Hennen et al. 2005). This appears to be the first collection of this rust fungus since the type was collected in the East Usambara Mountains, Tanzania, in 1903. However, it may be more common than this suggests – Whiteside (1966) reported *Dietelia portoricensis* (Whetzel & Olive) Buriticá & J.F.Hennen (as *Endophylloides protoricensis* Whetzel & Olive) from Zimbabwe, but this species is otherwise only known from South America and the Caribbean, and this record may rather represent *E. austroafricana*. Aecidioid-teliospores germinating on water agar (2% *w:v*) in Petri dishes produced sterigmata and basidiospores, proving that this is an endocyclic form (Figure 8), and therefore it is raised to species rank and transferred.

3. **Milesina silvae-knysnae** *(R.Berndt) A.R.Wood, comb. nov.*, *Milesia silvae-knysnae* R.Berndt, in Mycol. Prog. 7: 14, 2008.

TYPE: SOUTH AFRICA, **Western Cape**, N of Wilderness, Seven Passes Rd., Woodville Big Tree, 27 Oct. 2004, *R. Berndt & E. Uhlmann*, (PREM 59737, holo., not examined).

MycoBank: MB856041.

Morphology as described by Berndt (2008b). Use of *Milesina* is recommended over *Milesia* (Aime et al. 2018).

Newly recorded species for South Africa

1. **Aecidium jasminicola** *Henn.*, in Engler, Die Pflanzenwelt Ost-Afrikas und der Nachbargebiete, Teil C: 53 (1895).

Description

Spermogonia not produced, uredinia and telia not observed. *Aecia* hypophyllous or on stems, hypotrophic, cupulate, few to many, not arranged in rings, crowded, peridium not or only slightly exerted, yellow. *Aeciospores* globular to ellipsoid, 14–26 × 10–18 μm (18–24 × 15–18 μm in Hennings 1895), hyaline, wall 1 μm thick, closely verruculose.

Specimen examined

SOUTH AFRICA, **KwaZulu-Natal**: Pigeon Valley Nature Reserve, Durban, on *Jasminum breviflorum* Harv. (Oleaceae), 26 Jun. 2019, *A.R. Wood 1051* (PREM 63119).

Notes

Aecidium longaense Henn., also on *Jasminum* in Africa, differs from *A. jasminicola* by presence of spermogonia, aecia opposite spermogonia, hypophyllous, arranged in circles, peridium emerging from leaf, lacerated; aeciospores yellow, smooth walled and smaller (15–18 × 13–17 μm, vs. 18–24 × 15–18 μm in *A. jasminicola*) (Hennings 1895, 1903). The aeciospores of the specimen from South Africa included aeciospores that spanned the range of both species [14–21(–26) × 10–18 μm], but in other respects matched the description for *A. jasminicola* rather than *A. longaensis*. Figure 9A, 9B.

2. **Coleosporium plumeriae** *Pat.* [as ‘plumierae’], Bulletin de la Société Mycologique de France 18(2): 178 (1902).

Description

Uredinia only present, hypophyllous. *Urediniospores* subglobose, ellipsoid or angular, 25–37 × 19–25 μm, wall coarsely verrucose, 1 μm thick, with large to small verruculae and bald patches so that the wall is 2–3 μm in total.

Specimen examined

SOUTH AFRICA, **Eastern Cape**: Qolora River Mouth, Kei Mouth, E of East London, on *Plumeria* sp. (Apocynaceae), 2 Feb. 2021, *A.R. Wood 1123* (PREM 63271).

Notes

This species was first recorded from South Africa by a sequence of the large subunit (28S) of the ribosomal DNA repeat deposited in GenBank (KR110056) by W. Maier. Its presence is here confirmed. Elsewhere in Africa this fungus has been recorded in Nigeria (Hernández et al. 2005) and has spread through much of the world where its host plant is a commonly grown garden plant (Kakishima et al. 2017).

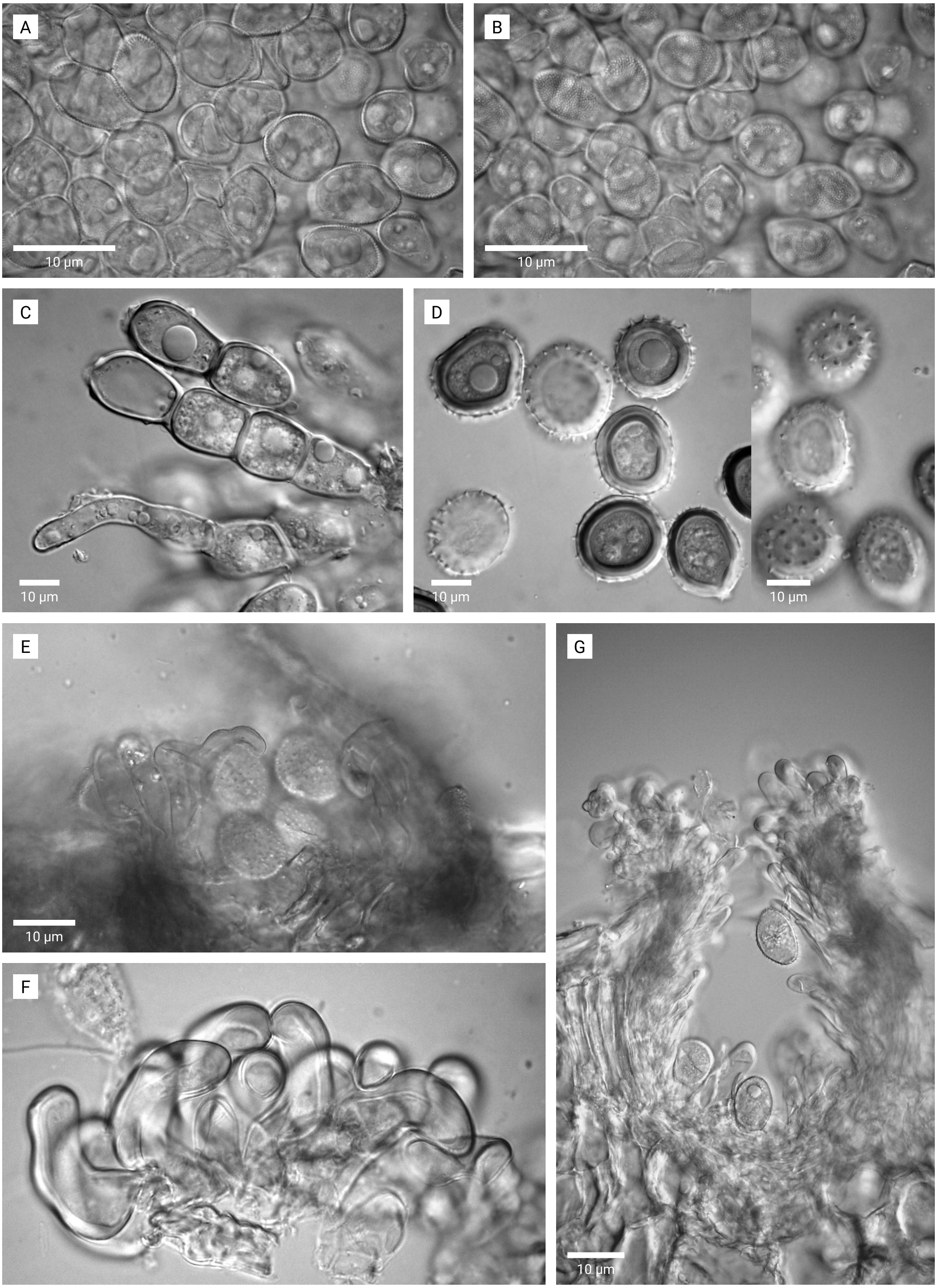

Figure 9. *Aecidium jasminicola*, A, median view of aeciospores; B, surface view of aeciospores. *Newinia kigeliae*, C, telia consisting of chains of cells, the terminal cell on the lowest chain producing a metabasidium; D, median and surface view of urediniospores showing sparce echinulation. *Phakopsora setariae*, E, cross-section through subepidermal uredinium; F, paraphyses. *Uredo dombeyicola*, G, cross-section through uredinium.

3. **Newinia kigeliae** *Eboh*, Mycologia 75(2): 316 (1983).

Description

Spermogonia, uredinia and telia on lesions 2–5 mm in diameter, amphiphyllous, brown. *Spermogonia* type 7. *Uredinia* subcuticular or subepidermal, with few long and thin-walled paraphyses scattered through the pustule. *Telia* subepidermal, no paraphyses. *Urediniospores* globose to ovoid, 19–25 × 17–20 µm, sparsely echinulate, 3–4 µm thick. *Teliospores* consisting of 4–12 cells in chains, cells separated by transverse septa, each cell globose to ovoid, 17–30 × 13–17 µm, wall 1 µm thick. Figure 9C, 9D.

Specimens examined

SOUTH AFRICA, **Limpopo**: Skukuza nursery, Skukuza, Kruger National Park, on *Kigelia africana* (Lam.) Benth. (Fabaceae), 8 Feb. 2022, *A.R. Wood 1200* (PREM 63384); **KwaZulu-Natal**: Twinstreams nursery, Mtinzini, on *Kigelia africana* (Lam.) Benth. (Fabaceae), 3 Mar. 2022, *A.R. Wood 1206* (PREM 63385).

4. **Phakopsora setariae** *Cummins*, Bulletin of the Torrey Botanical Club 83: 223 (1956).

Description

Uredinia small, erumpent, often covered by remnants of leaf epidermis, surrounded by paraphyses. *Paraphyses* curved, thick walled. *Urediniospores* ellipsoid, echinulate, spines 1–3 µm apart, 20–32 × 16–21 µm, wall 1 µm thick, germ pores indistinct. *Telia* not observed. Figure 9E, 9F.

Specimen examined

SOUTH AFRICA, **KwaZulu-Natal**: Palmiet Nature Reserve, Durban, on *Setaria megaphylla* (Steud.) T.Durand & Schinz (Poaceae), 27 Jun. 2019, *A.R. Wood 1058* (PREM 63116).

5. **Puccinia aframomi** Hansf., Proceedings of the Linnean Society London 161: 176 (1949).

Description

Urediniospores 21–32 × 14–17 µm, light brown to honey-coloured, wall 1.5–2 µm thick, 2 equatorial germ pores, sparsely echinulate. *Teliospores* 23–33 × 13–18 µm, constricted at septum, wall 1 µm thick, hyaline, apex occasionally thickened 2–3 µm. *Pedicels* not persistent. Figure 10A, 10B.

Specimen examined

SOUTH AFRICA, **Mpumalanga**: Lowveld National Botanical Garden, Nelspruit, on *Aframomum alboviolaceum (Ridl.) K.Schum*. (Zingiberaceae), 13 Dec. 2010, *A.R. Wood 810* (PREM 63118).

Notes

The host plant does not occur naturally in South Africa, but does so in Mozambique, Zambia and elsewhere in tropical Africa. The specimen collected was on cultivated plants, and it is likely to be found on this species where it grows naturally. This species has been recorded on other species of *Aframomum* in Malawi, Uganda and Nigeria (Farr & Rossman 2024).

6. **Puccinia arechavaletae** *Speg*., Anales de la Sociedad Científica Argentina 12(1): 67 (1881).

Description

Spermogonia, aecia and uredinia not present. Microcyclic, leptosporic. *Telia* amphigenous or on stems, not on leaf spots, expanding with age, forming circles of small dark brown pustules up to 10 mm diameter, turning light grey after spores germinate, neighbouring telia coalescing, may be slightly hypotrophic. *Teliospores* mostly two-celled, one-celled spores in low to moderate quantities, the proportions differing between collections, two-celled spores globoid, ellipsoid or oblong, 20–31 × 14–24 µm, not constricted at septum, lateral walls 1.5–3 µm, apex slightly thickened 2.5–4 µm, honey-brown, one-celled spores similar 20–24 × 15–20 µm, pedicels persistent, thin walled up to 60 µm, often obliquely inserted, some diorchidioid.

Specimens examined

SOUTH AFRICA, **KwaZulu-Natal**: Durban, University of KwaZulu-Natal, Westville campus, on *Cardiospermum grandiflorum* Sw. (Sapindaceae), 25 Jun. 2019, *A.R. Wood 1044* (PREM 63171); Hayfields, Pietermaritzburg, on *Cardiospermum grandiflorum*, 16 Feb. 2021, *A.R. Wood 1130* (PREM 63273). **Mpumalanga**: E of Nelspruit along N4, on *Cardiospermum grandiflorum*, 28 Feb. 2020, *A.R. Wood 1069* (PREM 63191). **Limpopo**: Letsitele, on *Cardiospermum grandiflorum*, 13 Mar. 2019, *A.R. Wood 1062* (PREM 63184); Louis Trichardt, on *Cardiospermum grandiflorum*, 25 Feb. 2020, *A.R. Wood 1068* (PREM 63190); Tzaneen, on *Cardiospermum halicacabum* L., 13 Mar. 2019, *A.R.*

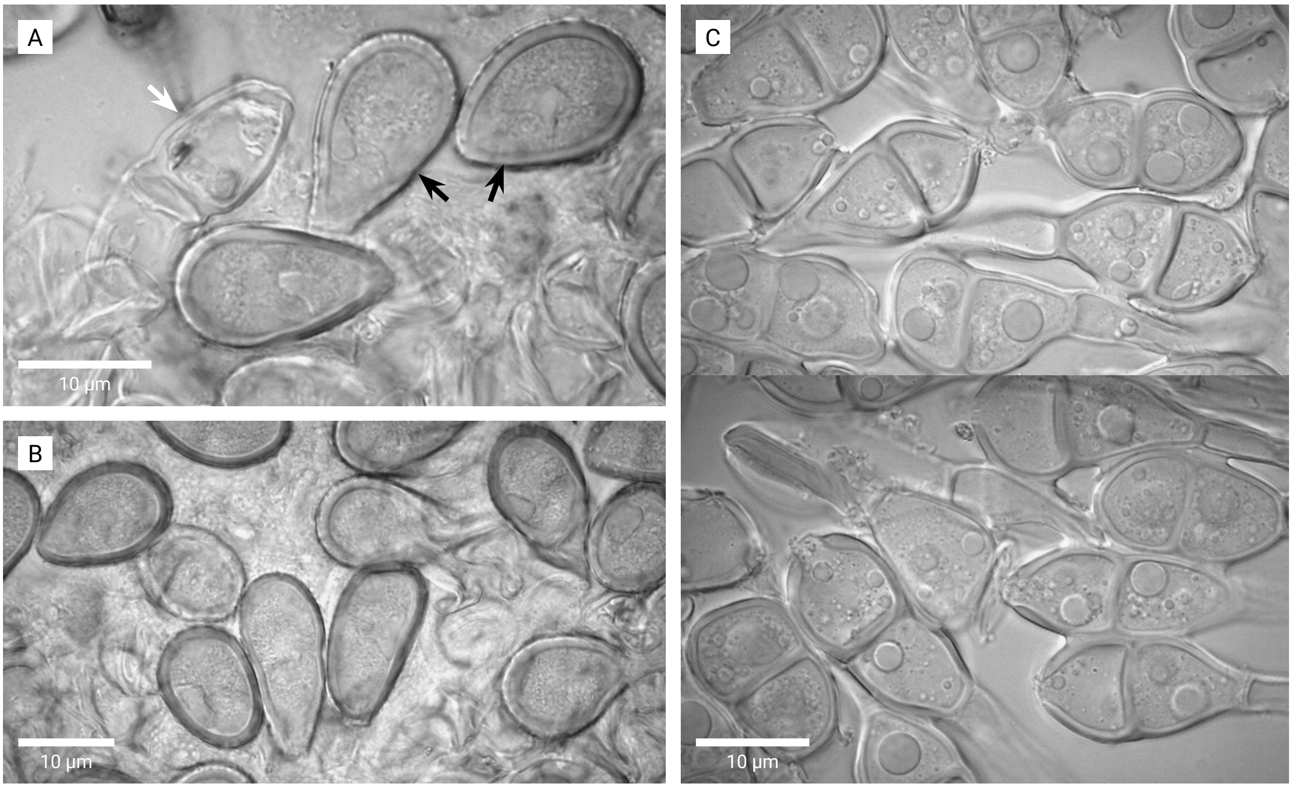

Figure 10. *Puccinia aframomi*, A, urediniospores (solid arrows) and thin-walled teliospores (white arrow); B, urediniospores. *Puccinia exilis* var. *hibisci*, C, teliospores.

Wood 1077 (PREM 63189). **Eastern Cape**: Port St John's, on *Cardiospermum grandiflorum*, 8 Oct. 2018, *I. Patterson* (PREM 63202).

Notes

Puccinia arechavaletae has been investigated for possible release as a biological control agent against the alien invasive plant *Cardiospermum grandiflorum* (Fourie & Wood 2018, 2019). However, an indigenous congeneric plant was found to be susceptible (*C. corindum* L.), and therefore the culture being studied within the plant pathogen quarantine facilities in Stellenbosch was destroyed in 2012. This rust fungus was first observed in 2018 in the field in KwaZulu-Natal. The pathway of introduction of this rust is unknown, it is one of a number of rust fungi recorded as introduced accidentally in the last few decades, a reminder that microbes are constantly being unintentionally carried across international borders.

7. **Puccinia exilis** *P.Syd. & Syd.* var. **hibisci** Grove, Bulletin of Miscellaneous Information, Kew: 270 (1916).

Description

Spermogonia, aecia and uredinia not present. Microcyclic, leptosporic. *Telia* erumpent, in groups up to 5 mm diam. *Teliospores* 27–41 × 15–18 μm, walls tinged with light yellow, thin, 1 μm thick at sides, apex 1–2 μm, germ pore at apex, distinct. *Pedicels* > 100 μm, thin walled, hyaline, persistent. Figure 10C.

Specimens examined

SOUTH AFRICA, **KwaZulu-Natal**: Pigeon Valley Nature Reserve, Durban, on *Hibiscus surattensis* L. (Malvaceae), 26 Jun. 2019, *A.R. Wood 1052* (PREM 63117).

8. **Uredo dombeyicola** *Cummins*, Bulletin of the Torrey Botanical Club 87(1): 41 (1960).

Description

Spermogonia, aecia and telia not observed. *Uredinia* small, subepidermal in origin, erumpent, surrounded by paraphyses that form an emergent palisade around the uredinia. *Urediniospores* ellipsoid, echinulate, spines 1–3 μm apart, (17–)22–33 × 16–21 μm, wall 1.0–1.5 μm thick, germ pores indistinct. Figure 9G.

Specimens examined

SOUTH AFRICA, **KwaZulu-Natal**: University of KwaZulu-Natal, Westville campus, Durban, on *Dombeya* *tiliacea* (Endl.) Planch. (Malvaceae), 27 Jun. 2019, *A.R. Wood 1059* (PREM 63185).

Notes

Uredo dombeyae, on the same host, is readily distinguished by the heavily thickened urediniospore walls.

Taxonomic notes

1. **Puccinia kalchbrenneriana** De Toni, Syll. fung. (Abellini) 7(2): 661 (1888).

= *Puccinia ornithogali* Kalchbr., in Kalchbrenner & Cooke, Grevillea 9, 49: 21 (1880). *nom. illegit.*, Art. 53.1 (later homonym of *Puccinia ornithogali* Hazsl.).

= ***Puccinia drimiae*** Van der Bijl, South African Journal of Science 23: 284 (1926), *stat. nov*.

Specimens examined

SOUTH AFRICA, **Western Cape**: De Hoop Nature Reserve, E of Bredasdorp, on *Drimia altissima* (L.f.) Ker Gawl (Asparagaceae), 18 Aug. 2001, *A.R. Wood 349* (PREM 62319); Die Plaas farm, Ouplaas, E of Bredasdorp, on *Drimia altissima*, 14 Oct. 2009, *A.R. Wood 759* (PREM 62318).

Doidge (1927) provides the most complete descriptions for *P. kalchbrenneriana* and *P. drimiae*. The descriptions are almost identical, though *P. drimiae* apparently differed by having occasional mesospores and slightly thicker teliospore walls (3–4 µm, compared to 2.0–2.5 µm in *P. kalchbrenneriana*). At that time, rust fungi on different host plant genera were considered as distinct even if morphologically very similar, *P. drimiae* was known on *Drimia* and *P. kalchbrenneriana* on *Urginea*. However, currently the latter plant genus is considered a synonym of the former. Collections of a rust fungus on *Drimia altissima*, the type host of *P. kalchbrenneriana* had teliospores that fitted the descriptions of both species. Teliospores 40–58 × 22–34 µm, wall 2–4 µm thick, occasional mesospores present (31–38 × 22–28 µm, wall 2 µm thick). Therefore, *P. drimiae* is best considered a synonym of *P. kalchbrenneriana*.

2. **Endophyllum rhamni-prinoides** *(Thüm.) A.R.Wood, stat. & comb. nov.*

Aecidium rhamni J.F.Gmel. f. *rhamni-prinoides* Thüm., Flora 60: 411 (1877) (as *Aecidium rhamni* Pers. f. *rhamni prinoides* Thümen); Types: SOUTH AFRICA, **Eastern Cape**, 'Boschberg' [Bosberg], Somerset East, on *Rhamnus prinoides* L'Hér. (Rhamnaceae), Oct. 1876, *P. MacOwan 933* (PREM20761, lecto.); **Western Cape**, Saasveld College, George, on *Rhamnus prinoides* L'Hér. (Rhamnaceae), 6 May 2003, *A.R. Wood 517* (PREM57835 holo-epitype; K(M)122449, BPI871504 iso-epitypes); GenBank: 28S = OQ215013.

= *Aecidium elegans* Dietel, Hedwigia 28: 180 (1889) (nom. illegit., Art. 53.1, a later homonym of *Aecidium elegans* Berk. & M.A. Curtis), currently recognised as *Uromyces elegans* (Berk. & M.A. Curtis) Lagerh.).

= *Endophyllum macowanianum* Pole-Evans, Report of the Transvaal Department of Agriculture 1906–1907: 165 (1908) (nomen nudum) (non *Endophyllum macowanianum* (Thüm.) A.R. Wood).

= *Endophyllum macowanii* Pole-Evans [as '*macowani*'], Report of the South African Association for the Advancement of Science 6(6): 252 (1909) (Nom. illegit., Art. 36 of Vienna rules then valid).

= *Endophyllum elegans* (Dietel) Pole-Evans, Annals of the Bolus Herbarium 2(4): 188 (1918).

MycoBank: MB 856043.

Etymology

Named for its host plant, *Rhamnus prinoides*.

Diagnosis

Telia aecidium-like, aecidioid-teliospores endocyclic, on *Rhamnus prinoides*. As described by Pole-Evans (1918).

Notes

Pole-Evans (1909) showed that the species collected by Peter MacOwan, first recorded by Thümen then described by Dietel as *Aecidium elegans*, should be transferred to *Endophyllum* and renamed it in honour of its collector as *Endophyllum macowanii*. However, the Vienna rules of Botanical Nomenclature had come into effect from 1 Jan. 1908, and therefore this name was invalidly published as it did not have a Latin diagnosis accompanying this new name [Art. 36]. Because of this, Pole-Evans (1918) published the name *Endophyllum elegans* providing a Latin description. This combination has been ignored since. Unfortunately, the basionym of this name is invalid as it is a later homonym of an existing name, making this combination also invalid. Therefore, a new name is provided, using the first name given for this species. A full description is provided by Pole-Evans (1918), and further details of spore germination in Wood (2004). The lectotype is MacOwan's collection listed in Dietel (1889), and an epitype is provided.

Pole-Evans first gave notice of his intention to make the above name change, but in doing so unintentionally published the name *Endophyllum macowanianum*, a nomen nudum ('I propose to describe and name this fungus as *Endophyllum MacOwanianum*, n.sp.' Pole-Evans 1908, p. 165). This fungus is different to the species currently known as *Endophyllum macowanianum* (Thüm.) A.R.Wood, as it was clearly identified as occurring on *Rhamnus prinoides* L'Hér. (Rhamnaceae) and was thought to possibly be the alternate stage of crown rust (Pole-Evans 1908). However, despite this name simply being a manuscript name invalidly published, it still renders the later name an invalid homonym, and a new name is provided. *Endophyllum macowanianum* Pole-Evans was not considered to be a published name by earlier workers and therefore was ignored in all subsequent publications (e.g. Pole-Evans 1909, 1918, Doidge 1950) and remained obscure.

3 **Endophyllum conyzae-scabridae** *A.R.Wood, sp. nov.*

Type: SOUTH AFRICA, **Eastern Cape,** 'Boschberg' [Bosberg], Somerset East, on *Conyza scabrida* DC. (Asteraceae) [incorrectly identified as *Erigeron ivifolius* Sch.Bip. (= *Conyza ivifolia* (L.) Less., as '*Conyza ivaefolia* Less.')], 1874, *P. MacOwan 1037* (PREM20753, lecto.).

= *Aecidium macowanianum* Thüm., Flora, Regensburg 58: 380 (1875).

= *Endophyllum macowanianum* (Thüm.) A.R.Wood, South African Journal of Botany 70(4): 667 (2004) (nom. illegit., Art. 53.1, a later homonym of *Endophyllum macowanianum* Pole-Evans, a nomen nudum).

MycoBank: MB 856044.

Diagnosis

Telia aecidium-like, aecidioid-teliospores endocyclic, spore wall uniformly thin, on *Conyza* species.

Etymology

Named for one of its host species, *Conyza scabrida* (Asteraceae).

Notes

Doidge (1927) and Wood (2004) listed *P. MacOwan 1037* (PREM20753) as the type.

Aecidium macowanianum f. *conyzae-pinnatilobatae* Thüm. was raised to species rank in Sydow and Sydow (1924), differing from the above species in having a thickened apical wall.

4 **Puccinia satyrii** *P.Syd. & Syd.*, Monographia Uredinearum (Lipsiae) 1(4): 594 (1903) [1904]

= *Puccinia aurea* G.Winter, Flora, Regensburg 67(14): 260 (1884), nom. illegit., Art. 53.1, a later homonym of *Puccinia aurea* Spreng. [now known as *Allodus podophylli* (Schwein.) Arthur].

Jørstad (1956) recognised that these described species were conspecific and used the older name. However, this is an illegitimate name, and therefore *P. satyrii* should be used as the first legitimate name available for this species.

5 **Ravenelia peglerae** *Pole-Evans*, in Doidge & Pole-Evans, The Annals of the Bolus Herbarium 2(3): 111 (1917).

= *Ravenelia peglerae* Doidge, Bothalia 2(1a): 146 (1927) Nom. illegit., Art. 53.1.

It is uncertain why Doidge described this species after Pole-Evans had done so, and using the same specimens as he had used, but the correct authority was given in Doidge (1950). The original description seems to have been lost since.

Corrected identifications

Several rust fungi were listed as occurring in southern Africa by Doidge (1950), but subsequently were found to be based on incorrectly identified specimens. These, and their correct identifications, are:

Phragmidium violaceum (R. Schultz) G.Winter now correctly identified as *Kuehneola uredinis* (Link) Arthur (Van Reenen 1995).

Puccinia kuehnii (Krüg.) Butler now correctly identified as *Puccinia melanocephala* Syd. & P.Syd. (Gorter 1982).

Puccinia luxuriosa Syd. now correctly identified as *Puccinia vilfae* Arthur. & Holw. (Cummins & Greene 1961).

Puccinia tosta Arthur now correctly identified as *Puccinia kakamariensis* Wakef. & Hansf. (Cummins & Greene 1961).

Uromyces bidentis Lagerh. now correctly identified as *Uromyces bidenticola* (Henn.) Arthur (see note under *Uromyces bidenticola* in Supplement 1).

Excluded species

Melampsora puccinioides G.Winter, Hedwigia 24: 22 (1885).

Sydow and Sydow (1915) listed *M. puccinioides* as an excluded species from *Melampsora*. They stated that the 'teliospores' described were not observed, only urediniospores were found and they did not belong to *Melampsora*. It is possible that this species may actually be *Phakopsora nyasalandica*, as *Phakopsora* species were frequently assigned to *Melampsora* or *Schroeteriaster* in the early literature. Unfortunately, no specimen of this species has so far been traced, to determine if this supposition is correct. It is best to consider *M. puccinioides* as a doubtful species.

Aecidium flustra Berk., Grevillea 20 (no. 96): 110 (1892).

This name was published with no description, the only information given was that the host was an *Aster* species, and that there were specimens from Valparaiso (Chile) and Natal (now KwaZulu-Natal, South Africa) (Anon. 1892). Sydow and Sydow (1924) give a description, presumably based on the Chilean specimen. This differs substantially from the South African specimen, which Doidge (1927) described as *A. woodianum*. *Aecidium flustra* therefore does not occur in South Africa.

Puccinia vernoniae Cooke, Grevillea 10 (no. 56): 126 (1882).

This name is a later homonym of *P. vernoniae* Schwein. from N. America and is therefore illegitimate. Sydow and Sydow (1904) state that it is not possible to correctly determine the identity of this species as the sori are too immature. It is best regarded as a doubtful species.

Puccinia torosa Thüm., Mycothecia Universalis, cent. 18: no. 1725 (1880).

Described from South African material where the host (*Arundo donax* L.) is an introduced alien weed, this rust species is not known in the host's native range. This species is likely only a variant of *Puccinia phragmitis*, which is one of several rust fungi occurring on this host in its native range. Cummins (1971) notes that it differs from *P. phragmitis* only in having slightly broader spores. It is best regarded as a doubtful species.

Puccinia salviae Unger, Über den Einfluss des Bodens auf die Vertheilung der Gewächse: 218 (1836).

This species is known from South Africa from a single specimen identified by Kalchbrenner (1882). Urediniospores occurred in this specimen, yet *P. salviae* is microcyclic (Baxter 1955), and the specimen probably represents *Puccinia salviae-runcinatae*. Therefore, this species is regarded as not occurring in South Africa.

The following two species have structures which appear to be type 4 spermogonia, this type of spermogonium is not associated with *Caeoma*-type aecia (Sato & Sato 1985). Both are best regarded as doubtful species:

Caeoma heteromorphae Doidge, Bothalia 2: 190 (1927). Figure 11A, 11B.

Specimens examined

SOUTH AFRICA, **Free State,** Braamhoek, Gumtree, Ficksburg District, on *Heteromorpha arborescens* (Spreng.) Cham. & Schltdl. (Apiaceae), 1935, *M. Vels* (PREM 28509); **KwaZulu-Natal,** Drakensberg, on *Heteromorpha arborescens*, 1940, *Mrs Gore Brown* (PREM 32780).

Two specimens of this fungus are listed in Doidge (1927). PREM 28509 is morphologically as described by Doidge (1927) from the type specimen. However, the spores in the supposed aecia are not catenulate nor verrucose as expected for *Caeoma*, all spores are of the same age throughout the structure, the spores are closely bound to one another, no spore producing layer of fungal cells (hymenium) is discernible, and no hyphae are visible in the surrounding plant tissue. It appears that all spores originate by division of a common matrix throughout the pustule, with wall deposition of all spores occurring simultaneously. This species appears to belong to a chytrid-like fungus rather than the Pucciniales. It is uncertain whether the spermogonia-like structures belong to this chytrid-like fungus. In contrast, PREM 32780 is different, having only phakopsoroid uredinia and is therefore not the same fungus as PREM 28509.

Caeoma lichtensteiniae Doidge, Bothalia 4(1): 229 (1941). Figure 11C, 11D.

Specimens examined

ZIMBABWE, **Salisbury**, host not determined (Apiaceae?), Dec. 1919, *F. Eyles 1966* (PREM 14009, holotype).

Doidge (1941) described structures that were interpreted as spermogonia and aecia without peridia for this

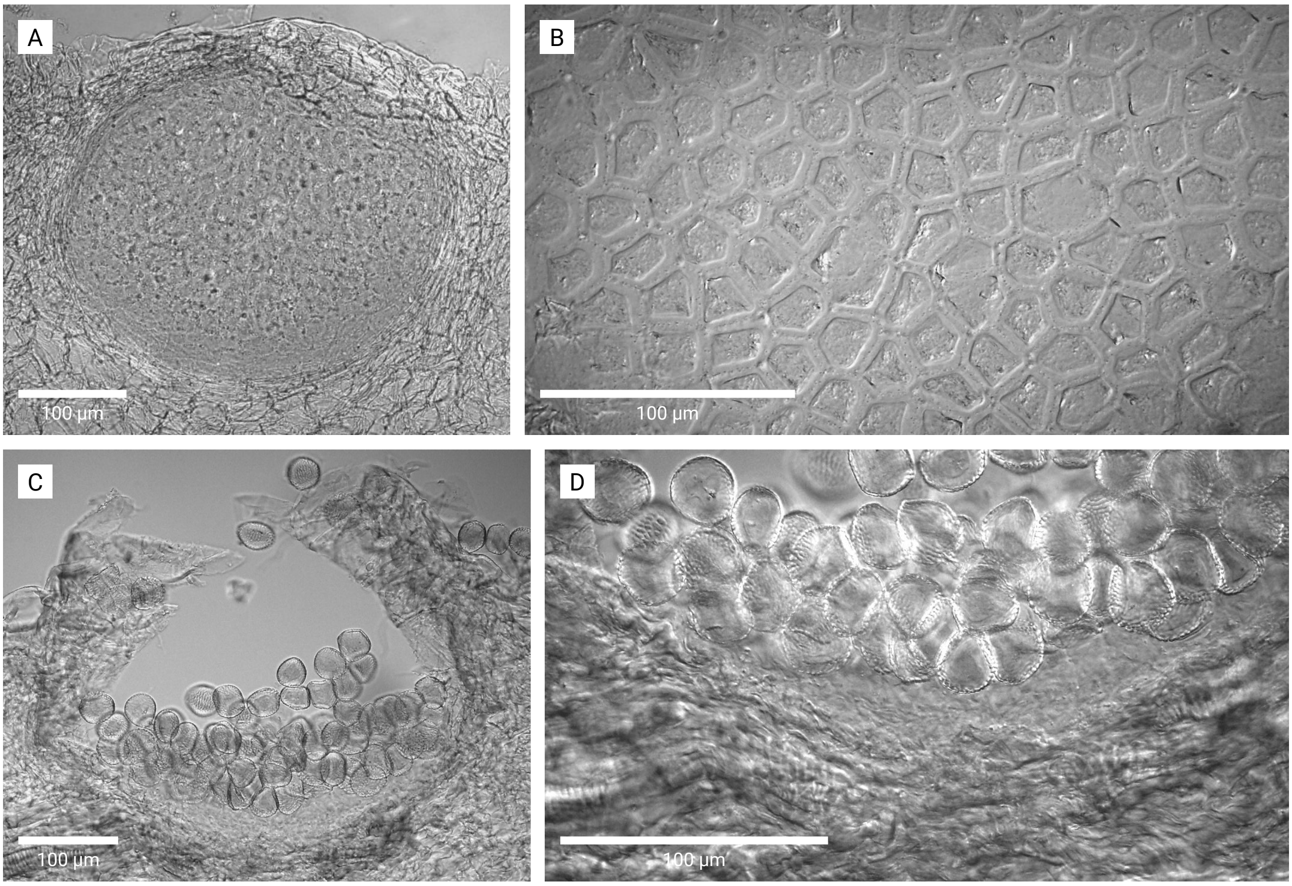

Figure 11. *Caeoma heteromorphae*, A, cross-section through a pustule; B, spores. *Caeoma lichtensteiniae*, C, cross-section through a pustule; D, spores.

fungus. The spores present have large, smooth, rounded verrucae. However, no spore producing hymenium is apparent and what appears to be a layer of fungal cells surrounding the spores has disintegrated. This species may not belong to the Pucciniales. It is uncertain whether the spermogonia-like structures belong to this fungus, though they are sometimes adjacent. The identity of the host plant is not certain. Originally identified as *Lichtensteinia* sp. (Doidge 1941), no species in this genus of the Apiaceae are known from Zimbabwe (Mapaura & Timberlake 2004). Additional material is required to determine the true identity and host of this fungus.

Discussion

This checklist brings together the dispersed literature on a diverse and ecologically important group of pathogenic fungi, to provide baseline information on the biodiversity of these fungi in southern Africa. By summarising what is known, several areas of study for future work are indicated. Future taxonomic studies are needed of various species described in the 1800's and early 1900's to bring them in line with changed concepts of what constitutes a species. Botswana, Lesotho, Mozambique and Eswatini need to be explored, as well as continued exploration of northern and western South Africa and Namibia, to improve knowledge on biodiversity, distribution and host plants of the indigenous rust fungi.

The species recorded from southern Africa were evaluated as to whether they are indigenous or alien (neomycetes), with 78 considered alien (Table 3). Berndt (2008a) considered only 32 as alien. Most of these species are widespread crop pathogens, or pathogens of alien host plant species grown as horticultural subjects or which have become weeds in the region. However, some occur on both alien and indigenous plant species, and therefore a subjective decision was made as to whether these were widespread species (cosmopolitan) or had been introduced from elsewhere in the world and then spread to indigenous plants. Two are considered to be invasive and alien, in that they are new-association parasites of indigenous plant species, namely *Puccinia lagenophorae* (Scholler et al. 2011) and *Austropuccinia psidii* (Roux et al. 2013, 2016), and likely are impacting on their new host's population dynamics. Several cereal rust fungi are a threat to one highly localised indigenous grass (Pretorius et al. 2015). The rate at which rust fungi are invading southern Africa appears to be accelerating, a total of 13 were first recorded between 1946 and 1990 (average 0.382 species per year), whereas 20 have been first recorded from 1991 until the present (average 0.625 species per year). Of interest is that there are a few rust fungi that have been described from alien plants in southern Africa and which are not known from any indigenous plant, e.g. *Phakopsora myrtacearum* (Maier et al. 2016), *Dietelia cardiospermi* (Berndt & Wood 2012) and *Uromyces capensis* (Doidge 1927). The status of these is uncertain but are herein considered indigenous until proven otherwise. One species was first described from Australia, where it was introduced, before being discovered in its native range in South Africa (*Puccinia ursiniae*, Shivas 1991).

Four species have been deliberately introduced as biological control agents of alien invasive plants: *Puccinia eupatorii* (on *Eupatorium macrocephalum*), *Puccinia xanthii* var. *parthenii-hysterophori* (on *Parthenium hysterophorus*), *Uromycladium morrisii* (on *Acacia saligna*), and *Uromycladium woodii* (on *Paraserianthes lophantha*). Attempts were made to establish another species, *Prospodium transformans*, on *Tecoma stans*, but it did not successfully establish and therefore is not present in the region (Wood 2014). A number of species were accidentally introduced over time and may contribute to the biological control of their alien hosts: *Melampsora ricini* (on *Ricinus communis*), *Puccinia abrupta* var. *partheniicola* (on *Parthenium hysterophorus*), *Puccinia arechavaletae* (on *Cardiospermum grandiflora*), *Puccinia malvacearum* (on *Malva parviflora*, *Malva pusilla*), *Puccinia cannae* (on *Canna indica*), *Puccinia xanthii* (on *Xanthium strumarium*) and *Uromyces bidenticola* (on *Bidens pilosa*). One indigenous rust has been recorded as occasionally impacting on an alien invasive weed – *Kuehneola uredinis* is an outbreak species on *Rubus* sect. *Cuneifolii* (Wager 1947).

Several rust fungi from South Africa have been introduced to other parts of the world, becoming problem pathogens of some widely grown ornamental plants. These include *Puccinia pelargonii-zonalis* (on *Pelargonium* hybrids, which include *P. zonale* in their parentage), *Uromyces aloes* (on *Aloe* spp.), and *U. transversalis* (on *Gladiolus* spp. and hybrids) (Farr & Rossman 2024).

Of concern is that other than traditional morphological taxonomy, almost no research has been carried out on indigenous rust fungi despite plant pathogens being important components of ecosystems. Very little work has been done on proving the life cycles of the species by cultural studies, most of which was done approximately a century ago (Pole-Evans 1909, 1923a, 1923b, Putterill 1918). After the first *Endophyllum* species was recorded (Pole-Evans 1909), a century passed before eight more species of *Endophyllum* were added (Berndt & Wood 2012, Wood 1997, 2004, Wood & Crous 2005a, this publication). Cultural and microscopic studies were done to determine the life cycle of the microcyclic *Uromyces aloes* (Putterill 1918), and later the heteroecious life cycle of *Puccinia tristachyae* (Pole-Evans 1923b). After almost a century had passed, the second indigenous heteroecious species was identified by cultural and molecular studies, Boshoff et al. (2022a) demonstrated the full life cycle of *Puccinia digitariae* on *Digitaria eriantha* the gametothallus of which occurs on *Solanum* species. Recently, *Aecidium oxalidis* was identified by molecular data as the gametothallus of *Uromyces ixiae* (Wood & Aime 2024). All other heteroecious species known to occur in southern Africa are either alien or widespread throughout Africa and Europe or Asia. Other than these few above-mentioned species, the assumed life cycles of southern Africa's indigenous rust fungi have been based solely on association of various spore stages on the same leaves or plants. Where life cycles have been determined by cultural studies, these have been undertaken by workers in Asia, Europe or the Americas.

Biological and epidemiological studies have only been undertaken on *Uromyces rumicis* (Morris 1982a), *Endophyllum osteospermi* (Morris 1982b, Wood 2002a, Wood et al. 2004, Wood & Crous 2005b) and *Puccinia digitariae* (Rey & Garnett 1985, 1988). Ultrastructural studies have been undertaken on *Puccinia digitariae* (Rey & Garnett 1983) and *Uromyces transversalis* (Ferreira & Rijkenberg 1989, 1990, 1991, Ferreira et al. 1990).

Thus, studies have been conducted by South African mycologists on some aspect of the biology of a total of only eight out of the ± 460 (1.7%) rust fungi indigenous to South Africa. As far as the author is aware, no study on the biology of any of the species indigenous to the other southern African countries has been conducted in these countries. In contrast, numerous studies have been undertaken on alien rust fungi pathogenic on crops.

Berndt (2008a) provided an analysis of the floristic and distribution relationships of southern African rust fungi. A high proportion of the rust fungi recorded from southern Africa are either endemic to the region (± 44%) or are more widespread in Africa (± 20%). The remainder are 'subcosmopolitan' (particularly some species of *Puccinia* and *Uromyces*), pantropical or paleotropical (Berndt 2008a). One of the four genera of rust fungi endemic to Africa is restricted to the area covered by this list, *Cumminsina*, which is currently known only from a single specimen collected in Angola (Von Petrak 1955). Two species of *Stomatisora* are known, one from South Africa (*S. psychotriicola*), and the other from West Africa (Wood et al. 2014). The other African endemic genera are known only from West Africa, *Sphenorchidium* (Beenken & Wood 2015), and East Africa, *Joerstadia* (Gjærum & Cummins 1982). Interestingly a number of small genera have a disjunct distribution between southern Africa (or Africa) and southeast Asia or India, including *Didymopsorella*, *Elateraecium*, *Newinia* and *Puccorchidium*.

The Pucciniaceae (in the sense of Aime 2006, Aime et al. 2018, Aime & McTaggart 2021) form the largest

Table 3. Rust fungi occurring in southern Africa and considered to be alien to the region (neomycetes), having been accidentally or deliberately introduced. The alien and indigenous host plants on which they have been recorded in the region are listed

Name	Natural Distribution	Alien hosts	Indigenous hosts
Angiopsora apoda	Tropical Africa	*Cenchrus clandestinus*, *C. alopecuroides*	
Austropuccinia psidii[a]	S America	*Backhousia citriodora*, *Myrtus communis*	*Eugenia* spp., *Heteropyxis natalensis*
Cerotelium fici[a]	Asia	*Ficus carica*	*Ficus cordata*
Coleosporium plumeriae	Asia	*Plumeria* sp.	
Hemileia vastatrix	Tropical Africa	*Coffea arabica*, *C. liberica*	
Melampsora allii-populina	Europe, Asia	*Populus deltoides*	
Melampsora coleosporioides	Asia	*Salix babylonica*	
Melampsora euphorbiae	Europe, Asia	*Euphorbia helioscopia*, *E. heterophylla*, *E. peplus*	*Euphorbia kraussiana*, *E. striata*
Melampsora hypericorum	N hemisphere	*Hypericum androsaenum*	
Melampsora laricis-populina	Europe, Asia	*Populus deltoides*, *P. nigra*, *P. wislizenii*,	
Melampsora lini	N hemisphere	*Linum usitatissimum*	*Linum africanum*
Melampsora medusae-populina	New Zealand	*Populus deltoides*	
Melampsora ricini[b]	Mediterranean	*Ricinus communis*	
Miyagia pseudosphaeria	Europe	*Sonchus oleraceus*	
Phakopsora desmium	Africa	*Gossypium* sp.	
Phakopsora nishidana	Asia	*Ficus carica*	
Phakopsora pachyrhizi	Asia	*Glycine max*, *Phaseolus vulgaris*, *Pueraria lobata*	*Psoralea pinnata*
Phragmidium mexicanum	N America	*Potentilla indica*	
Phragmidium mucronatum	Europe, Asia	*Rosa* hybrids	
Puccinia abrupta var. *partheniicola*[b]	Americas	*Parthenium hysterophorus*	
Puccinia allii	N hemisphere	*Allium cepa*, *A. sativum*	*Allium synnotii*
Puccinia antirrhini	N America	*Antirrhinum majus*, *Linaria* sp.	
Puccinia arachidis	S America	*Arachis hypogea*	
Puccinia arechavaletae[b]	S America	*Cardiospermum grandiflorum*, *C. halicacabum*	*Cardiospermum corindum* (≡ *C. alatum*)
Puccinia asparagi	Europe	*Asparagus officinalis*	
Puccinia brachypodii var. *poae-nemoralis*	Europe	*Poa annua*	
Puccinia cannae[b]	S America	*Canna indica*	
Puccinia carthami	N hemisphere	*Carthamus tinctorius*	
Puccinia chrysanthemi	Europe	*Chrysanthemum coronarium*, *C. morifolium*	

[a] Species highlighted in dark orange are considered to be alien invasive microorganisms, being new association pathogens of indigenous plant species and negatively impacting their health. Species highlighted in light orange are pathogens of crop plants.
[b] Pathogens of alien invasive plants listed in the NEM:BA regulations that were accidentally introduced by unknown pathways.
[c] Pathogens of alien invasive plants listed in the NEM:BA regulations that were deliberately introduced as biocontrol agents.

Table 3. Rust fungi occurring in southern Africa and considered to be alien to the region (neomycetes), having been accidentally or deliberately introduced. The alien and indigenous host plants on which they have been recorded in the region are listed (continued)

Name	Natural Distribution	Alien hosts	Indigenous hosts
Puccinia coronata	Europe, Asia	*Avena* spp., *Lolium multiflorum*, *L. perenne*, *Poa annua*	*Chloris virgata*, *Trisetopsis imberbis*
Puccinia cyani	Europe	*Centaurea cyanus*	
Puccinia cymbopogonis	SE Asia	*Cymbopogon citratus*	
Puccinia eupatorii[c]	S America	*Campuloclinium macrocephalum*	
Puccinia graminis	Europe	*Arrhenatherum elatius*, *Avena* spp., *Bromus rigidus*, (*Cymbopogon citratus*?), *Dactylis glomerata*, *Festuca elatior*, *Hordeum* spp., *Lolium perenne*, *L. temulentum*, *Secale cereale*, *Triticum aestivum*, ×*Triticosecale schlanstedtense*	*Agrostis lachnantha*, *Polypogon strictus*, *Secale africanum*, *Thinopyrum distichum*
Puccinia helianthi-mollis (= *Puccinia helianthi*)	N America	*Helianthus annus*	
Puccinia hemerocallidis	Asia	*Hemerocallis* hybrids	
Puccinia hieracii	N hemisphere	*Cichorium intybus*, *Hypochaeris radicata*	
Puccinia hordei	N hemisphere	*Bromus pectinatus*, *Hordeum murinum*, *H. vulgare*, *Vulpia bromoides*, *V. myuros*	
Puccinia horiana	Europe	*Chrysanthemum morifolium*	
Puccinia hyptidis-mutabilis	N America	*Hyptis pectinata*	
Puccinia iridis	Europe, Asia	*Iris germanica*	
Puccinia lagenophorae	Australia	*Calendula officinalis*, *Senecio vulgaris*	Numerous Asteraceae, mainly annuals (see Scholler et al. 2011)
Puccinia malvacearum	S America	*Alcea rosea*, *Anisodontea triloba*, *Malva parviflora*, *M. pusilla*	
Puccinia melanocephala	New Guinea	*Saccharum officinarum*, *S. spontaneum*	
Puccinia menthae	N hemisphere	*Mentha arvensis*, *M. spicata*	*Mentha longifolia*
Puccinia oenotherae	N America	*Oenothera* spp.	
Puccinia oxalidis	Americas	*Oxalis latifolia*	*Oxalis semiloba*
Puccinia penicillariae	Tropical Africa	*Cenchrus americanus*	
Puccinia polygoni-amphibii	N hemisphere	*Polygonum tomentosum*	*Persicaria acuminata*
Puccinia polypogonis	Europe	*Polypogon monspeliensis*	
Puccinia polysora	S America	*Zea mays*	
Puccinia porri	Europe	*Allium ampeloprasum*, *A. fistulosum*	
Puccinia purpurea	Africa	*Sorghum* × *drummondii*, *S. virgatum*	*Sorghum arundinaceum*, *S. bicolor*

[a] Species highlighted in dark orange are considered to be alien invasive microorganisms, being new association pathogens of indigenous plant species and negatively impacting their health. Species highlighted in light orange are pathogens of crop plants.

[b] Pathogens of alien invasive plants listed in the NEM:BA regulations that were accidentally introduced by unknown pathways.

[c] Pathogens of alien invasive plants listed in the NEM:BA regulations that were deliberately introduced as biocontrol agents.

Table 3. Rust fungi occurring in southern Africa and considered to be alien to the region (neomycetes), having been accidentally or deliberately introduced. The alien and indigenous host plants on which they have been recorded in the region are listed (continued)

Name	Natural Distribution	Alien hosts	Indigenous hosts
Puccinia recondita	Cosmopolitan	*Bromus pectinatus*, *B. rigidus*, *Hordeum intermedium*, *H. murinum*, *Secale cereale*	*Secale africanum* (also various genera elsewhere in Africa)
Puccinia sorghi	S America	*Zea mays*	
Puccinia striiformis	Europe, Asia	*Bromus pectinatus*, *Triticum aestivum*	*Secale africanum*
Puccinia triticina	Cosmopolitan	*Aegilops cylindrica*, *Triticum aestivum*, ×*Triticosecale schlanstedtense*	
Puccinia xanthii	N America	*Helianthus annus*, *Xanthium strumarium*	
Puccinia xanthii var. *parthenii-hysterophori*[c]	Americas	*Parthenium hysterophorus*	
Puccinia sp.	Unknown	*Eryngium planum*	
Pucciniastrum epilobii	N hemisphere	*Fuchsia* spp.	
Pucciniastrum minimum	N America	*Vaccinium corymbosum*	
Ravenelia mesilliana[b]	Americas	*Senna bicapsularis*	
Tranzschelia discolor	N hemisphere	*Prunus* spp.	
Uredo cajani	India	*Cajanus cajan*	
Uromyces appendiculatus	N hemisphere	*Phaseolus acutifolius*, *P. coccineus*, *P. vulgaris*	*Vigna unguiculata*
Uromyces betae	Europe	*Beta vulgaris*	
Uromyces bidenticola	S America	*Bidens pilosa*	
Uromyces dianthi	N hemisphere	*Dianthus barbatus*, *D. caryophyllus*	*Dianthus crenatus*, *Dianthus zeyheri*
Uromyces euphorbiae	Americas	*Euphorbia prostrata*	*Euphorbia inaequilatera*, *Euphorbia natalensis*
Uromyces limonii	N hemisphere	*Limonium platyphyllum*	
Uromyces polygoni-avicularis	N hemisphere	*Polygonum aviculare*, *Polygonum tomentosum*	
Uromyces rumicis	Europe	*Rumex crispus*, *R. nepalensis*	*Emex australis*, *Rumex woodii*
Uromyces striatus	Europe	*Medicago* spp.	
Uromyces trifolii	N hemisphere	*Trifolium* sp.	
Uromyces trifolii-repentis	N hemisphere	*Trifolium repens*, *T. resupinatum*	
Uromyces viciae-fabae	N hemisphere	*Pisum sativum*, *Vicia fabae*, *V. lens*	
Uromycladium sp	Australia	*Acacia mearnsii*	
Uromycladium morrisii[c]	Australia	*Acacia saligna*	
Uromycladium woodii[c]	Australia	*Paraserianthes lophantha*	

[a] Species highlighted in dark orange are considered to be alien invasive microorganisms, being new association pathogens of indigenous plant species and negatively impacting their health. Species highlighted in light orange are pathogens of crop plants.

[b] Pathogens of alien invasive plants listed in the NEM:BA regulations that were accidentally introduced by unknown pathways.

[c] Pathogens of alien invasive plants listed in the NEM:BA regulations that were deliberately introduced as biocontrol agents.

proportion of the rust flora (76 %). Most of the remainder of the diversity is made up of a tropical element, consisting of the Mikronegeriinieae (2.4 %) and the families other than Pucciniaceae of the Uredinineae (13.2 %) (Berndt 2008a). With the addition of *Endophyllum austroafricana*, South Africa currently has a total of nine species of *Endophyllum*, representing 21 % of the total number of species known within this genus.

The northern temperate Melampsorineae make up only 3.6 % of the flora, half of which are alien in southern Africa (10 of 21 species). Only urediniospores have been recorded in southern Africa for the majority of these species, both indigenous and alien. This is true of the four species endemic to South Africa, *Coleosporium hedyotidis*, *C. hewittiae*, *Milesina nervisequa* and *M. silvae-knysnae*, and several species with a temperate Northern Hemisphere and South African disjunct distribution including *Coleosporium clematidis* (autoecious), *Milesina blechni* (heteroecious), *M. nervisequa* (heteroecious), *Pucciniastrum agrimoniae* (autoecious) and *Uredinopsis pteridis* (heteroecious).

The conservation status of the majority of species cannot presently be determined due to a lack of distribution data for them. Currently only some species, which have been found to be widespread and/or common, could be listed as being 'of Least Concern'. For instance, *Cephalotelium macowanianum* is likely the most common and widespread species in the country, as its host plant *Vachellia karoo* is one of the most widespread trees in the region. For many, they have only been collected once or a few times, but whether this is an artefact of a lack of collecting effort, or whether they actually are rare and should be on a red list, is not yet known. These biotrophic pathogens are commonly ephemeral in patches of their host plants, their populations increasing or decreasing due to fluctuations in rainfall and other climatic factors. Therefore, the fragmentation of the natural environment is likely to lead to at least some becoming rarer or extinct, as their host populations decline and occur only in small discrete conserved areas. Rust fungi, as well as other groups of biotrophic pathogenic fungi, may therefore be another group of organisms that can function as indicator species of the integrity and sustainability of conserved areas or landscapes. These fungi can be collected, preserved using standard herbarium specimen techniques (i.e., low cost and simple technology), and generally identified rapidly if their host is correctly identified and using basic microscopy. This checklist will assist in the identification of these species.

The rust fungi of southern Africa are a diverse and important component of the local ecosystems. Further collecting and taxonomic studies are needed to determine the complete diversity and species distributions. However, much more research is required to confirm their life histories, their full host range, and to elucidate the impacts on their host plant's population dynamics and influence on ecosystem functioning.

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Supplementary Material

Supplementary material has not been edited, designed or proofread by SANBI Graphics & Editing as approved by the two Editors-in-Chief.

Supplement 1

Checklist of rust fungi (Pucciniales, Basidiomycota) recorded as occurring in southern Africa, including South Africa, Angola, Botswana, eSwatini (formerly Swaziland), Lesotho, Mozambique, Namibia and Zimbabwe.

http://dx.doi.org/10.38201/abc.v55.14

Supplement 2

Checklist of host plants of the rust fungi (Pucciniales, Basidiomycota) recorded as occurring in southern Africa, including South Africa, Angola, Botswana, eSwatini (formerly Swaziland), Lesotho, Mozambique, Namibia and Zimbabwe.

http://dx.doi.org/10.38201/abc.v55.14

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Preliminary checklist for freshwater diatom species of the Karoo, South Africa

Authors
[1,2]M. Holmes
[1]E.E. Campbell
[2]M. de Wit
[3,4]J.C. Taylor

Affiliations
[1] Department of Botany, Nelson Mandela University, Nelson Mandela Bay, South Africa.
[2] Africa Earth Observatory Network (AEON) – Earth Stewardship Science Research Institute (ESSRI), Nelson Mandela University, Nelson Mandela Bay, South Africa.
[3] Unit for Environmental Science and Management, North-West University, Potchefstroom, South Africa.
[4] South African Institute for Aquatic Biodiversity (SAIAB), P/Bag 1015, Makhanda 6140, South Africa.

Corresponding Author
M. Holmes, e-mail: karoocats007@gmail.com

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Background: Species checklists are a way in which local biodiversity can be monitored. There is no readily accessible database or checklist of diatom flora of South Africa. This publication gives an account of the diatom taxa encountered during two survey projects (2010–2012 and 2015–2017) within the Eastern Karoo.

Objectives: This list has been compiled to allow for: (1) comparisons with future research in the geographical area; (2) comparison with ecological data from other countries; (3) monitoring the occurrence of new species; and (4) documentation of the disappearance of 'clean water' indicator species.

Methods: Sampling took place in the area known as the Eastern Karoo during the two projects. Samples were scrubbed, cleaned and checked for live cells. Permanent slides were made and diatoms identified using light and electron microscopy. Each species was assigned a four-letter code from the software *Omnidia* version 6.

Results: A total of 474 taxa were encountered, some of which are, as yet, undescribed. This list contains taxonomic rank currently assigned as well as the *Omnidia* codes as this software is commonly used throughout the world and in South Africa for diatom assessment protocols.

Conclusion: The National Environmental Management: Biodiversity Act does not cover the protection of diatom species, which can only realistically be conserved if the habitats in which they are found are also conserved. This species checklist can serve as a catalyst for a move towards legislation accepting the use of diatoms as bioindicators for freshwater within South Africa.

Keywords: diatoms, freshwater, bioindicator, Karoo.

Introduction

Species lists cover the occurrence of taxa in a geographical area and provides an overview of biodiversity in an area as well as a benchmark for environmental decision-making. Information of species occurring on such a list needs to be traceable (Garnett et al. 2020). Occurring in every aquatic and moist habitat, diatoms are living representatives of the environmental conditions of the habitat in which they are found. These single-celled organisms (Bacillariophyceae) are found together in associations that can be considered indicators of a particular type of water body (Schoeman 1976).

In South Africa, diatoms have been tested as bioindicators of water quality (Taylor 2004; De la Rey 2008; Matlala et al. 2008; Holmes & Taylor 2015; Pelser 2015; Musa & Greenfield 2018; Cameron 2019; Mangadze et al. 2019; Joubert 2021; Holmes et al. 2022). Diatoms, with their robust silica cell walls, have been successfully used in forensic analysis (Scott et al. 2014; Piegari et al. 2019) and historical assessments of water quality (Barker 1992; Dixit et al. 1992; Otu et al. 2011; Gordon et al. 2012; Schmidt et al. 2017). Successful application of bioindicators requires that they be correctly identified. It is for this reason that a checklist of species recorded during two projects within the Eastern Karoo area has been compiled.

The correct identification of diatoms is often perceived to be difficult (Taylor et al. 2007a). While the processing of samples as well as the identification thereof requires light microscopy, it is not impossible for this to be done by trained observers. The datasets from which this article is produced were processed on a farm in the Karoo where a laboratory was set up with a limited budget. Identification and enumeration for both datasets were done using an entry level phase contrast light microscope. Confirmation of the identification of those cells with uncertain identification was done with high resolution microscopes at either North-West University (Potchefstroom) or Nelson Mandela University (South Campus). This demonstrates that the use of diatoms as bioindicators is not limited to only those with access to university or research institution facilities.

In 2009, diatoms were included as biomonitoring organisms in the Rapid Habitat Assessment Method Manual (Department of Water Affairs and Forestry) and in 2012 they were included in the draft Rapid Ecological Reserve Assessment. The River Eco-status Monitoring Programme (REMP) replaced the River Health Programme (RHP) in 2016 and currently forms part of the National Aquatic Ecosystem Health Monitoring Programme (Department of Water and Sanitation 2016). This programme, as did its predecessor, uses only fish, invertebrates and riparian conditions to assess ecosystem health. However, in 2017, diatoms were included in the report pertaining to the development of operational procedures for the monitoring of rivers (Department of Water and Sanitation).

Although diatoms are not routinely included, they were included in several Determination of Water Resource reports (Department of Water and Sanitation 2022a, 2022b). Unfortunately, in the Karoo, fish are rarely found and, due to the extreme cold in the Karoo, insects often only occur in the summer months. It would therefore be beneficial if diatoms (occurring all year round) become part of the monitoring programme.

Red Data Species Lists classify species according to their risk of extinction and highlight areas that require conservation. While Red Data Species Lists exist for fauna and terrestrial flora in South Africa, there is no such list for diatoms. The diatom Red Data List currently in use was developed for European conditions (Cantonati et al. 2022).

The objective of this paper was to compile a preliminary checklist of diatom species from the Eastern Karoo and to highlight species found on the Red Data List. An attempt was made to include older species lists (Archibald 1983; Bate et al. 2004; Janse van Vuuren & Taylor 2015; Roussouw et al. 2018) but none of these documents have been digitised and given that there was no uniform method of reporting the species lists within the Karoo, it will be a mammoth undertaking to collate a complete list. The species list from Bate et al. (2004) has not yet been found but the permanent slides are available for perusal.

Materials and methods

Sampling took place in the area known as the Eastern Karoo (Figure 1) during the two projects. The first project included the upper reaches of the Great Fish River (spring-fed, Holmes & Taylor 2015) while the second project took place within the whole area shown in Figure 1 covering both stream and reservoir sites during the period 2015 to 2017 (Holmes et al. 2022, 2023). This semi-arid area is reliant on underground water (often stored in reservoirs above ground) and, mostly intermittent, springs. The area has extremes in weather between the winter (down to -8°C) and summer months (> 40°C) (pers. obs., M. Holmes).

Reservoirs are filled with underground water either by windmill or solar pumps. The water in these reservoirs is stored for future use and water turnover rates vary depending on water use. In the case of the reservoirs, samples were taken from the reservoir wall (usually cement substrate), unglazed ceramic tiles (placed in the reservoir after the first sampling and used as a comparison substrate for subsequent samples) and then at random sites from the plastic floatation devices from which the tiles were suspended.

Springs have a shallow water environment (1 cm to 30 cm depth) that relies completely on rain and underground water sources for recharge. Samples were scrubbed from cobbles and pebbles within riffles, using a well-cleaned toothbrush (Taylor et al. 2007b). One toothbrush per sample was used and upon returning to the laboratory, was well cleaned with detergent and water. Random samples of aquatic plants having epiphytic diatoms were taken for comparison. Samples were checked (using light microscopy) for the percentage of live cells, with chloroplasts in the cells.

Diatom samples were processed using acid digestion with the hot $KMnO_4$ and HCl method (Taylor et al. 2007b). Permanent slides were mounted using *Pleurax*. All wet material and permanent slides are held on the farm Clifton.

Identification was done using a Nikon E100 phase contrast microscope with an Olympus 100×/1.30 N.A. phase contrast objective and a Nikon 100×/1.25 N.A.

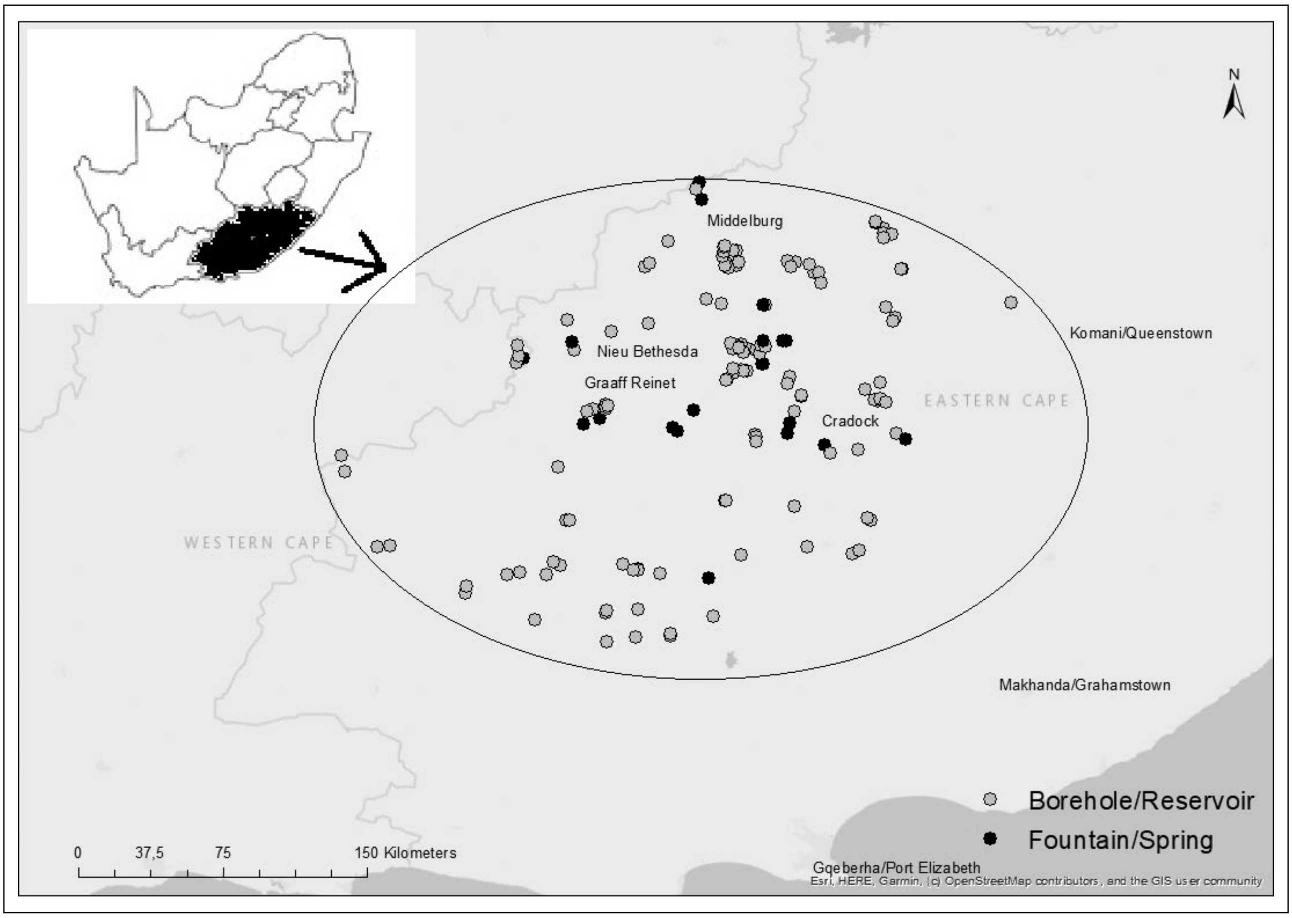

Figure 1. Sample sites (inside circle) within the Eastern Karoo from which the diatom species were identified.

phase objective. Photomicrographs were taken with a 1/2.5-Inch 5Mp CMOS Digital Image Sensor using the software IC Measure (The Imaging Software Company). At Nelson Mandela University an Olympus BX51 microscope with differential interference contrast (100x 13 N.A.) was used. Photographs and measurements of cells were taken with the mounted camera and *analySIS* image processing software. Scanning electron microscopy was done at the Centre for High Resolution Transmission Electron Microscopy (CHRTEM) at the Nelson Mandela University using a JEOL JSM7001F scanning electron microscope. Cleaned samples were placed on an isopore 0.2 μm pore-size membrane (Millipore™) filter precoated with gold. Once dried, the samples were attached to an aluminium stub with carbon conductive double-sided tape and sputter coated with gold at 25 mA for 30 seconds. Imaging was done at an accelerating voltage of 3 kV.

Each species was assigned a four-letter code from the software *Omnidia* version 6 (Lecointe et al. 1993, 1999, 2016). *Omnidia* (v6) was used to compile the species lists from the projects. For species that could only be identified to genus level, a unique code was assigned to each species while for those that could not be identified to a genus level, the code ZZZZ was assigned. Although environmental preferences for cosmopolitan diatoms can vary, there are some species that are always considered pollution sensitive. As pristine conditions decline, some of these diatom species have been placed on Red Data Lists. Species occurring on the two most recent Red Data Lists for diatoms in Europe were accessed (Rote Liste Zentrum 2018; Täuscher 2020).

Results

A table with an alphabetical list – including the four-letter *Omnidia* codes – of the diatoms identified in the Eastern Karoo is given in Table 1. The list of species only identified to genus-level or above can be requested from the corresponding author (with images, file size >50 MB).

A total of 474 taxa were recorded from 607 samples (n = 101 from 2010 to 2012 and n = 506 from 2015 to 2017). Several species that could not be identified to genus level were given the code ZZZZ. The species in this grouping (ZZZZ) that were of the same morphological 'taxa' were grouped together (n = 48 'taxa'). Several species previously misidentified are now placed in different groupings and listed in Table 2. *Amphora* sp0 was found to have a range of morphological variation within the same sample (Figure 2, Table 2).

Table 1. Preliminary diatom species list for the Eastern Karoo with the *Omnidia* (v6) codes. Species with * are on the Red List (Täuscher 2020) and ⁺ indicates inclusion in the 2018 list (Rote Liste Zentrum). Species in bold occurred with a relative abundance >10% in at least one sample. When names have changed, the new names are provided alongside their synonyms. These changes were verified through AlgaeBase as on 31 October 2024

Taxa	Omnidia Code
Cells not identified to genus level	**ZZZZ**
Deformed diatom cells	DEFO
***Achnanthes brevipes* C.Agardh**	**ABRE**
Achnanthes brevipes var. *angustata* (Greville) Cleve	ABAN
Achnanthes brevipes var. *intermedia* (Kützing) Cleve	ABIN
Achnanthes coarctata (Brébisson) Grunow	ACOA
Achnanthes spp.	ACHS
Achnanthidium affine (Grunow) Czarnecki	ACAF
Achnanthidium atomoides Monnier, Lange-Bertalot & Ector	ADAM
Achnanthidium caledonicum (Lange-Bertalot) Lange-Bertalot	ADCA
Achnanthidium catenatum (Bily & Marvan) Lange-Bertalot	ADCT
Achnanthidium crassum (Hustedt) Potapova & Ponader	ADCR
***Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot**	**ADEU**
Achnanthidium exile (Kützing) Heiberg	ADEX
Achnanthidium gracillimum (F.Meister) Lange-Bertalot	ADGL
***Achnanthidium jackii* Rabenhorst**	**ADJK**
Achnanthidium macrocephalum (Hustedt) Round & Bukhtiyarova	ADMA
Achnanthidium microcephalum Kützing	ADMC
***Achnanthidium minutissimum* (Kützing) Czarnecki**	**ADMI**
Achnanthidium neomicrocephalum Lange-Bertalot & Staab	ADNM
Achnanthidium pyrenaicum (Hustedt) H.Kobayasi	ADPY
Achnanthidium rivulare Potapova & Ponader	ADRI
***Achnanthidium saprophilum* (H.Kobayasi & Mayama) Round & Bukhtiyarova**	**ADSA**
***Achnanthidium* spp.**	**ACHD**
Achnanthidium straubianum (Lange-Bertalot) Lange-Bertalot	ADSB
*⁺*Achnanthidium subatomus* (Hustedt) Lange-Bertalot	ADSU
***Adlafia bryophila* (Petersen) Lange-Bertalot**	**ABRY**
Adlafia minuscula (Grunow) Lange-Bertalot	ADMS
Adlafia spp.	ADSP
Amphipleura pellucida (Kützing) Kützing	APEL
Amphora copulata (Kützing) Schoeman & R.E.M.Archibald	ACOP
Amphora inariensis Krammer	AINA
Amphora ovalis (Kützing) Kützing	AOVA
***Amphora pediculus* (Kützing) Grunow**	**APED**
***Amphora* spp.**	**AMPS**
Aneumastus spp.	ANES
Anomoeoneis sp.	ANOS

Table 1. Preliminary diatom species list for the Eastern Karoo with the *Omnidia* (v6) codes. Species with * are on the Red List (Täuscher 2020) and + indicates inclusion in the 2018 list (Rote Liste Zentrum). Species in bold occurred with a relative abundance >10% in at least one sample. When names have changed, the new names are provided alongside their synonyms. These changes were verified through AlgaeBase as on 31 October 2024 (continued)

Taxa	Omnidia Code
Anomoeoneis sphaerophora (Ehrenberg) Pfitzer	ASPH
Aulacoseira distans (Ehrenberg) Simonsen	AUDI
Aulacoseira granulata (Ehrenberg) Simonsen	AUGR
***Aulacoseira granulata* (Ehrenberg) Simonsen var. *angustissima* (O.Müller) Simonsen**	**AUGA**
Aulacoseira pusilla (F.Meister) A.Tuji & A.Houki	AUPU
Aulacoseira sp.	AULS
Bacillaria paxillifera (O.F.Müller) T.Marsson	BPAX
SYN *Bacillaria paradoxa* Gmelin	BPAR
Brachysira calcicola Lange-Bertalot	BCAL
+*Brachysira liliana* Lange-Bertalot	BLIL
***Brachysira* sp. (*B. neoexilis*) shape**	**BNEO**
***Brachysira* spp.**	**BRCS**
Caloneis sp.	CALO
Caloneis bacillum (Grunow) Cleve	CBAC
Caloneis molaris (Grunow) Krammer	CMOL
Caloneis tenuis (W.Gregory) Krammer	CATE
***Chaetoceros* sp.**	**CHTS**
Chamaepinnularia spp.	CHSP
Cocconeis sp.	COCO
***Cocconeis engelbrechtii* Cholnoky**	**CENG**
***Cocconeis lineata* Ehrenberg**	**CLNT**
SYN *Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck	**CPLI**
***Cocconeis pediculus* Ehrenberg**	**CPED**
***Cocconeis placentula* Ehrenberg**	**CPLA**
***Cocconeis euglypta* Ehrenberg**	**CEUG**
SYN *Cocconeis placentula* var. *euglypta* (Ehrenberg) Cleve	**CPLE**
Conticribra weissflogii (Grunow) Stachura-Suchoples & D.M.Williams	CTWE
SYN *Thalassiosira weissflogii* (Grunow) G.A.Fryxell & Hasle	TWEI
Craticula accomoda (Hustedt) D.G.Mann	CRAC
Craticula accomodiformis Lange-Bertalot	CACM
Craticula ambigua (Ehrenberg) D.G.Mann	CAMB
***Craticula* cf. *buderi* (Hustedt) Lange-Bertalot**	**CRBU**
Craticula elkab (O.Müller ex O.Müller) Lange-Bertalot, Kusber & Cocquyt	CREK
Craticula halophila (Grunow) D.G.Mann	CHAL
Craticula molestiformis (Hustedt) Mayama	CMFO
cf. *Craticula simplex* (Krasske) Levkov	**CRSI**
***Craticula* spp.**	**CRTS**

Table 1. Preliminary diatom species list for the Eastern Karoo with the *Omnidia* (v6) codes. Species with * are on the Red List (Täuscher 2020) and + indicates inclusion in the 2018 list (Rote Liste Zentrum). Species in bold occurred with a relative abundance >10% in at least one sample. When names have changed, the new names are provided alongside their synonyms. These changes were verified through AlgaeBase as on 31 October 2024 (continued)

Taxa	Omnidia Code
***Craticula subminuscula* (Manguin) C.E.Wetzel & Ector**	**CSNU**
Craticula vixnegligenda Lange-Bertalot	CVIX
Craticula zizix (VanLandingham) Guiry	CZIZ
SYN Craticula molesta Lange-Bertalot & Willmann	CRML
Cyclostephanos dubius (Hustedt) Round	CDUB
Cyclostephanos invisitatus (M.H.Hohn & Hellerman) E.C.Theriot, Stoermer & Håkansson	CINV
Cyclostephanos sp.	CYCS
***Cyclotella atomus* Hustedt**	**CATO**
Cyclotella atomus var. *gracilis* Genkal & Kiss	CAGR
Cyclotella meduanae H.Germain	CMED
Cyclotella spp.	CYCL
Cymbella affiniformis Krammer	CAFM
Cymbella bengalensis Grunow	CBEN
*+*Cymbella cymbiformis* C.Agardh	CCYM
Cymbella dorsenotata Østrup	CDNO
***Cymbella kappii* (Cholnoky) Cholnoky**	**CKPP**
Cymbella kolbei Hustedt	CKOL
***Cymbella neocistula* Krammer**	**CNCI**
***Cymbella percymbiformis* Krammer**	**CPCF**
Cymbella simonsenii Krammer	CSMO
Cymbella spp.	CYMB
Cymbella tumida (Brébisson) Van Heurck	CTUM
Cymbella zambesiana Krammer	CZAM
***Denticula kuetzingii* Grunow**	**DKUE**
***Denticula kuetzingii* var. *rumrichae* Krammer**	**DKRU**
***Denticula* spp.**	**DENS**
Denticula subtilis Grunow	DSUB
Diadesmis confervacea Kützing	DCOF
***Diatoma vulgaris* Bory**	**DVUL**
Diploneis puella (Schumann) Cleve	DPUE
Diploneis smithii (Brébisson) Cleve	DSMI
***Diploneis* sp. previously identified as *D. elliptica* (Kützing) Cleve**	**DIPS0**
Diploneis spp.	DIPS
Diploneis subovalis Cleve	DSBO
***Discostella pseudostelligera* (Hustedt) Houk & Klee**	**DPSG**
Discostella stelligera (Cleve & Grunow) Houk & Klee	DSTE
Encyonema cespitosum Kützing	ECAE

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Taxa	Omnidia Code
Encyonema minutum (Hilse) D.G.Mann	ENMI
Encyonema silesiacum (Bleisch) D.G.Mann	ELSE
Encyonema volkii (U.Rumrich, Krammer & Lange-Bertalot) Krammer	EVOL
Encyonopsis buedelii Krammer	ECBU
***+*Encyonopsis cesatii* (Rabenhorst) Krammer**	**ECES**
***Encyonopsis* cf. *cesatiformis* Krammer**	**ECCF**
***Encyonopsis krammeri* E.Reichardt**	**ECKR**
Encyonopsis krammerioides Lange-Bertalot & U.Rumrich	EKMD
***Encyonopsis microcephala* (Grunow) Krammer**	**ENCM**
***Encyonopsis minuta* Krammer & E.Reichardt**	**ECPM**
***Encyonopsis* spp.**	**ECNS**
***Encyonopsis subminuta* Krammer & E.Reichardt**	**ESUM**
Encyonopsis thumensis Krammer	ETHU
***Entomoneis paludosa* (W.Smith) Reimer**	**EPAL**
***Epithemia adnata* (Kützing) Brébisson**	**EADN**
***Epithemia gibba* (Ehrenberg) Kützing**	**EGBA**
SYN *Rhopalodia gibba* (Ehrenberg) O.Müller	**RGIB**
***Epithemia operculata* (C.Agardh) Ruck & Nakov**	**EOPE**
SYN *Rhopalodia operculata* (C.Agardh) Håkansson	**ROPE**
***Epithemia sorex* Kützing**	**ESOR**
Epithemia spp.	EPIS1
Epithemia turgida (Ehrenberg) Kützing	EELG
SYN *Cymbella turgida* W.Gregory	CTUR
Eunotia sp.	EUNO
Fallacia pygmaea (Kützing) Stickle & D.G.Mann	FPYG
Fallacia sp.	FALS
Fallacia tenera (Hustedt) D.G.Mann	FTNR
Fistulifera pelliculosa (Kützing) Lange-Bertalot	FPEL
Fragilaria capucina Desmazieres	FCAP
***Fragilaria vaucheriae* (Kützing) J.B.Petersen**	**FVAU**
SYN *Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot	**FCVA**
Fragilaria crotonensis Kitton	FCRO
Fragilaria pararumpens Lange-Bertalot, G.Hofmann & Werum	FPRU
Fragilaria radians (Kützing) D.M.Williams & Round	FRAD
SYN *Fragilaria gracilis* Østrup	FGRA
Fragilaria rumpens (Kützing) G.W.F.Carlson	FRUM
SYN *Fragilaria capucina* subsp. *rumpens* (Kützing) Lange-Bertalot	FCRP

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Taxa	Omnidia Code
***Fragilaria* spp.**	**FRAS**
***Fragilaria tenera* (W.Smith) Lange-Bertalot**	**FTEN**
***Fragilaria tenera* var. *nanana* (Lange-Bertalot) Lange-Bertalot & S.Ulrich**	**FTNA**
SYN *Fragilaria nanana* Lange-Bertalot	**FNAN**
Frustulia vulgaris (Thwaites) De Toni	FVUL
Frustulia sp.	FRUS
***Gogorevia exilis* (Kützing) Kulikovskiy & Kociolek**	**GGEX**
SYN *Achnanthidium exiguum* (Grunow) Czarnecki	**ADEG**
Gomphonema acuminatum Ehrenberg	GACU
Gomphonema affine Kützing	GAFF
Gomphonema affine var. *insigne* (W.Gregory) G.W.Andrews	GAFI
Gomphonema angustatum (Kützing) Rabenhorst	GANG
*$^{+}$*Gomphonema auritum* A.Braun ex Kützing	GAUR
Gomphonema clavatulum E.Reichardt	GCVT
*$^{+}$*Gomphonema exilissimum* (Grunow) Lange-Bertalot & E.Reichardt	GEXL
***Gomphonema gracile* Ehrenberg**	**GGRA**
*$^{+}$*Gomphonema insigne* W.Gregory	GINS
Gomphonema italicum Kützing	GITA
Gomphonema lagenula Kützing	GLGN
Gomphonema laticollum E.Reichardt	GLTC
Gomphonema minutum (C.Agardh) C.Agardh	GMIN
***Gomphonema parvulum* (Kützing) Kützing**	**GPAR**
Gomphonema pseudoaugur Lange-Bertalot	GPSA
Gomphonema pumilum (Grunow) E.Reichardt & Lange-Bertalot	GPUM
Gomphonema pumilum var. *rigidum* E.Reichardt & Lange-Bertalot	GPRI
Gomphonema spp.	GOMP
Gomphonema spiculoides H.P.Gandhi	GSPI
Gomphonema subclavatum (Grunow) Grunow	GSCL
Gomphonema venustum S.I.Passy, Kociolek & R.C.Lowe	GVNU
Gyrosigma acuminatum (Kützing) Rabenhorst	GYAC
Gyrosigma rautenbachiae Cholnoky	GRAU
Gyrosigma scalproides (Rabenhorst) Cleve	GSCA
Halamphora coffeiformis (C.Agardh) Mereschkowsky	HACO
Halamphora montana Krasske (Levkov)	HLMO
Halamphora oligotraphenta (Lange-Bertalot) Levkov	HOLI
Halamphora sp.	HALS
***Halamphora veneta* (Kützing) Levkov**	**HVEN**

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Taxa	Omnidia Code
Hantzschia amphioxys (Ehrenberg) Grunow	HAMP
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	HCAP
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	HHUN
Hippodonta spp.	HIPO1
Lemnicola hungarica (Grunow) Round & Basson	LHUN
Luticola mutica (Kützing) D.G.Mann	LMUT
Luticola nivalis (Ehrenberg) D.G.Mann	LNIV
Mastogloia dansei (Thwaites) Thwaites ex W.Smith	MDAN
Mastogloia elliptica (C.Agardh) Cleve	MELL
Mayamaea atomus (Kützing) Lange-Bertalot	MAAT
***Mayamaea permitis* (Hustedt) Bruder & Medlin**	**MPMI**
Melosira varians C.Agardh	MVAR
Microcostatus Johansen & Sray	MCCT
Navicula amphiceropsis Lange-Bertalot & U.Rumrich	NAAM
**Navicula angusta* Grunow	NAAN
Navicula antonii Lange-Bertalot	NANT
Navicula arvensis var. *dubia* Lange-Bertalot	NARM
SYN *Navicula arvensis* var. *major* Lange-Bertalot	NAMA
***Navicula capitatoradiata* H.Germain ex Gasse**	**NCPR**
Navicula cincta (Ehrenberg) Ralfs	NCIN
Navicula cryptocephala Kützing	NCRY
Navicula cryptotenella Lange-Bertalot	NCTE
Navicula cryptotenelloides Lange-Bertalot	NCTO
***Navicula erifuga* Lange-Bertalot**	**NERI**
$^+$*Navicula exilis* Kützing	NEXI
Navicula germainii J.H.Wallace	NGER
Navicula gregaria Donkin	NGRE
Navicula libonensis Schoeman	NLIB
***Navicula metareichardtiana* Lange-Bertalot & Kusber**	**NMTA**
SYN *Navicula reichardtiana* Lange-Bertalot	**NRCH**
Navicula microcari Lange-Bertalot	NMCA
$^+$*Navicula notha* J.H.Wallace	NNOT
***Navicula radiosa* Kützing**	**NRAD**
Navicula ranomafanensis (Manguin) Metzeltin & Lange-Bertalot	NRAN
Navicula recens (Lange-Bertalot) Lange-Bertalot	NRCS
Navicula reinhardtii (Grunow) Grunow	NREI
Navicula rhynchocephala Kützing	NRHY

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Taxa	Omnidia Code
Navicula riediana Lange-Bertalot & Rumrich	NRIE
Navicula rostellata Kützing	NROS
***Navicula salinicola* Hustedt**	**NSLC**
Navicula schroeteri F.Meister	NSHR
Navicula spp.	NAVI
Navicula subhamulata Grunow	NSBH
+*Navicula subrhynchocephala* Hustedt	NSRH
Navicula symmetrica R.M.Patrick	NSYM
Navicula tenelloides Hustedt	NTEN
Navicula tripunctata (O.F.Müller) Bory	NTPT
Navicula trivialis Lange-Bertalot	NTRV
Navicula vandamii Schoeman & R.E.M.Archibald	NVDA
Navicula vandamii var. *mertensiae* Lange-Bertalot	NVDM
***Navicula veneta* Kützing**	**NVEN**
Navicula viridula (Kützing) Ehrenberg	NVIR
Navicula zanoni Hustedt	NZAN
***Navigeia decussis* (Østrup) Bukhtiyarova**	**NGDU**
SYN *Geissleria decussis* (Østrup) Lange-Bertalot & Metzeltin	**GDEC**
*+*Neidium productum* (W.Smith) Cleve	NEPR
Neidium sp.	NEID
Nitzschia acicularis (Kützing) W.Smith	NACI
*+*Nitzschia acidoclinata* Lange-Bertalot	NACD
***Nitzschia agnewii* Cholnoky**	**NAGW**
Nitzschia agnita Hustedt	NAGN
***Nitzschia amphibia* Grunow**	**NAMP**
Nitzschia amphibia f. *frauenfeldii* (Grunow) Lange-Bertalot	NAFR
***Nitzschia archibaldii* Lange-Bertalot**	**NIAR**
Nitzschia aurariae Cholnoky	NAUR
***Nitzschia bacata* Hustedt**	**NZBA**
Nitzschia bacillum Hustedt	NBCL
Nitzschia capitellata Hustedt	NCPL
Nitzschia clausii Hantzsch	NCLA
***Nitzschia communis* Rabenhorst**	**NCOM**
Nitzschia commutata Grunow	NICO
Nitzschia desertorum Hustedt	NDES
***Nitzschia dissipata* (Kützing) Grunow**	**NDIS**
Nitzschia draveillensis Coste & Ricard	NDRA

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Taxa	Omnidia Code
Nitzschia elegantula **Grunow**	**NELE**
Nitzschia etoshensis Cholnoky	NETO
Nitzschia filiformis (W.Smith) Van Heurck	NFIL
Nitzschia fonticola **(Grunow) Grunow**	**NFON**
Nitzschia frequens Hustedt	NIFQ
Nitzschia frustulum **(Kützing) Grunow**	**NIFR**
Nitzschia fruticosa Hustedt	NIFT
+ *Nitzschia gisela* Lange-Bertalot	NGIS
Nitzschia gracilis **Hantzsch**	**NIGR**
*+ *Nitzschia hantzschiana* Rabenhorst	NHAN
Nitzschia heufleriana Grunow	NHEU
Nitzschia inconspicua **Grunow**	**NINC**
Nitzschia intermedia **Hantzsch ex Cleve & Grunow**	**NINT**
Nitzschia irremissa Cholnoky	NIRM
Nitzschia lancettula O.Müller	NLTL
Nitzschia liebethruthii **Rabenhorst**	**NLBT**
Nitzschia linearis **W.Smith**	**NLIN**
Nitzschia linearis **var.** ***subtilis*** **Hustedt**	**NLSU**
+ *Nitzschia media Hantzsch*	NIME
SYN *Nitzschia dissipata* var. *media (Hantzsch) Grunow*	NDME
Nitzschia microcephala Grunow	NMIC
Nitzschia nana Grunow	NNAN
Nitzschia palea **(Kützing) W.Smith**	**NPAL**
Nitzschia palea var. *debilis* (Kützing) Grunow	NPAD
Nitzschia palea var. *tenuirostris* Grunow	NPAT
Nitzschia paleacea **(Grunow) Grunow**	**NPAE**
Nitzschia cf. *paleaeformis* Hustedt	NIPF
Nitzschia perminuta **Grunow**	**NIPM**
Nitzschia perspicua Cholnoky	NPRP
**Nitzschia pumila* Hustedt	NPML
Nitzschia pura Hustedt	NIPR
Nitzschia pusilla Grunow	NIPU
+*Nitzschia radicula* Hustedt	NZRA
Nitzschia rautenbachiae Cholnoky	NRTB
Nitzschia recta Hantzsch	NREC
+*Nitzschia regula* Hustedt	NIRE
Nitzschia reversa W.Smith	NREV

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Taxa	Omnidia Code
Nitzschia rosenstockii Lange-Bertalot	NRST
Nitzschia scalpelliformis (Grunow) Grunow	NISC
Nitzschia semirobusta Lange-Bertalot	NSRB
Nitzschia sigma (Kützing) W.Smith	NSIG
Nitzschia sigmoidea (Nitzsch) W.Smith	NSIO
Nitzschia siliqua R.E.M.Archibald	NSLQ
Nitzschia sociabilis **Hustedt**	**NSOC**
Nitzschia solita Hustedt	NISO
Nitzschia spp.	NZSS
Nitzschia **cf.** ***spiculoides*** **Hustedt**	**NSLO**
Nitzschia spiculum Hustedt	NISP
Nitzschia subacicularis Hustedt	NSUA
Nitzschia **cf.** ***subsalsa*** **Cholnoky**	**NSSA**
Nitzschia subtilis (Kützing) Grunow	NISU
Nitzschia supralitorea **Lange-Bertalot**	**NZSU**
Nitzschia tropica **Hustedt**	**NTRO**
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	NUMB
*+*Nitzschia valdecostata* Lange-Bertalot & Simonsen	NVLC
Nitzschia vildaryana U.Rumrich & Lange-Bertalot	NVDR
+*Pinnularia bertrandii* var. *angustefasciata* Krammer	PBEA
Pinnularia borealis Ehrenberg	PBOR
**Pinnularia brebissonii* (Kützing) Rabenhorst	PBRE
+*Pinnularia divergens* W.Smith	PDIV
+*Pinnularia microstauron* (Ehrenberg) Cleve	PMIC
Pinnularia microstauron var. *rostrata* Krammer	PMRO
Pinnularia spp.	PINS
Pinnularia subbrevistriata Krammer	PSBV
Pinnularia subcapitata W.Gregory	PSCA
Placoneis dicephala (Ehrenberg) Mereschkowsky	PDIC
Placoneis elginensis (W.Gregory) E.J.Cox	PELG
Placoneis sp.	PLAC
Planothidium delicatulum (Kützing) Round & Bukhtiyarova	PTDE
Planothidium engelbrechtii (Cholnoky) Round & Bukhtiyarova	PLEN
Planothidium frequentissimum **(Lange-Bertalot) Lange-Bertalot**	**PLFR**
Planothidium lanceolatum **(Brébisson ex Kützing) Lange-Bertalot**	**PTLA**
Planothidium rostratum (Østrup) Round & Bukhtiyarova	PRST
Planothidium sp. Round & Bukhtiyarova	PTDS

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Taxa	Omnidia Code
Platessa oblongella (Østrup) C.E.Wetzel, Lange-Bertalot & Ector	POBL
Pleurosigma salinarum (Grunow) Cleve & Grunow	PSAL
Pseudofallacia monoculata (Hustedt) Y.Liu, Kociolek & Q.Wang	PMOC
SYN *Fallacia monoculata* (Hustedt) D.G.Mann	FMOC
***Pseudostaurosira brevistriata* (Grunow) Williams & Round**	**PSBR**
***Pseudostaurosira elliptica* (Schumann) Edlund, Morales & Spaulding**	**PSSE**
SYN *Staurosira elliptica* (Schumann) Williams & Round	**SELI**
***Pseudostaurosira subsalina* (Hustedt) Morales**	**PSSB**
Reimeria sinuata (W.Gregory) Kociolek & Stoermer	RSIN
***Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot**	**RABB**
Rhopalodia gibberula (Ehrenberg) O.Müller	RGBL
Rhopalodia sp.	RHOS
Sellaphora bacilloides (Hustedt) Levkov, Krstic & Nakov	SBLO
***Sellaphora nigri* (De Notaris) Wetzel & Ector**	**SNIG**
SYN *Eolimna minima* (Grunow) Lange-Bertalot	**EOMI**
Sellaphora pupula (Kützing) Mereschkowsky	SPUP
Sellaphora seminulum (Grunow) D.G.Mann	SSEM
$^{+}$***Sellaphora stroemii* (Hustedt) H.Kobayasi**	**SSTM**
***Seminavis pusilla* (Grunow) E.J.Cox & G.Reid**	**SMPU**
SYN *Navicymbula pusilla* (Grunow) Krammer	**NCPU**
Simonsenia delognei Lange-Bertalot	SIDE
Stauroneis sp.	STAU
Stauroneis smithii Grunow	SSMI
***Staurosira construens* Ehrenberg**	**SCON**
Staurosira sp.	SSPE
***Staurosira venter* (Ehrenberg) Cleve & J.D.Möller**	**SSVE**
SYN *Staurosira construens* var. *venter* (Ehrenberg) Hamilton	**SCVE**
***Staurosirella pinnata* (Ehrenberg) Williams & Round**	**SPIN**
Stephanocyclus cryptica (Reimann, Levin & Guillard) Kulikovskiy, Genkal & Kociolek	SCCR
SYN *Cyclotella cryptica* Reimann, Lewin & Guillard	CCRY
***Stephanocyclus meneghiniana* (Kützing) Kulikovskiy, Genkal & Kociolek**	**SCME**
SYN *Cyclotella meneghiniana Kützing*	**CMEN**
Stephanodiscus agassizensis Håkansson & Kling	SAGA
Stephanodiscus hantzschii Grunow	SHAN
Stephanodiscus minutulus (Kützing) Cleve & Moller	STMI
Surirella angusta Kützing	SANG
Surirella brebissonii Krammer & Lange-Bertalot	SBRE

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Taxa	**Omnidia Code**
Surirella librile Ehrenberg	SULI
SYN *Cymatopleura solea* (Brébisson) W.Smith	CSOL
Surirella microlibrile Van de Vijver, Pottiez & Jüttner	SMLI
SYN *Cymatopleura solea* var. *apiculata* (W. Smith) Ralfs	CSAP
Surirella ostentata Cholnoky	SUOS
Surirella ovalis Brébisson	SOVI
Tabularia fasciculata **(C.Agardh) Williams & Round**	**TFAS**
Tryblionella angustata **W.Smith**	**TANG**
SYN ***Nitzschia angustata*** **(W.Smith) Grunow**	**NIAN**
Tryblionella angustatula (Lange-Bertalot) Cantonati & Lange-Bertalot	**TATU**
SYN *Nitzschia angustatula* Lange-Bertalot	**NZAG**
Tryblionella apiculata **W.Gregory**	**TAPI**
Tryblionella calida (Grunow) D.G.Mann	TCAL
Tryblionella debilis Arnott	TDEB
Tryblionella gracilis W.Smith	TGRL
Tryblionella hungarica (Grunow) D.G.Mann	THUN
Tryblionella levidensis W.Smith	TLEV
Tryblionella littoralis (Grunow) D.G.Mann	TLIT
Tryblionella sp.	TRYB
Ulnaria acus **(Kützing) Aboal**	**UACU**
Ulnaria **cf.** ***delicatissima*** **(W.Smith) Aboal & P.C.Silva**	**UDEL**
SYN ***Fragilaria*** **cf.** ***delicatissima*** **(W.Smith) Lange-Bertalot**	**FDEL**
Ulnaria grunowii (Lange-Bertalot & S.Ulrich) Cantonati & Lange-Bertalot	UGRU
SYN Fragilaria grunowii Lange-Bertalot & S.Ulrich	FGNO
Ulnaria monodii **(Guermeur) Cantonati & Lange-Bertalot (complex)**	**UMON**
Ulnaria ulna **(Nitzsch) Compère**	**UULN**

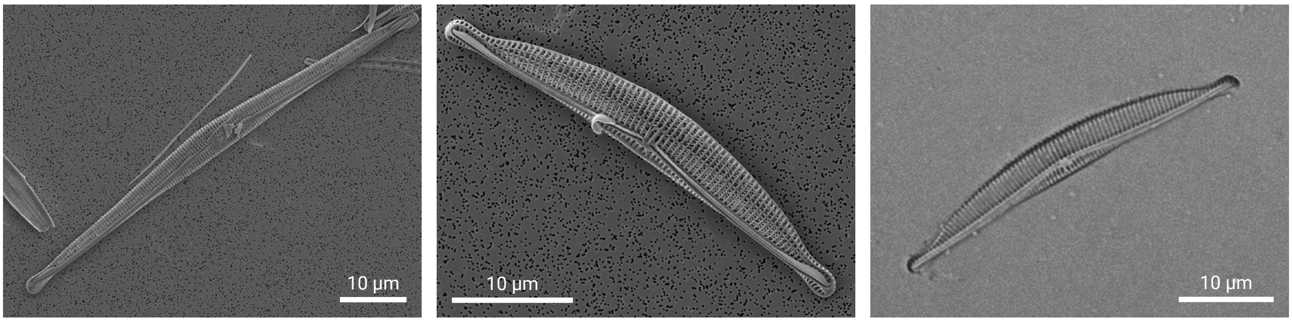

Figure 2. Morphological variations found within *Amphora* sp0 under SEM and LM found within the Eastern Karoo.

Table 2. Diatom species that were originally incorrectly identified in the Karoo with the new species allocation information

Original species name	Current species name	Reason for change
Amphora pediculus (Kützing) Grunow	*Amphora* spp.	Seven different small *Amphora* taxa were found and separated from *A. pediculus*.
Halamphora coffeiformis (C.Agardh) Mereschkowsky	*Amphora* sp.	This species was incorrectly identified in Holmes (2022) as *H. coffeaeformis* (corrected form: *H. coffeiformis*). Further investigation together with SEM has shown this is not that species and was separated from the correct identifications. It was widespread and dominant in several samples.
Brachysira neoexilis Lange-Bertalot	*Brachysira* sp. (*B. neoexilis*) shape	This species was incorrectly identified, and various morphologies were grouped together under this complex. Subsequent SEM studies have shown that these cells are not *B. neoexilis*. To differentiate this shape from the other morphologies found, the original name has been kept in the new identification to show cells were according to the distinctive *B. neoexilis* shape.
Brachysira neoexilis Lange-Bertalot	*Brachysira* spp.	Seven different morphotypes, besides the *B. neoexilis* shape, were found and allocated to different groups. Until additional data is available these are listed as separate morphotypes.
Chaetoceros sp.	*Chaetoceros* sp.	These cells had varying numbers of setae. As these may be the same species with varying stages in their life cycle or different morphologies depending on their point of attachment in chain-like colonies, along with the difficulty in identification under LM, all *Chaetoceros* species were grouped together. This genus is poorly studied in freshwaters in South Africa and no previously identified taxa could be found that share the distinct morphology areolae in the setae of the Karoo taxa.
Craticula buderi (Hustedt) Lange-Bertalot	*Craticula* cf. *buderi* (Hustedt) Lange-Bertalot	There were different morphotypes of what were thought to be *C. buderi* (Holmes 2022; Holmes et al. 2023). SEM revealed that these taxa all have distinct morphological characteristics. The species were separated based on morphological differences under LM. The ones that, under LM, fit within the 'normal' morphology was kept in this group as *C.* cf. *buderi*.
Craticula buderi (Hustedt) Lange-Bertalot	*Craticula* spp.	The species that did not fit within the *C. buderi* morphology (under LM) were placed in to eight different groups.
Diploneis elliptica (Kützing) Cleve	*Diploneis* sp. previously identified as *D. elliptica* (Kützing) Cleve	This species was originally identified using Taylor et al. (2007c, Plate 40). That identification differs from Cantonati et al. 2017 (Plate 6, Figure 1–5) and www.diatoms.org. The SEM images from the Karoo samples do not match those from Sala et al. (2018) for *D. elliptica*. It was, therefore, decided to change this species determination. This taxon was dominant in several samples in the Karoo.
Ulnaria biceps (Kützing) Compère	*Ulnaria monodii* (Guermeur) Cantonati & Lange-Bertalot comb. nov. (COMPLEX)	According to Cantonati et al. (2018), *U. biceps* is routinely misidentified. Upon rechecking the Karoo samples, it was found that not all the species fitted within the *Fragilaria biceps* (Kützing) Lange-Bertalot, *Ulnaria acuscypriacus* Lange-Bertalot & Cantonati or *U. monodii* species identifications. These species were all placed in the *U. monodii* complex. This genus needs complete revision in South Africa to gain clarity on identifications.

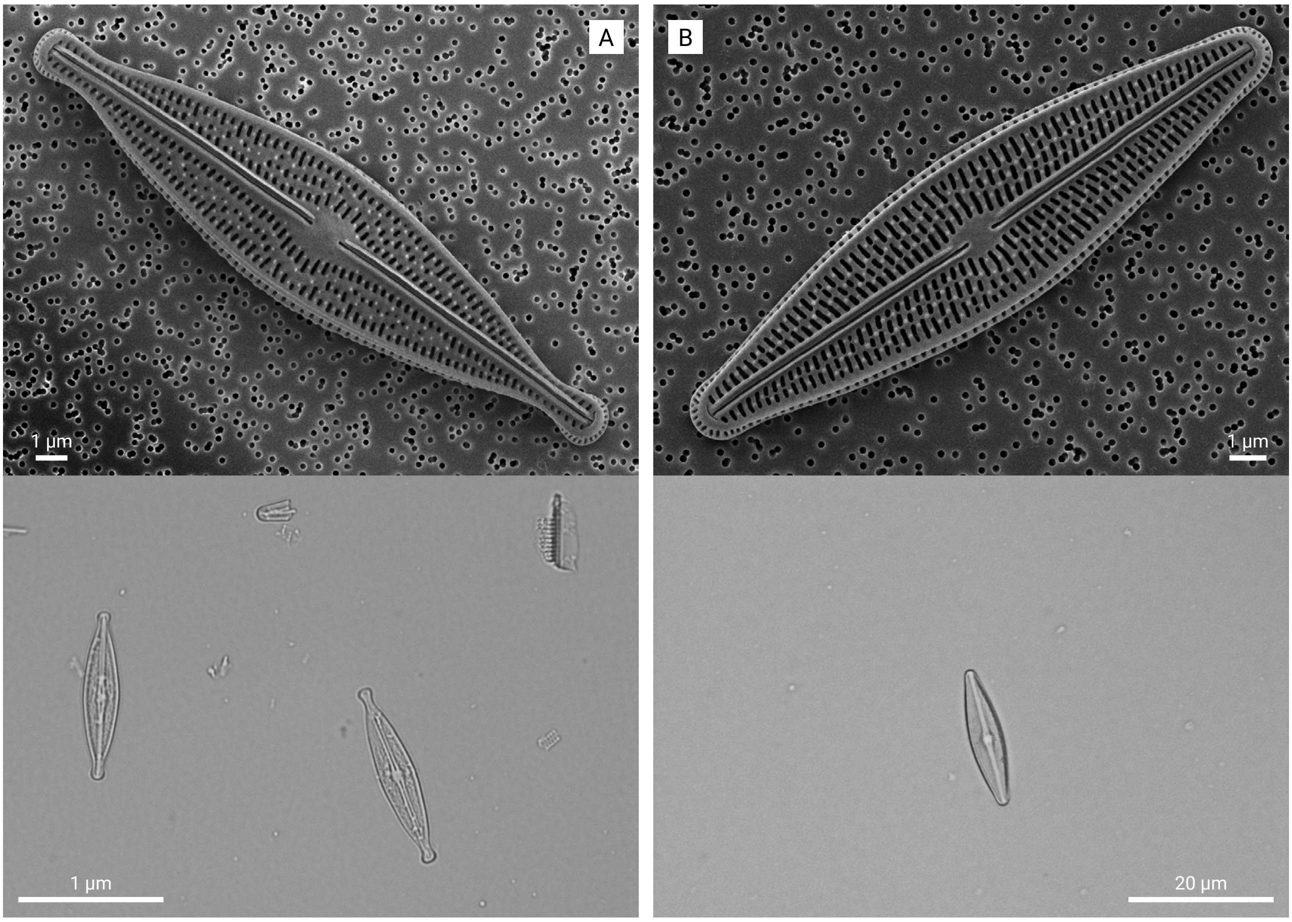

Figure 3. Two species groupings within the *Brachysira* genus found in the Eastern Karoo; A – *Brachysira* cf. *neoexilis*; B – *Brachysira* sp. 2.

There were six species groupings within the genus *Brachysira*. Although the cell in Figure 3A is similar in shape to *B. neoexilis*, under SEM it is shown not to be that species. *Brachysira* sp. 2 (Figure 3B) occurred in many samples and both sometimes in large numbers but did not occur together in the same sample.

The dominant species (from flowing water) from Holmes and Taylor (2015, n = 101) was *Nitzschia frustulum* (15.8 %) followed by *Rhopalodia gibba* [= *Epithemia gibba*] (9.6 %). The most prolific species for the Karoo Shale Gas Project, (both standing and running waters, n = 506), were *Achnanthidium minutissimum* (17.4 %), *Denticula kuetzingii* (10.1 %) and *Encyonopsis krammeri* (5.8 %).

Discussion

This species list shows the diversity in the diatom flora of the Karoo. It can be used to assist with and update freshwater diatom identification in South Africa. The list provides a basis from which to improve species occurrence information and identification.

The waters of the Karoo are alkaline (pH >6.1) with large differences in electrical conductivity (158–8400 μS/ cm), as well as wide ranges of calcium, chloride, oxidised nitrogen and sulphate (Janse van Vuuren & Taylor 2015; Holmes et al. 2023, and in progress).

The list covers species that were recorded in standing water (water reservoirs containing borehole water) and fountains (slow running water). This list excludes the information from Archibald (1983 for upper Sundays and Great Fish rivers) and upper Sundays River (Bate et al. 2004; Janse van Vuuren & Taylor 2015; Roussouw et al. 2018). No other studies on diatoms within the Karoo could be found.

As the species list is based on diatom counts from various projects that had a set number of cells counted, it must be noted that there may be species present in the Karoo that were not enumerated within that limit and are not accounted for on this preliminary species list.

Species within the *Nitzschia frustulum* group are often identified as *N. frustulum* when they are actually *N. inconspicua* or *N. soratensis*. While *N. frustulum* is known to withstand changes in osmotic pressure (and thereby fluctuating water levels, Taylor et al. 2007c), *N. inconspicua* indicates brackish-marine conditions with *N. soratensis* found in freshwater only (Trobajo et al. 2013).

Another common species complex prone to have species lumped together is *Achnanthidium minutissimum* complex. As was found during the Karoo Shale Gas Project, there were at least 24 *Achnanthidium* taxa that could not be placed in a species with certainty. The *A. minutissimum* grouping is constantly evolving as information on new species is published. Misunderstanding surrounds the identification of *Ulnaria biceps* and *Ulnaria monodii* (and similar species, Cantonati et al. 2018) in South Africa (Table 2). These species have different ecological requirements, which could lead to incorrect ecological inference. It is therefore imperative that the identification of these species be revisited.

Limitations

Although the diatom Red Lists are based on species found in Germany, it is widely known that these sensitive species occur in unimpacted habitats and may disappear in disturbed habitats. It is suggested that nitrates (and therefore human activities) could pose a threat to these species (Cantonati et al. 2022). Autecological information for diatoms in South Africa is often taken from the literature based on surveys from different regions around the world. As was shown by Holmes (2022), this information cannot be broadly superimposed on to South African conditions. Local conditions do have an effect on diatom community composition. The lack of an accessible database for the identification of South African diatoms, together with the lack of standardised data for South African ecological conditions, hampers the inclusion of these organisms as a biomonitoring tool.

This review of the Karoo diatom samples (2010 to 2012 and 2015 to 2017) with the preliminary species list presented here highlights the shortcomings for diatom identification in South Africa. A revised diatom identification guide for South African diatoms is overdue with current literature being outdated both in terms of nomenclature and taxonomy.

Several species in the Karoo are possibly, as yet, undescribed. Of the issues that came to light during the compilation of this list was the difficulty of access to historical records. The question surrounding identification of certain species, some of which are mentioned in Table 2, is an area which requires further investigation. This work may be considered as only a preliminary list of diatom species found in two projects within the Eastern Karoo.

Recommendations

For ecological studies to be effective, validated and updated checklists are essential. Checklists of an area allow for changes in community structure to be detected. As with any checklist, there is a constant need for it to be updated to remain useful. Human activities have the potential to pose great risk to biodiversity and as diatoms are good indicators of environmental change, it is important to know about any changes in species composition.

In view of the climate change crisis issues around the world, diatom records are important to infer changes in environmental conditions (past and present day). Many of the historical records in South Africa are not easily accessible to researchers. It would be highly beneficial for the scientific community if these records could be catalogued (in a central database) together with geolocation and, where possible, water chemistry before they are lost.

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Authors' contributions

M. Holmes (Nelson Mandela University and AEON-ESSRI) was responsible for both the MSc and PhD project designs used for the compilation of this species list in addition to conducting all field work (including field work costs), all diatom identification (with the assistance of J.C Taylor) and enumeration. She performed all the statistical analysis for the projects with input from both E.E. Campbell and J.C. Taylor. E.E. Campbell (Nelson Mandela University) was the supervisor of the PhD for M. Holmes for the Karoo Shale Gas Project, which included a preliminary diatom baseline of Karoo waters (2015–2017). J.C. Taylor (North-West University) was the supervisor for the MSc project for M. Holmes (2010–2012) based on the diatoms of the upper Great Fish River. He was instrumental in assisting with the set-up of the laboratory on Clifton and was co-supervisor on the above-mentioned PhD. He continues to collaborate on diatom identification. M. de Wit, as head of AEON-ESSRI (Nelson Mandela University), was responsible for all researchers under the Karoo Shale Gas Project. He unfortunately passed away during the PhD project and his contribution was therefore limited. He was, however, instrumental in the concept of the PhD project being accepted and implemented.

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Endemic plants and animals are susceptible to extinction in an imperilled alpine hotspot in southern Africa

Authors

*Peter J. Taylor et al.

*Full list of authors and their affiliations are provided at the end of the paper.

Corresponding Author

Peter J. Taylor; e-mail: taylorpj@ufs.ac.za

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Background: As global temperatures rise, alpine species at the upper limit of their distribution are at risk of decline and extinction due to shrinking habitats downslope. The alpine (> 2 800 m a.s.l.) biodiversity of the Maloti-Drakensberg is poorly known but may be threatened by climate change.

Objectives: Using expert BioBlitzes, we documented species richness and elevational patterns of distribution in 14 plant and animal higher taxa from alpine and upper-montane zones in an unexplored corner of the Maloti-Drakensberg.

Methods: Using standardised methods such as Sherman traps, acoustic monitoring, bird timed counts, pitfall traps, sweep nets, aquatic SASS5 kick-nets, timed searches and herbarium collections, we assessed elevational zonation of flowering plant and selected invertebrate and vertebrate diversity in the Witsieshoek Community Conservation Area (WCCA).

Results: GBIF records complemented expert BioBlitz data, together enumerating 1 216 plant, vertebrate and invertebrate species along an elevation gradient from 1 760 m to 3 145 m at WCCA. Birds, insects and plants showed concordant beta diversity patterns from BioBlitz and GBIF data: high turnover compared to nestedness in more sedentary insects and plants, and the opposite in more mobile birds (GBIF data not available for bats). Although identifications are ongoing, 17% of species or morphospecies were exclusively recorded in the alpine zone, including 82 species of plants and 92 of animals.

Conclusion: Alpine endemics are vulnerable to the 'escalator to extinction' process due to climate change. Surveys of under-explored alpine hotspots should be prioritised, drawing on mountain tourism-based citizen science. We advocate an ecotourism- and community-centred, restoration and rewilding approach for this strategic and biodiverse community conservation area.

Keywords: Drakensberg Mountains; climate change; ecology; escalator to extinction; GBIF.

Introduction

As global temperatures rise, alpine species at the upper edge of their distribution are at risk of decline and extinction due to shrinking habitats downslope, a phenomenon known as the 'escalator to extinction' (Freeman et al. al. 2018; Urban 2018; Watts et al. 2022; Environments [GLORIA] 2024).

Temperate grasslands, globally and in the Maloti-Drakensberg (MD) of southern Africa, are rapidly transforming, and are currently poorly protected (Carbutt et al. 2017; Bengtsson et al. 2019; Scholtz & Twidwell 2022). Comprising both montane (1 800–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) elements, the

MD is a key area of endemism and diversity for plants (Carbutt & Edwards 2015; Brand et al. 2019; Carbutt 2019), vertebrates (Van As et al. 2014a,b; Kopij 2015), terrestrial invertebrates (Armstrong & Brand 2012; Van der Merwe et al. 2020; Modise 2023) and aquatic invertebrates (Hamer & Brendonck 1997; Martens et al. 1998; Van Damme et al. 2013; Deacon et al. 2020), with ongoing species discoveries of both plants (Clark et al. 2011; 2015; 2016a,b) and animals (Hamer & Martens 1998; Hamer & Slotow 2009; Conradie 2014; Conradie et al. 2018; Taylor et al. 2020; Haddad et al. 2021; Mdidimba et al. 2021; Cornette et al. 2022).

Alpine grasslands and shrublands in Africa are predominantly found in two regions: the tropical Afroalpine 'sky islands' of northeast Africa (3 400–4 600 m) and the higher slopes and plateaux of the MD (2 800–3 482 m). The latter is located within Lesotho (90%) and adjacent areas of South Africa (10%) (Carbutt 2020). Reflecting a biome in crisis, these alpine areas are mostly unprotected and vulnerable to anthropogenic and climate change (Dinerstein et al. 2017; Carbutt 2019, 2020). The Qwaqwa Mountains form a northern outpost of the MD spanning both montane and alpine elevations (Figure 1). Within South Africa, along its Free State province's border with Lesotho, these mountains fall within the Witsieshoek Community Conservation Area (WCCA), which is valuable for ecotourism and biodiversity, but poorly researched with few biological studies (Delves et al. 2021; Shezi et al. 2021; Praeg et al. 2023). The WCCA is an important conservation buffer bordering two protected areas, Royal Natal National Park (RNNP) and Golden Gate Highlands National Park (GGHNP). However, it is being transformed by conversion into settlements, bush encroachment and livestock overgrazing, leading to reduced plant diversity (Shezi et al. 2021), while hunting and competition with people and livestock has reduced populations of larger mammals (Morake 2010). Rewilding of the WCCA from adjacent protected areas is therefore viable in conjunction with community-based sustainable rangeland management. However, conservation efforts in the WCCA require engaged scholarship to understand the multidimensional social, environmental and biodiversity challenges of the area (Delves et al. 2021). This should be underpinned by robust assessments of grassland and rangeland biodiversity, particularly alpine biodiversity potentially at risk from the escalator to extinction.

In 2023, the Witsieshoek Mountain Lodge and the Afromontane Research Unit of the University of the Free State (ARU) established a joint Alpine Research Station, facilitating surveys of hitherto poorly explored alpine biota. Leveraging improved access and conducting five expert BioBlitzes (i.e., surveys by specialist taxonomists; Parker et al. 2018) between October 2021 and November 2023, we documented elevational patterns across 14 animal and plant higher taxa at WCCA. We identified the extent of alpine endemism among these taxa within the scope of our study, and consequently, assessed the risk of extinction for these species. At the time of our study, tourist and scientist visitors to the Witsieshoek Mountain Lodge contributed 3 438 georeferenced biodiversity records to public platforms such as the Global Biodiversity Information Facility (GBIF), mostly concentrated along the hiking trail leading from the lodge to the alpine summit (Figure 1). We compared our BioBlitz data with records from the GBIF database (which were validated by experts in our study), thereby demonstrating the complementarity of the two approaches.

Methods

Study area

The geographical context of the WCCA is described above (Figure 1). Surveys were conducted from our bases of the Witsieshoek Lodge (at 2 200 m; GPS: 28.6860°S, 28.9014°E) and the ARU Alpine Research Station (at 3 145 m; GPS: 28.7536°S, 28.8672°E). The vegetation of the lower sites is classified as uKhahlamba Basalt Grassland while sites above 2 800 m are classified as Drakensberg Afroalpine Heathland (Table 1). A total of 17 sites (ten terrestrial and seven aquatic) were surveyed within the study area, classified into lower-montane (< 2 400 m a.s.l.), upper-montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) zones (Table 1, Figure 1).

The area receives between 1 200 and 1 500 mm annual rainfall, and falls within a cool, wet, summer rainfall region, with cold winters. Precise data were not available for the WCCA, but the mean annual temperature for the adjacent Lesotho Highlands is about 7°C, with a summer mean of 20°C and a winter minimum of -6.3°C (Lesotho Meteorological Services). Five distinct plant communities have been recognised in the study area (Shezi 2014), the Cheche Open Shrubland, the Ledile–*Eragrostis plana*, the Lodi, the Lekgapu and the Red Grass communities. Generally, the lower-lying Cheche Open Scrub and Ledile-*Eragrostis plana* communities are dominated by encroaching shrubs (*Leucosidea sericea* Eckl. & Zeyh; Rosaceae) and grasses (*Eragrostis plana* Nees; Poaceae) respectively, indicating the effects of over-grazing. The Lodi and Red Grass communities are both characterised by a grass species (*Themeda triandra* Forssk.; Poaceae) that indicates good rangeland quality. The Lekgapu community is characterised by dwarf shrubs dominated by *Erica dominans* Killick (Ericaceae), characteristically occurring on the high plateau. In general, lower and gentler slopes showed evidence of overgrazing by livestock from local communities while the summit plateau showed evidence of overgrazing in summer by livestock of Basotho herders from Lesotho (Table 1; Kotzé et al. 2023). The soils of the alpine zone in the Amphitheatre summit area are characterised by exceptionally high soil organic carbon (SOC) (Kotzé et al. 2023).

GBIF records

A search of the GBIF database was conducted on 18 February 2023 for all records within a polygon that defined the study area, using the search term 'Geometry POLYGON((28.867 -28.755, 28.902 -28.755, 28.902 -28.677, 28.867 -28.677, 28.867 -28.755))'. The DOI citation is 'GBIF.org (18 February 2023) GBIF Occurrence Download 10.15468/dl.ykm4r7'. The search yielded 3 438 records. After excluding chromista, fungi and uncertain records, a final list of 3 366 flowering plant and animal records was obtained for

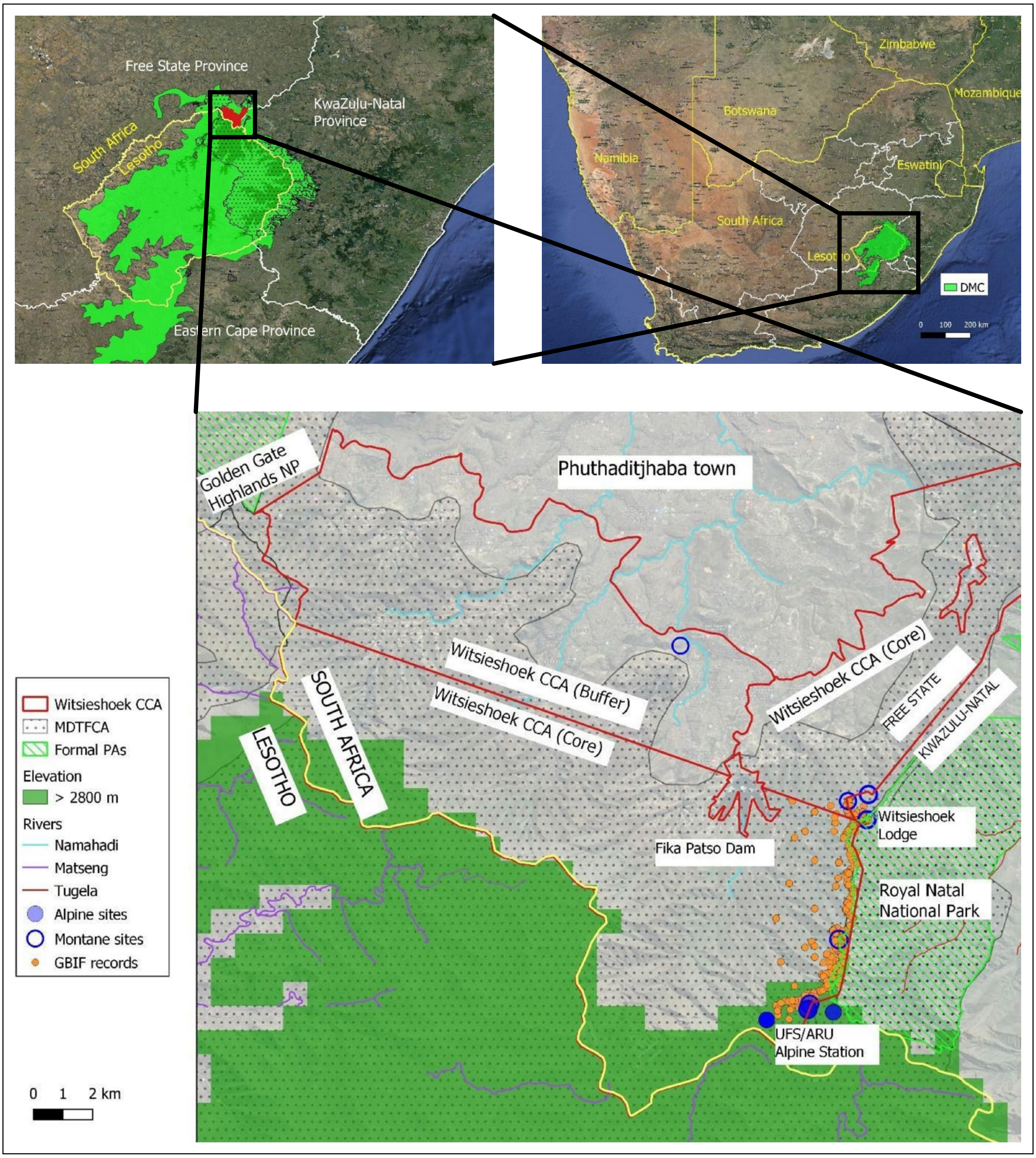

Figure 1. Maps showing (top panels) the location of Witsieshoek Community Conservation Area (WCCA; red shading) in relation to the Drakensberg Mountain Centre of southern Africa (green shading; Carbutt 2019, with elevations > 2 800 m a.s.l. shown in darker green in the top left panel), including the Maloti Drakensberg Transfrontier Conservation Area (stippled; MDTFCA), and (bottom panel) detailed map of WCCA showing aquatic invertebrate and terrestrial plant and animal sampling sites and GBIF records from montane (≤ 2 800 m) and alpine (> 2 800 m) zones within the WCCA, which connects the Golden Gate Highlands (west) and Royal Natal (east) National Parks. The study area is a watershed for three major drainage systems draining east (Tugela R), west (Matseng R) and north (Namahadi R). Maps for MDTFCA © Peace Parks Foundation Open Data. Maps for WCCA © MDTFCA.

Table 1. Details of terrestrial (TER) and aquatic (AQS) sites for five expert BioBlitzes conducted between October 2021 and November 2023. For this study, sites were grouped in three elevational zones as lower montane (< 2 400 m a.s.l.), upper montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.)

Site ID	Longitude	Latitude	Site name	Elevation (m a.s.l.)	Elevation zone	Vegetation type (Mucina & Rutherford 2006)	Site description (where available)	Grazing pressure
TER 1	28.9019	-28.6773	Witsieshoek Dam	2 058	Lower Montane	Ukhahlamba Basalt Grassland		Mod–High
TER 2	28.90138	-28.686	Witsieshoek Lodge (=Pollinator ‘lower montane’ Site 1)	2 200	Lower Montane	Ukhahlamba Basalt Grassland	Gentle southerly facing slope, short grassland with low flowering forbs and relatively few bushes; some low rocks and bare stoney areas; signs of grazing by cattle.	Mod–High
TER 2a	28.90138	-28.686	Witsieshoek Lodge (=Pollinator ‘lower montane’ Site 2)	2 197	Lower Montane	Ukhahlamba Basalt Grassland	Gentle slope; short grassland with forbs; signs of grazing by livestock.	Mod–High
TER 3	28.8917	-28.7273	Sentinel Car Park (=Pollinator ‘upper montane’ Site 2)	2 590	Upper Montane	Ukhahlamba Basalt Grassland	Westerly facing slope, short grassland; many flowering forbs; some bare stoney areas; some low rocks.	Low
TER 3a	28.89249	-28.72574	Sentinel Car Park (=Pollinator ‘upper montane’ Site 1)	2 567	Upper Montane	Ukhahlamba Basalt Grassland	Variable (gentle to moderately steep) slope; short grassland with forbs.	Low
TER 4	28.88101	-28.7514	Top of chain ladder	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
TER 5	28.86723	-28.75359	ARU Alpine Station (=Pollinator Alpine Site 1 & MIREN upper site)	3 145	Alpine	Drakensberg Afroalpine Heathland	Gentle easterly facing hillside; low bushes, forbs and grass; with stoney bare areas and low rocks.	Mod–High (summer)
TER 6	28.8693	-28.75279	Near ARU Alpine Station (=Pollinator Alpine Site 2)	3 124	Alpine	Drakensberg Afroalpine Heathland	Flattish area; some standing water; many rocks, some bare areas with stoney soil; low bushes, many flowering forbs and tall grasses.	Mod–High (summer)
TER 7	28.88274	-28.75136	Royal Natal NP, top of Amphitheatre (=Pollinator Alpine Site 3)	3 037	Alpine	Drakensberg Afroalpine Heathland	Flattish area; slightly marshy, some standing water; many sedges, grasses and *Helichrysum* flowers.	Mod–High (summer)

Table 1. Details of terrestrial (TER) and aquatic (AQS) sites for five expert BioBlitzes conducted between October 2021 and November 2023. For this study, sites were grouped in three elevational zones as lower montane (< 2 400 m a.s.l.), upper montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) (continued)

Site ID	Longitude	Latitude	Site name	Elevation (m a.s.l.)	Elevation zone	Vegetation type (Mucina & Rutherford 2006)	Site description (where available)	Grazing pressure
TER 8	28.88468	-28.75246	Royal Natal NP, top of Amphitheatre (=Pollinator Alpine Site 4)	3 038	Alpine	Drakensberg Afroalpine Heathland	Easterly facing slope; fairly rocky; some small bushes and tallish grass clumps; sparse short grass and many flowering forbs including *Helichrysum*.	Mod–High (summer)
AQS 1 (~TER 1)	28.9019	-28.6773	River feeding Witsieshoek Dam	2 060	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 2	28.837	-28.626	Namahadi River near Phuthaditjhaba	1 710	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 3 (~TER 2)	28.90138	-28.686	Temporary wetland near Witsieshoek Lodge	2 200	Lower Montane	Ukhahlamba Basalt Grassland	Not described.	Mod–High
AQS 4 (~TER 4)	28.88101	-28.7514	Tugela River, just above the chain ladders	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 5 (~TER 4)	28.88101	-28.7514	Pool on summit, just above the chain ladders	3 044	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 6	28.88993	-28.75229	Pool near Tugela Falls	3 019	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)
AQS 7	28.88968	-28.75237	Tugela River, just upstream of Tugela Falls	3 019	Alpine	Drakensberg Afroalpine Heathland	Not described.	Mod–High (summer)

599 species. The geographical and taxonomic accuracy of these records was checked by specialists for mammals, amphibians, reptiles, birds, insects and plants, resulting in 434 fully validated species used for this study.

Sampling

During five expert BioBlitzes between November 2021 and November 2023 (Table 2), we sampled 10 terrestrial (TER 1, 2, 2a, 3, 3a, 4–8) and seven aquatic sites (AQS 1–7), divided into lower-montane (< 2 400 m a.s.l.), upper-montane (2 400–2 800 m a.s.l.) and alpine (> 2 800 m a.s.l.) elevation zones (Table 1). For taxa that lacked data for upper-montane or alpine sites, we further subdivided the lower-montane zone into lower (TER 1; Witsieshoek Dam; 2 058 m a.s.l.) and upper (TER 2; Witsieshoek Mountain Lodge; 2 200 m a.s.l.) sub-zones. This allowed us to maintain three elevational intervals for standardised plotting of Venn diagrams.

Using standard methods, we compiled site and elevation zone checklists of 14 higher taxa: i) small mammals (Sherman traps) and ii) their ectoparasites; iii) bats (acoustic methods); iv) birds (timed counts); v) ants (pitfall traps); vi) insect flower-visitors (timed collections); vii) leafhoppers (sweep nets); viii) dung beetles (baited pitfall traps); ix) grasshoppers (sweep nets and timed counts); x) bugs (sweep nets); xi) flies (sweep nets), xii) spiders (pitfall traps), xiii) aquatic macroinvertebrates (kick-nets) and xiv) flowering plants (herbarium specimens collected during transects or searches). Identification was provided by relevant specialists to species level in plants, vertebrates, dung beetles, insect pollinators and flower visitors, grasshoppers and leafhoppers; to genus level in ants; and to family level in aquatic macroinvertebrates, flies and bugs. Samples identified to genus or family level were further sorted into morphospecies, and all collected specimens were deposited in relevant institutional repositories (Table 2). We conducted sample replication within a site where possible, e.g. two bat detectors, rodent trap grids or arthropod pitfall arrays placed 300–500 m apart at a site. Some invertebrate taxa not mentioned here are still being processed and identified for future publications.

Taxon-specific methods

Small mammals and their ectoparasites

Paired grids of Sherman traps were set at Sites TER 1, TER 2 (lower montane), and TER 3 (upper montane) (Table 1). Each grid was configured in a 3 × 7 layout, with traps 10 m apart (totalling 42 traps per night at each site). Trapping was conducted for three nights per session, repeated three times at Sites TER 1–3 in October 2021, March 2022 and February 2023. Additionally, alpine sites (Site TER 4 and TER 5) were sampled opportunistically in October 2022 and February 2023 for two nights each using 20 Sherman traps and two modified 'Hickman' mole-traps (Hickman 1979). Sherman traps were baited with a mixture of peanut butter and oats and checked every morning and evening. Individual rodents and shrews were identified using Monadjem et al. (2015). Sex and reproductive status were determined, and standard external measurements were taken following McCleery et al. (2021). For all rodents, shrews and bats captured, their fur was inspected and lightly brushed for ectoparasites, collecting mites, fleas and ticks into 95% ethanol for later identification by N.I. Nyembe and L. Mofokeng.

Bats

Pairs of Song Meter Mini-4 (SM4+) bat detectors (Wildlife Acoustics), set at least 300 m apart, were deployed at Sites TER 1, TER 2, TER 3 and TER 4, recording passively from dusk until dawn for 2–4 nights. Sampling was repeated in October 2021, March 2022, October 2022 and February 2023. Echolocation calls were saved in '.wav' format and identified manually by V.M. Mdluli using Kaleidoscope Pro (Wildlife Acoustics) and available call reference libraries (P.J. Taylor unpublished; A. Monadjem unpublished; Taylor et al. 2013, Monadjem et al. 2020).

Birds

Bird counts were conducted from 11 to 14 October 2021 across all elevation zones, from Sites TER 1 and TER 2 (lower montane), TER 3 (upper montane) and TER 4 (alpine) recording all species seen (with binoculars) or heard. Each site was visited for at least an hour. To increase species numbers, birds seen or heard while walking between sites were also recorded, creating a preliminary checklist for the area. All bird species were logged on the BirdLasser app, with a new list for each of the four days of sampling. Standardised timed counts of 10 min duration were conducted on three further occasions: 8–12 March 2022 (all sites), 3–6 November 2022 (Sites TER 2 and TER 4) and 6–8 February 2023 (all sites), with between 6 and 12 counts per site per occasion.

Invertebrate sampling method 1 (Focus: Ants)

During the first BioBlitz, following Munyai and Foord (2015), pitfall grid arrays were set at Sites TER 1 (Witsieshoek Dam), TER 2 (Witsieshoek Lodge) and TER 3 (Sentinel Car Park). Each grid consisted of 20 pitfall traps in a 4 × 5 grid. Test-tube shaped plastic containers (30 mm diameter) were half-filled with propylene glycol and left open for 48 hours before collection.

Table 2. Total and alpine observed and asymptotic species richness, sampling methods, institutional repositories and collection effort of taxa sampled during five expert BioBlitzes (2021–2023) at WCCA compared with GBIF point records and ADU Virtual Museum (VM) records from the locus 2828D and a previous herpetological survey of WCCA (Van As 2014a). Shaded rows represent taxa surveyed in this study, while unshaded rows represent taxa only incidentally recorded. Abbreviation of institutional museum collections as follows: ANSP = Academy of Natural Sciences, Philadelphia; DMSA = Durban Natural Science Museum; NMB = National Museum, Bloemfontein, South Africa; NMSA = Natal Museum, South Africa; SANC = South African National Collection of Insects, South Africa; TMSA = Ditsong National Museum of Natural History [previously Transvaal Museum], South Africa. Other abbreviations: SC = sample coverage (%); SR = species richness; UKZN = University of KwaZulu-Natal; UFS Zoo & Ento = University of the Free State, Department of Zoology and Entomology, Qwaqwa Campus

Taxon	ADU VM locus 2828D	GBIF + BB	GBIF	Herps (Van As 2014a)	Witsieshoek BioBlitz (BB) results, covering five field sessions of 3–6 days each. Session 1: Oct 2021; Session 2: Mar 2022; Session 3: Nov 2022; Session 4: Feb 2023; Session 5: Nov 2023										
					Sampling method	**Institution**	**Sessions**	**No. records**	**SR**	**SC(%)**	**Asymptotic SR**	**95% limits**	**No. alpine spp.**	**% alpine spp.**	**No. new spp.**
Domestic mammals	1	8	0	–	Field observations, records of Witsieshoek Lodge	NA	Incidental	NA	8	NA	NA	NA	NA	NA	0
Larger indigenous mammals	30	6	5	–	Field observations, records of Witsieshoek Lodge	NA	Incidental	NA	4	NA	NA	NA	NA	NA	0
Small mammals	–	9	0	–	Sherman traps, pitfalls	NMB	1, 2, 4	59	9	0.98	9	9.0–17.3	3	30	0
Bats	–	8	0	–	Acoustic bat detectors	NMB	1, 2, 3, 4, 5	16 442	8	1	8	8.0–9.38	0	0	1
Birds	–	120	110	–	Timed bird counts	NA	1, 2, 3, 4	411	60	0.94	97	72.0–172.0	10	16.7	0
Frogs	28	24	5	21	Collections/ photos	NMB	Incidental	3	1	NA	NA	NA	1	4.8	0
Reptiles	48	33	5	32	Collections/ photos	NMB	Incidental	4	2	NA	NA	NA	2	6.2	0
Ants (Formicidae)		20	0	–	Pitfalls, collection	UKZN	1	1 214	20	0.99	20.2	20.0–23.5		NA	0

Table 2. Total and alpine observed and asymptotic species richness, sampling methods, institutional repositories and collection effort of taxa sampled during five expert BioBlitzes (2021–2023) at WCCA compared with GBIF point records and ADU Virtual Museum (VM) records from the locus 2828D and a previous herpetological survey of WCCA (Van As 2014a). Shaded rows represent taxa surveyed in this study, while unshaded rows represent taxa only incidentally recorded. Abbreviation of institutional museum collections as follows: ANSP = Academy of Natural Sciences, Philadelphia; DMSA = Durban Natural Science Museum; NMB = National Museum, Bloemfontein, South Africa; NMSA = Natal Museum, South Africa; SANC = South African National Collection of Insects, South Africa; TMSA = Ditsong National Museum of Natural History [previously Transvaal Museum], South Africa. Other abbreviations: SC = sample coverage (%); SR = species richness; UKZN = University of KwaZulu-Natal; UFS Zoo & Ento = University of the Free State, Department of Zoology and Entomology, Qwaqwa Campus (continued)

Taxon	ADU VM locus 2828D	GBIF + BB	GBIF	Herps (Van As 2014a)	Witsieshoek BioBlitz (BB) results, covering five field sessions of 3–6 days each. Session 1: Oct 2021; Session 2: Mar 2022; Session 3: Nov 2022; Session 4: Feb 2023; Session 5: Nov 2023										
					Sampling method	**Institution**	**Sessions**	**No. records**	**SR**	**SC(%)**	**Asymptotic SR**	**95% limits**	**No. alpine spp.**	**% alpine spp.**	**No. new spp.**
Pollinators, other flower visitors & grasshoppers	145	151	43	–	Timed collection of flower visitors	DMSA, NMSA, TMSA, SANC	4, 5	649	115	0.91	265	186–431	38	33.0	12
Leafhoppers	–	35	0	–	Sweep nets, collection		5 only	532	35	0.99	43	36.5–77.4	13	37.1	3
Dung beetles	–	29	0	–	Pitfalls, collection	UFS Zoo & Ento; ARC-SG	2, 4	512	29	0.98	36	30.5–58.4	2	6.9	1
Grasshoppers	–	65	2	–	Pitfalls, sweep nets, collection	UFS Zoo & Ento	1, 2	506	65	0.94	106	81.2–167.8		NA	0
Bugs	–	69	–	–	Pitfalls, sweep nets, collection	UFS Zoo & Ento	1, 2	352	69	0.91	112	86.5–177.6		NA	0
Flies	–	91	3	–	Sweep nets, collection	UFS Zoo & Ento	1, 2	919	91	0.96	148	115.3–224.8		NA	0
Aquatic macro-invertebrates	–	60	1	–	Kick-net, SAS Net, collections	Albany Museum	1, 2	647	60	0.97	120	78.3–259.1	23	33.3	0
Mammalian ectoparasites	–	5	0	–	Collection from small mammal hosts	UFS Zoo & Ento	1, 2, 4	78	5	1	5	5.0–6.5	0	0	0
Spiders & harvestmen	7	47	0	–	Pitfalls, collection	UFS Zoo & Ento	1, 2	200	47	0.92	60	51–88		NA	0

Table 2. Total and alpine observed and asymptotic species richness, sampling methods, institutional repositories and collection effort of taxa sampled during five expert BioBlitzes (2021–2023) at WCCA compared with GBIF point records and ADU Virtual Museum (VM) records from the locus 2828D and a previous herpetological survey of WCCA (Van As 2014a). Shaded rows represent taxa surveyed in this study, while unshaded rows represent taxa only incidentally recorded. Abbreviation of institutional museum collections as follows: ANSP = Academy of Natural Sciences, Philadelphia; DMSA = Durban Natural Science Museum; NMB = National Museum, Bloemfontein, South Africa; NMSA = Natal Museum, South Africa; SANC = South African National Collection of Insects, South Africa; TMSA = Ditsong National Museum of Natural History [previously Transvaal Museum], South Africa. Other abbreviations: SC = sample coverage (%); SR = species richness; UKZN = University of KwaZulu-Natal; UFS Zoo & Ento = University of the Free State, Department of Zoology and Entomology, Qwaqwa Campus (continued)

Taxon	ADU VM locus 2828D	GBIF + BB	GBIF	Herps (Van As 2014a)	Witsieshoek BioBlitz (BB) results, covering five field sessions of 3–6 days each. Session 1: Oct 2021; Session 2: Mar 2022; Session 3: Nov 2022; Session 4: Feb 2023; Session 5: Nov 2023										
					Sampling method	**Institution**	**Sessions**	**No. records**	**SR**	**SC(%)**	**Asymptotic SR**	**95% limits**	**No. alpine spp.**	**% alpine spp.**	**No. new spp.**
Flowering plants	–	466	260	–	Herbarium specimens	UFS Qwaqwa Herbarium	1, 4 + additional collecting (see Methods)	2120	322	0.96	420	380–490	82	25.4	0
Totals or Means	**259**	**1 215**	**434**	53				**23 624**	**950**		**1 449**		**174**	**17.6**	17

Invertebrate sampling method 2 (Focus: Ground-dwelling insects)

In March 2022 (second BioBlitz) and February 2023 (fourth BioBlitz), pitfall sizes were increased to 250 ml plastic containers (60 mm diameter), half-filled with a 2:1 mixture of 70% ethanol and propylene glycol. Sites TER 1, TER 2 and TER 3 were sampled with 20 pitfalls per site in a random grid to cover surrounding vegetation diversity. Pitfalls were left out for 48 hours. The alpine sites were excluded due to equipment transport difficulties.

Invertebrate sampling method 3 (Focus: Dung beetles)

Dung beetles were collected at Sites TER 1–3 in March 2022, and at Sites TER 1–4 in February 2023, using pitfall traps baited with pig dung. Pitfall traps were made from 2-litre cold drink bottles, cut to form a funnel system. Three plots per site, spaced 50 m apart, each contained four traps, spaced 5 m apart. Traps were left for 48 hours. Samples from the four traps in each plot were pooled. Identification was conducted using published keys and morphological comparison with specimens at the National Museum Bloemfontein (BMSA). Some voucher specimens were deposited at BMSA.

Invertebrate sampling method 4 (Focus: Flying insects)

During pitfall sampling (Sampling method 2 above), Sites TER 1–3 were also sampled using a sweep-net method along 10 × 100 m transects per site. Additional time was spent actively searching for large insects and observing secondary signs of insect activity.

Invertebrate sampling method 5 (Focus: Insect flower visitors and orthopteran herbivores)

Eight 1-ha sampling sites were set up: four in the alpine zone (TER 5–8), two in the upper-montane zone (TER 3, 3a), and two in the lower-montane zone (TER 2, 2a). Sampling was conducted on specific dates in February and March 2023 (fourth BioBlitz) and November 2023 (fifth BioBlitz), with weather conditions noted. Each site was sampled by two people for one hour, one focusing on flower visitors and the other on herbivorous Orthoptera, switching roles at the next site. Specimens were deposited in several museum collections (Table 2). Samples were frozen and later identified using published keys, reference to determined specimens in state collections, and expert consultation (A.J. Armstrong).

Invertebrate sampling method 6 (Focus: Leafhoppers)

Intensive searches for leafhoppers were conducted at lower-montane (TER 2, 2a), upper-montane (TER 3, 3a) and alpine (TER 4–8) sites in November 2023 (fifth BioBlitz). Males provided the best and convenient features for identification, with associated females or nymphs often more difficult to identify. Specimens were deposited in the South African National Insect Collection (SANC). Sweep netting was the common collection method, with some plants vacuumed for leafhoppers.

Invertebrate sampling method 7 (Focus: Aquatic macroinvertebrates)

Aquatic macroinvertebrates were collected from freshwater systems (temporary pools and rivers) in March 2022 and February 2023. Samples were collected using a SASS net (square frame size: 300 × 300 mm, mesh size 1 mm; Dickens & Graham [2002]) and preserved in 80% ethanol. Identification was conducted using published keys (Day et al. 2002; Day & De Moor 2002; De Moor et al. 2003a; b) and the collection will form a preliminary checklist for the Maloti-Drakensberg mountains, accessioned at the Albany Museum, Makhanda.

Flowering plants

Specimens of flowering plants were collected during transect searches at Sites TER 1 and TER 3 in October 2021, and at Sites TER 1 and TER 2 in February 2023. Additional specimens were collected in the alpine zone (TER 5) by MSc and PhD students. An independent dataset was collected using the Mountain Invasion Research Network (MIREN) sampling protocols (Liedtke et al. 2020; Haider et al. 2022) between October 2021 and February 2022, with coordinates recorded for future reference. All vascular plant species were identified and assigned their status as native or alien, and their endemism status. A total of 2 120 specimens were identified and vouchers stored in the Qwaqwa, UFS Herbarium (QWA).

Data analysis

To evaluate the sample coverage of our surveys, we conducted abundance-based rarefaction-extrapolation analyses for each taxon using the R-package, 'iNEXT' (Chao et al. 2014; Hsieh et al. 2022). Venn diagrams were produced using the R-package, 'VennDiagram' v1.7.3 (Chen 2022). After classifying both GBIF and BioBlitz records for birds, flying insects and plants into alpine, upper-montane and lower-montane zones (Table 1), we used a beta-partitioning approach to estimate nestedness, turnover and total taxonomic beta diversity from both sampling approaches using the R-package 'betapart' (Baselga & Oreme 2012). All analyses were performed under RStudio using R Statistical Software (v4.4.0; R Core Team 2024).

Results

Based on 16 442 bat acoustic calls, 411 bird counts, 5 663 animal and 2 120 plant specimens, and incidental observations of herpetofauna and large mammals, the expert BioBlitzes in WCCA recorded 950 species, including 322 plants, 92 vertebrates, and 536 invertebrates (Table 2). Rarefaction-extrapolation analysis estimated 1 449 species for those taxa here surveyed, with significant increases expected in plants, vertebrates and invertebrates (Figure 2), hence true species richness is likely to be higher. From these analyses, the sample coverage for different taxa was high (Table 2: mean 0.96; range 0.91–1; n=14). Combined BioBlitz and GBIF data revealed 1 216 species, which is closer to the estimated diversity, and highlights the complementarity of these two approaches (Figure 3; Table 2).

High species turnover between elevational zones was observed for more sedentary taxa such as invertebrates, plants and small mammals, whereas more mobile taxa such as birds and bats showed a more nested pattern (Figures 4, 5). In other respects, for easily identifiable taxa such as birds and flowering plants, based on the congruence in beta diversity patterns between approaches (Figure 5), GBIF data independently and accurately retrieved fine scale patterns of elevation turnover validated by expert BioBlitz data.

In the study, 174 species were found only in the alpine zone, 17.6% of all taxa sampled. This included 3 small mammals, 2 reptiles, 1 amphibian, 10 birds, 38 insect flower-visitors and Orthoptera, 13 leafhoppers, 2 dung beetles, 20 aquatic macroinvertebrates and 82 plants (Table 2). Beta diversity analyses of both BioBlitz and GBIF datasets for birds, flying insects and plants showed that mobile birds had more nested elevational patterns, while low-dispersal insects and plants were influenced by turnover between zones (Figure 5).

Taxonomic considerations

Although taxonomic identifications and reviews are still ongoing and more new species are likely to be recognised in time, specialists identified two new insect genera and 16 new or probably new bat and insect species. This included 11 species exclusive to the alpine zone: 1 leaf beetle (Coleoptera: Chrysomelidae: *Odontionopa* sp. nov.), 1 dung beetle (Coleoptera: Scarabaeinae: *Epirinus* sp. nov.), 1 flightless keratin

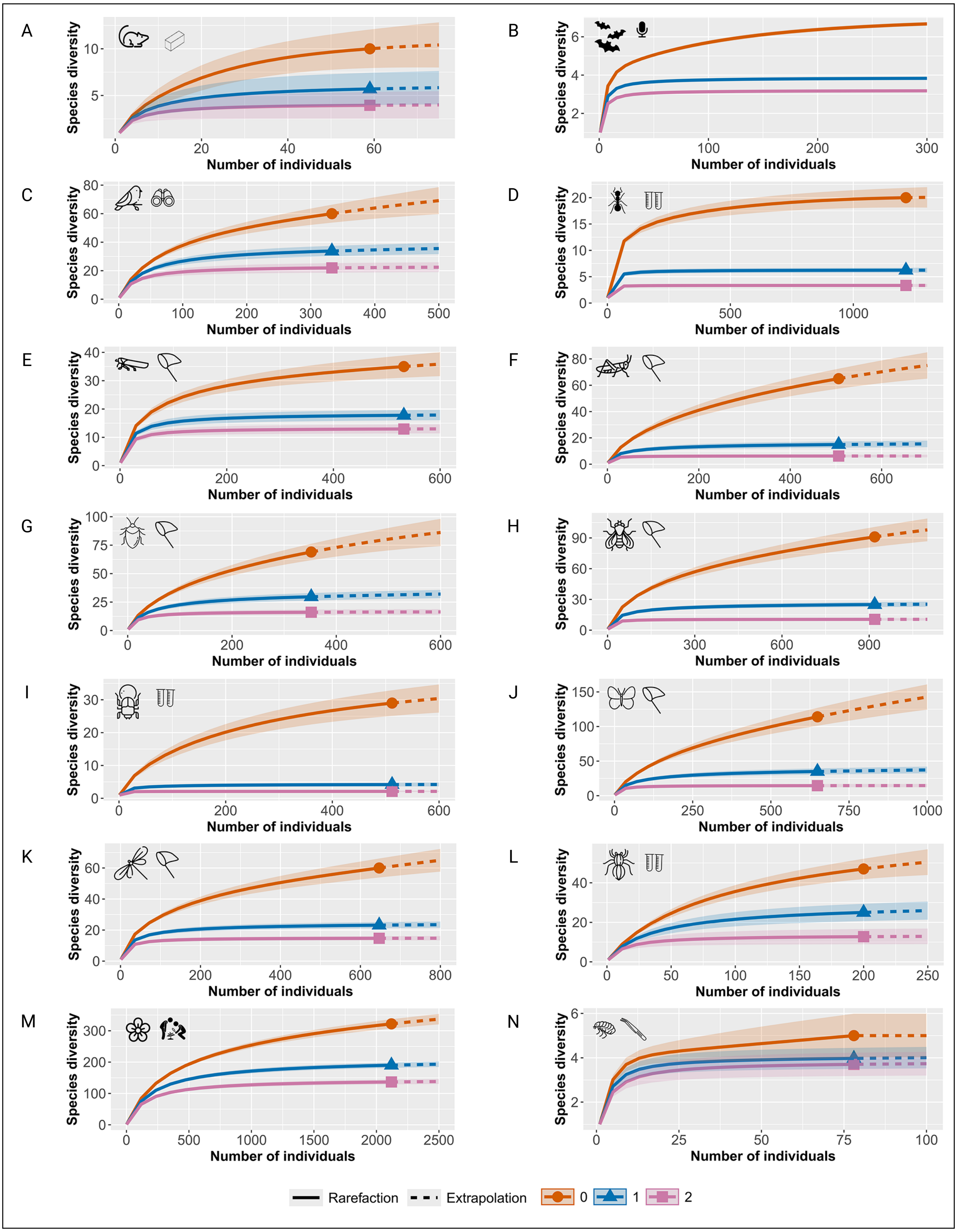

Figure 2. Rarefaction-extrapolation curves for Hill's numbers: 0 (richness), 1 (effective number of rare species, exponent of Shannon entropy) and 2 (effective number of abundant species, inverse Simpson index) for 14 plant, vertebrate and invertebrate taxa surveyed at Witsieshoek Community Conservation Area using different techniques as indicated (symbols on right in each panel): A, small mammals (Sherman traps); B, bats (SM4 mini bat detectors); C, birds (timed counts); D, ants (pitfall traps); E, leafhoppers (nets and searches); F, grasshoppers (pitfall traps and nets); G, bugs (pitfall traps, nets); H, flies (nets); I, dung beetles (baited pitfall traps); J, insect flower-visitors and grasshoppers (timed counts); K, aquatic macroinvertebrates (kick-net, SASS net); L, spiders (pitfall traps); M, flowering plants (specimen collection); N, small mammal ectoparasites. Refer to Table 2 for asymptotic values for species richness and sample coverage percentages for each taxon and method.

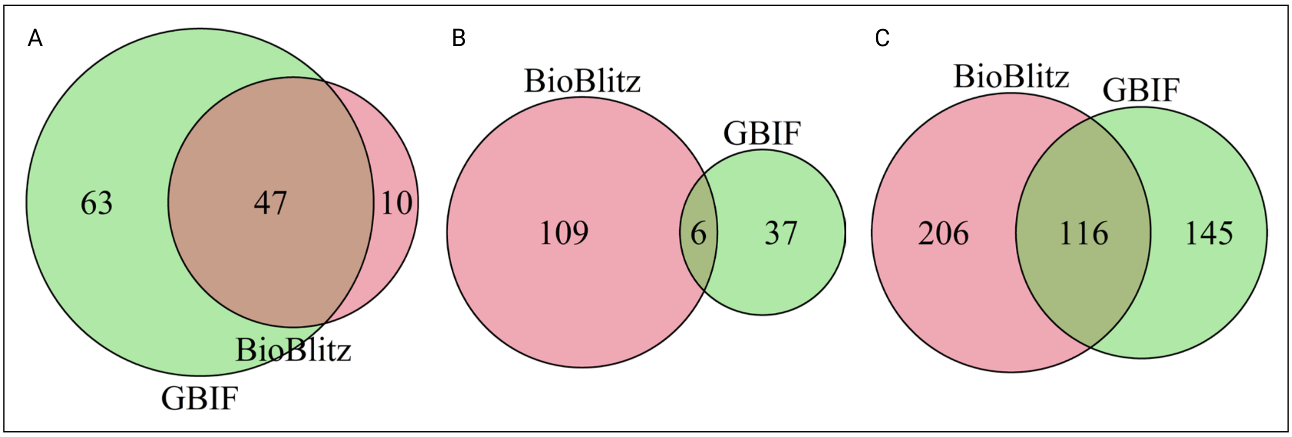

Figure 3. Venn diagrams summarising complementarity of species lists of A, birds; B, flying insects and C, flowering plants based on GBIF records and the current expert BioBlitz study from the Witsieshoek Community Conservation Area.

beetle (Coleoptera: Trogidae: *Phoberus* sp. nov. (Werner Strumpher, Ditsong Museum of Natural History, Pretoria, personal communication), 3 leafhoppers (Hemiptera: Cicadellidae: gen. and sp. nov.: *Bloemia* sp. nov.; *Henchunia* sp. nov.), 1 ambush bug (Hemiptera: Phymatidae: Phymatinae: gen. et sp. nov.), 2 hymenopterans (Hymenoptera: Colletidae: *Scrapter nitidus* (Friese) group sp. nov.; Hymenoptera: Eucharitidae: Eucharitinae: *Hydrorhoa* sp. nov.) and 1 grasshopper (Orthoptera: Caelifera: Acrididae: *Euloryma* sp. nov.). At least 6 additional new-to-science species were sampled either in the montane zone or both in the montane and alpine zones: 1 newly described horseshoe bat (Chiroptera: Rhinolophidae: *Rhinolophus cervenyi* Benda et al. 2024), 1 grasshopper (Orthoptera: Acrididae: Gomphocerinae: *Leva* sp. nov.), 1 wasp (Hymenoptera: Braconidae: Charmontinae: *Charmon* sp. nov.), 2 or more weevils [Coleoptera: Curculionidae: Entiminae: *Holcolaccus* sp. nov. (alpine and montane), Coleoptera: Curculionidae: *Bronchus* sp. nov. (montane)], and 1 leaf beetle (Coleoptera: Chrysomelidae: *Estcourtiana* sp. nov.), amongst others. Photographs of a few of the new species are featured in Figure 6.

Discussion

Discussion of taxon-specific results

Mammals

We incidentally recorded five species of native large and medium-sized mammals: baboon [*Papio ursinus* (Kerr)], klipspringer [*Oreotragus oreotragus* (Zimmerman)], grey rhebuck [*Pelea capreolus* (Forster)], rock hyrax [*Procavia capensis* (Pallas)] and Hewitt's red rock hare (*Pronolagus saundersiae* Hewitt) and eight domestic species including dogs, cats, rats, sheep, goats, cattle and horses. The WCCA, lacking formal protection or fencing, supported fewer large native mammals compared to the neighbouring Royal Natal National Park (RNNP) and Golden Gate Highlands National Park (GGHNP). These protected areas host 30 large to medium mammal species, as recorded by the MammalMap database for the 0.5 × 0.5° locus 2828D (which includes both protected areas). This includes 13 antelope species, plains zebra, two suids, three mustelids, two genets, three mongooses, two felids, two canids, rock hyrax and baboon. Many of these species are either extinct or very rare in neighbouring areas of Lesotho (Morake 2010) but would be potential candidates for a rewilding programme in the WCCA.

Out of 10 terrestrial small mammal species recorded, three were alpine endemics in our study area, Sclater's golden mole [*Chlorotalpa sclateri* (Broom)], the white-tailed rat [*Mystromys albicaudatus* (A.Smith)] and the ice rat (*Otomys sloggetti* Thomas). Although not previously recorded from the alpine zone (Lynch 1994; Taylor 1998; Taylor et al. 2020), the vlei rat (*Otomys auratus* Wroughton) was recorded from both montane and alpine zones in our study. Alpine-collected individuals were considerably smaller in body and skull size than montane-collected individuals, although their identity was confirmed by cytochrome-b sequences (Taylor; unpublished data). None of the three alpine endemics in our study have been recorded at either montane or alpine elevations in adjacent GGHNP (Avenant 1997) or RNNP (Taylor 1998), but *M. albicaudatus* has also been recorded in montane grasslands (ca. 1 500 m a.s.l.) elsewhere in the foothills of the Drakensberg in South Africa and Eswatini (Lynch 1983; Armstrong & Van Hensbergen 1996; Taylor 1998; Simelane et al. 2018) and in both montane and alpine habitats in Lesotho, ca. 1 600–3 000 m a.s.l. (Lynch 1994). Due to its rarity and patchy distribution, *M. albicaudatus* is listed as Vulnerable on the IUCN Red List (Avenant et al. 2019). Ice rats, *O. sloggetti* have been widely recorded in alpine habitats in Lesotho and the KwaZulu-Natal Drakensberg (Lynch & Watson 1992; Lynch 1994; Taylor 1998), while Sclater's golden mole, *C. sclateri* has been recorded from montane elevations in the KZN

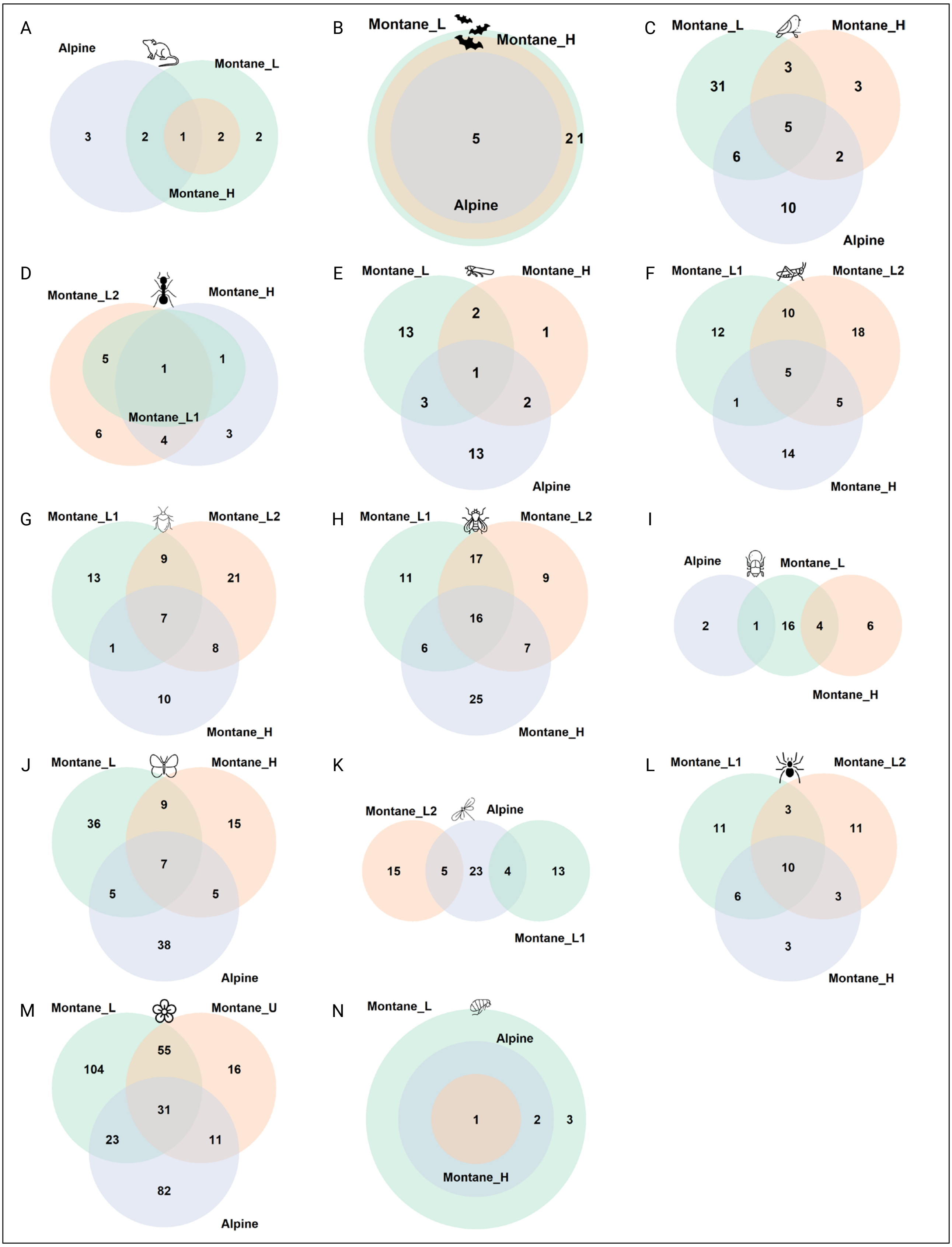

Figure 4. Venn Diagrams for 14 animal and plant taxa, illustrating the number of species shared between different elevational zones at WCCA, lower montane (Montane_L; sites TER 1, 2, 2a & AQS 1-3 in Table 1), upper montane (Montane_H; TER 3, 3a in Table 1) and alpine (TER 4–8 & AQS 4–7 in Table 1). In some taxa where data were not available for alpine or upper-montane sites, the lower-montane zone was further divided into lower (Montane_L1; TER 1 & AQS 1-2) and upper (Montane_L2; TER2 & AQS 3) zones. Venn diagrams represent 14 different taxa sampled: A, small mammals; B, bats; C, birds; D, ants; E, leafhoppers; F, grasshoppers; G, flies (nets); H, bugs; I, dung beetles; J, insect flower-visitors and herbivorous Orthoptera (plots); K, aquatic macroinvertebrates; L, spiders; M, flowering plants; N, small mammal ectoparasites.

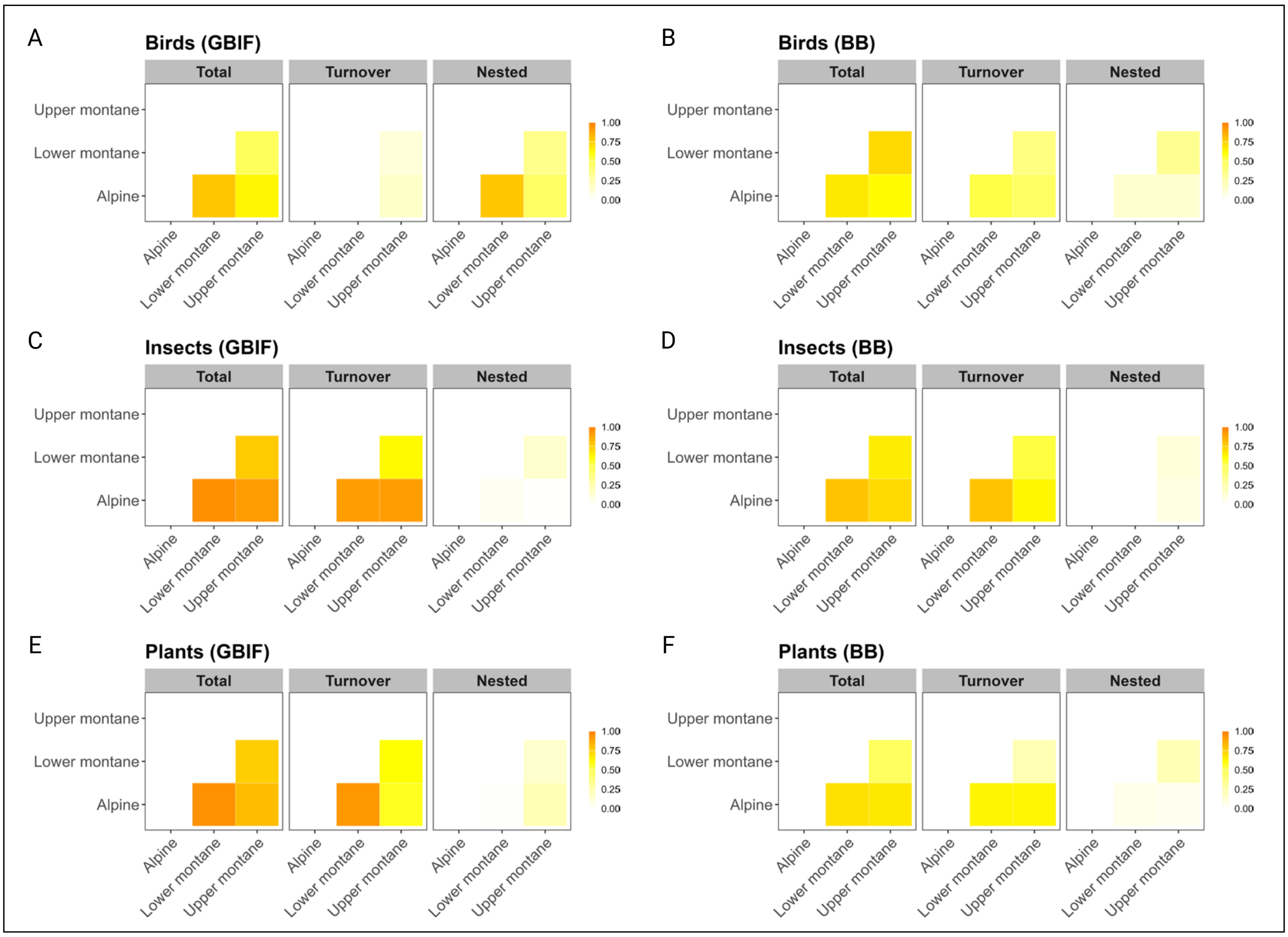

Figure 5. Heat maps representing total beta diversity and its components of turnover and nestedness in birds, insects and plants between grouped alpine, upper-montane and lower-montane sites in the Witsieshoek Community Conservation Area bordering South Africa and Lesotho, based on (left panel) GBIF records and (right panel) data acquired from recent field BioBlitz surveys. See text for methods of data collection, grouping and analysis.

Drakensberg (Taylor 1998) and montane to alpine elevations (1 750–3 000 m a.s.l.) in Lesotho (Lynch 1994). Elsewhere it is known patchily from montane habitats along the Great Escarpment from Sutherland and Beaufort West to the Sneeuberg Mountains to the Eastern Cape Drakensberg and from the northern Drakensberg in the vicinity of Wakkerstroom (Bronner 2013).

The terrestrial small mammal composition recorded at WCCA was distinctly different from that recorded in the neighbouring protected areas to the west (GGHNP; Avenant 1997) and east (RNNP; Taylor et al. 1998), possibly due to its intermediate geographic position, straddling three major watersheds between drier western and moister eastern slopes of the Drakensberg (Figure 1). Supporting this idea, the more arid-associated rodent, *Mastomys coucha* (A.Smith) was recorded at WCCA (identified from cytochrome-b sequence, unpublished data), while the more mesic-associated *M. natalensis* (A.Smith) was recorded at RNNP (Taylor et al. 1998). Taylor et al. (1998) recorded three of the species found in our study (two rodents and one shrew) and an additional two shrews and five rodent species, two of which [Mozambique thicket rat, *Grammomys cometes* (Thomas & Wroughton) and woodland dormouse, *Graphiurus murinus* (Desmarest)] were forest-associated. A small forest patch in WCCA was not sampled for small mammals in this study for logistic reasons and could be shown by future sampling to harbour these two rodents. Avenant (1997) recorded six of the small mammals (two shrews and four rodents) recorded by our study and an additional golden mole, hedgehog, two shrews and seven rodents.

Bat activity and species richness declined at the alpine sites compared with the upper- and lower-montane sites. Eight species were recorded at the lower-montane site, seven at the upper-montane site and five at the alpine site (Figure 4B). The eight species recorded in total are all known to occur in the area, except for one species of horseshoe bat, which is a newly described high elevation Drakensberg-endemic species, *Rhinolophus cervenyi* (Benda et al. 2024), having a distinctive echolocation peak frequency of 81 kHz (Taylor et al. 2024). This species was found at all sites in our study from 2 000 to 3 100 m a.s.l., whereas the congeneric *R. acrotis* Heuglin was only recorded at the lower-montane site (2 000 m a.s.l).

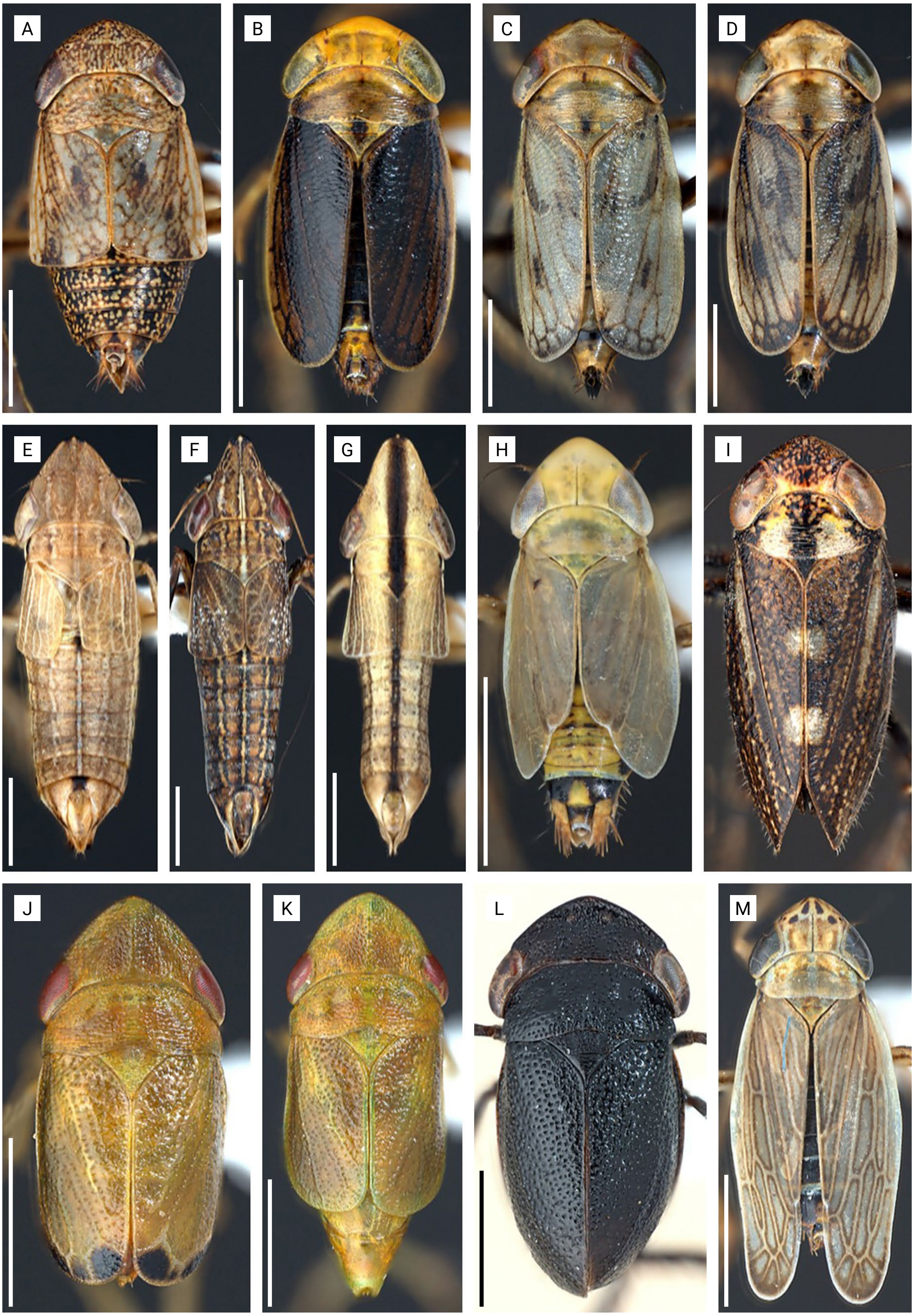

Figure 6. Different leafhopper species identified at WCCA: A, *Bloemia* sp. nov., records from Sani Pass, Rockeries Pass, Witsieshoek; B, Bonaspeiini gen. nov. and sp. nov., Witsieshoek, male; C, Bonaspeiini gen. nov. & sp. nov., Witsieshoek, female colour variant; D, Bonaspeiini gen. nov. and sp. nov. Witsieshoek, female colour variant; E, *Drakensbergena labeona*; F, *Drakensbergena ochracea*; G, *Drakensbergena simulata*; H, *Henchunia* sp. nov. male, only known from Namahadi Valley; I, *Mamates drakensi*; J, *Sichaea coriaria* male; K, *Sichaea coriaria* female; L, *Chiasmus* male; M, *Tetramelasma nodosatha*, new record, widespread grass-feeding, Drakensberg.

Birds

Of the 246 bird species known to occur in the KwaZulu-Natal Drakensberg (Little & Bainbridge 1992), some 130 bird species (39 of them endemic) are expected to occur in the Qwaqwa Maloti (Van As 2014b). Based on our time counts at the four sites, we recorded 60 species, which, when combined with GBIF data (110 species), resulted in the detection of all six Maloti-Drakensberg strict endemic or near-endemic bird species (see below). Birds commonly recorded at the lower elevations included widespread and abundant species such as Cape Longclaw [*Macronyx capensis* (Linnaeus)], Dark-capped Bulbul [*Pycnonotus barbatus* (Desfontaines)] and Cape Robin-chat [*Cossypha caffra* (Linnaeus)]. In contrast, birds seen at higher elevations included species endemic (or near endemic) to the Drakensberg such as Drakensberg Rockjumper (*Chaetops aurantius* E.L.Layard) and Sentinel Rock Thrush [*Monticola explorator* (Vieillot)]. The number of bird species recorded on GBIF for the study area was almost double the number recorded during our surveys.

Near Sani Top in Lesotho, Kopij (2015) recorded 30 bird species in alpine grassland and 69 in upper-montane grassland. The alpine habitat was considered to be much more important from a conservation standpoint since it supported high breeding densities of Maloti-Drakensberg endemics, e.g., Mountain Pipit (*Anthus hoeschi* Stresemann), Drakensberg Rockjumper and Drakensberg Siskin [*Crithagra symonsi* (Roberts)], and near endemics i.e. the Southern Bald Ibis [*Geronticus calvus* (Boddaert)], Sickle-winged Chat [*Emarginata sinuata* (Sundevall)] and Sentinel Rock Thrush, compared with non-alpine habitats. Our BioBlitzes recorded two of the three alpine endemics (all but the Drakensberg Siskin), and two of the three near-endemics (all but the Southern Bald Ibis), while the GBIF list included all six endemics and near-endemics. Kopij (2015) found endemic and near-endemic species to be more abundant/dominant in alpine versus upper-montane grasslands. Our BioBlitz data showed Mountain Pipit and Sickle-winged Chats to be present only at alpine but not upper montane sites, while the Drakensberg Rockjumper was recorded only at upper-montane sites. The Sentinel Rock Thrush was recorded in both sites but was far more common in alpine sites. None of these four species occurred in any of the lower sites.

Herpetofauna (reptiles and amphibians)

Although not comprehensively surveyed, Van As (2014a) recorded 32 reptile and 21 amphibian species in the study area. Two reptile species from the study area, Lang's Crag Lizard (*Pseudocordylus langi* Loveridge) and Essex's Mountain Lizard (*Tropidosaura essexi* Hewitt) can be considered alpine endemics or near-endemics, and both are listed as Least Concern (Tolley et al. 2023). Breyer's Long-tailed Seps (*Tetradactylus breyeri* Roux) occurs across a broader elevational range in montane grasslands of the Drakensberg but is listed as Near Threatened due to ongoing degradation and loss of grasslands (Tolley et al. 2023). The ice frog [(*Amietia vertebralis* (Hewitt)] is an alpine endemic and is expected to have been impacted by river impoundment, road construction and wetland degradation. All these alpine or montane endemics are therefore critical sentinels of climate change and should be monitored regularly.

Ants

A total of 20 ant morphospecies from 13 genera, and five subfamilies were sampled during a single sampling of two lower (TER 1, TER 2) and one upper (TER 3) montane sites in October 2021. Myrmicinae was the most dominant subfamily, representing 82% of the total ant abundance. Ponerinae and Formicinae subfamilies had 11% and 7% of the total abundance, respectively. Over half of the abundance was made up of one unidentified species, *Pheidole* UKZN_04. Six species were exclusively recorded in the vicinity of the Lodge (TER 2) while three were exclusively recorded from the Sentinel Car Park (TER 3). Other species were shared between two or three sites.

Dung beetles (Scarabaeidae)

A total of 29 dung beetle species from 10 genera were collected across montane and alpine elevation zones. Two species were recorded exclusively in the alpine zone, *Epirinus pygidialus* Scholtz & Howden and *Labarrus pseudolividus* Balthasar. The species collected in total represented six of the seven functional groups in a dung beetle assemblage (all except large, fast-burying paracoprids – Functional Group III), indicating a relatively intact ecosystem (Doube 1990). The functional groups were diverse and well represented over the elevational change. Ball-rolling dung beetles were present at WCCA but are largely absent from intensive mixed maize and livestock agricultural areas surrounding the WCCA (Astrid Jankielsohn, unpublished data).

Flower-visiting insects and orthopteran herbivores

We recorded 21 species of pollinator insects, 18 species of herbivorous orthopterans and 76 species of other flower-visiting insects at eight sites covering three elevation zones, lower and upper montane and alpine (Table 2; Figure 4). There was little overlap of species between the montane and alpine sites: 38 species were only recorded at alpine sites, 60 only at montane sites (upper and/or lower) and 17 species in both montane and alpine zones. Of the undescribed and probably undescribed species, four were collected at alpine sites, six at montane sites and two at both alpine and montane sites. The montane sites thus had a different fauna compared to the alpine sites, reflecting the montane and alpine sub-centres of floristic endemism in the Drakensberg Mountain Centre (Carbutt 2019). However, the exact number of species recorded that are alpine endemics has still to be established. The expert and public datasets were highly complementary, with little overlap between the species sampled and those in the citizen science dataset (Figure 3). Overlapping species represented those easily identifiable by citizen scientists. Field guides to less easily identified insect taxa should be published to assist citizen scientists with their identification, leading to more complete public databases of insects.

Leafhoppers

Several new species of leafhoppers have been described in the last 15 years (e.g., Stiller 2009, 2010, 2011, 2012). The first extensive examination of leafhoppers on the Drakensberg alpine summit and adjacent higher slopes identified 35 species, 13 of which were only found in the alpine zone (Figure 4, Table 2). Three new, undescribed species were collected from the alpine summit: *Henchunia* Vilbaste from grass (Figure 6H), a new species of *Bloemia* Theron (Figure 6A) and a new genus and species from the tribe Bonaspeiini from shrubs (Figure 6B–D). The latter was recorded from two locations on the alpine summit in this study and has also been recorded at Sehlabathebe National Park in Lesotho and Monks Cowl and possibly the summit of Organ Pipes Pass in the KwaZulu-Natal Drakensberg. Leafhoppers associated with small black-stick lily plants (*Xerophyta* spp., Velloziaceae) were not collected in this study, but are expected to occur, based on a single record of *Xerophytavorus rastrullus* Stiller from the summit of the KwaZulu-Natal Drakensberg (2 880 m a.s.l.) near the Orange River source (Stiller 2012).

We sampled shrubs, moribund grass and grass and sedge regrowth after fire. Species could be classified into functional groups based on feeding on grass (20 species), shrubs (11 species) or both (one species), and in the case of grass-feeding species, into Savanna Biome (6 species), Grassland Biome (10, including two wetland species) or both biomes (4 species). Grass-feeding Savanna Biome leafhoppers included *Aconurella* Ribault, *Balclutha* Kirkaldy, *Chiasmus hyalinus* (Evan) (short-winged), *Exitianus turneri* Ross, *Nicolaus* Lindberg and *Pravistylus exquadratus* (Naudé), while wetland-associated species included *Afrosteles distans* (Linnavuori) and *Teyasteles divisifrons* (Naudé). Grassland Biome-associated grass-feeders included three species of *Drakensbergena*, *D. labeona* Stiller (Figure 6E), *D. ochracea* Linnavuori (Figure 6F), *D. simulata* Stiller (short winged) (Figure 6G), as well as *Elginus falcatus* Stiller, *Henchunia* sp. nov. (short-winged) (Figure 6H), *Naudeus bivittatus* (Naudé), *Pravistylus interdiscus* Stiller (short winged), *Tetramelasma nodosatha* Stiller (Figure 6M) and *Sandia brevis* Theron (short-winged). Shrub-associated species included *Basutoia brachyptera* Linnavuori, 1961 (short-winged), *Bloemia* sp. nov. (short winged) (Figure 6A), *Chiasmus* Mulsant & Rey (short winged) (Figure 6L), *Mamates drakensi* Theron (short winged) (Figure 6I), *Molopopterus* Jacobi, Bonaspeiini gen. nov. & sp. nov. (short-winged) (Figure 6B–D), *Sichaea coriaria* Stål (short winged) (Figure 6J, K), *Typhlocybinae* (tree and shrub feeding) and *Tzitzikamaia irrorata* Linnavuori (short-winged, shrub or forb-feeding). Although considered to be grass-feeding (Stiller 2009), in this study *Drakensbergena* spp. were collected on shrubs and grass, in regrowth after fire and in moribund grass, but with nymphs only on grass.

Overgrazing and regular burning may be causing a decline in grass-feeding leafhoppers and an increase in shrub-associated ones (Michael Stiller, unpublished observations).

Other arthropods from pitfall traps and associated sweep nets

For logistical reasons, the alpine zone was not sampled for these groups in this study. General collections of spiders and insects from standardised pitfall arrays and sweep netting from lower (TER 1–2) and upper (TER 3–3a) montane sites resulted in 200 spiders (17 families; 47 morphospecies), 352 bugs (Hemiptera: 15 families; 69 morphospecies), 919 flies (Diptera: 30 families; 91 morphospecies) and 506 grasshoppers and other orthopterans (Orthoptera: 9 families; 65 morphospecies). Since most specimens were identified only to family and morphospecies for this study, species numbers are likely to change as specialist identifications are completed. Nevertheless, for all four groups mentioned above, there was low overlap (i.e., high turnover) in species composition of spider and insect assemblages among elevation zones (Figure 4F, G, H, L).

Aquatic macroinvertebrates

The Maloti-Drakensberg region including the WCCA is host to a diverse range of freshwater invertebrates, found in both river systems and temporary water bodies such as rockpools. Many of these species are endemic to the MD (Hamer & Brendonck 1997; Martens et al. 1998; Van Damme et al. 2013; Deacon et al. 2020). Those found in temporary water bodies often exhibit extraordinary eco-physiological adaptations to survive marked wet-dry seasons, harsh cold temperatures and nutrient-limited systems (Mdidimba et al. 2021).

We collected 647 aquatic macroinvertebrates (60 morphospecies from 33 families and 13 orders) from 2 montane (AQS 1–3) and 4 alpine (AQS 4–7) sites.

While 23 species were only recorded in alpine sites, 28 were only recorded in montane sites, and 9 species occurred in both montane and alpine sites (Figure 4K). Montane sites showed higher abundance and richness, but lower evenness and diversity scores, compared to alpine sites (Table 3). Assemblage composition differed, with Ephemeroptera, Plecoptera and Trichoptera (EPT) being most abundant at alpine (36%) compared with montane (26%) sites, and Plecoptera and Mollusca only found in montane sites. As identifications were generally made only to family and morphospecies, these numbers may change as specialist identifications are completed, and potential novel species are described. There were nevertheless clear differences in the insect communities between elevations, with 13 and 9 families only found in montane and alpine sites, respectively.

Aquatic beetles were well represented in these samples. This group has a high diversity in the Drakensberg (Perkins 2005a,b, 2008; Bilton 2017) but are still poorly known from WCCA, where cryptic diversity has been uncovered (Englund et al. 2020). Rockpools and ephemeral wetlands support a surprising diversity of large branchiopods (i.e., Anostraca, Notostraca, Spinicaudata and Laevicaudata) including the tadpole shrimp [*Triops granaries* (Lucas)] recorded from the Drakensberg summit and 4 out of 5 known *Branchipodopsis* species that are endemic to Maloti-Drakensberg rockpools (Hamer & Martens 1998). Although no specimens were collected in this study, the desiccation-tolerant chironomid, *Polypedilum cranstoni* Cornette, Motitsoe & Mlambo, 2022, was originally described from WCCA, near Fika-Patso Dam and seems to be endemic

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution

Phylum or Order	Family	Subfamily	Genus	Elevation (m a.s.l.)	
				Montane (1 700–2 100)	Alpine (>2 900)
Decapoda	Potamonautidae			2	
Hydrachnidia					1
Hirudinea					6
Ephemeroptera	Baetidae			74	6
	Baetidae		*Acanthiops* sp. 1	4	
	Baetidae		*Acanthiops* sp. 2	4	
	Baetidae		*Afroptilum* sp.		3
	Baetidae		*Cloeon* sp.	34	
	Baetidae		*Demoulinia* sp.		1
	Caenidae			5	
	Leptophlebiidae		*Adenophlebia* sp.	53	17
	Tricorythidae		*Tricorythus* sp.	11	
Odonata	Aeshnidae			3	
	Aeshnidae		*Anax* sp.	1	
	Coenagrionidae			17	
	Coenagrionidae		*Pseudagrion* sp.	36	
	Libellulidae				1
	Libellulidae		*Orthetrum* sp.	8	
Lepidoptera	Crambidae			6	2
Trichoptera	Barbarochthonidae		1		
	Leptoceridae			3	
	Leptoceridae		*Athripsodes* sp.		1

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution (continued)

Phylum or Order	Family	Subfamily	Genus	Elevation (m a.s.l.)	
				Montane (1 700–2 100)	Alpine (>2 900)
Plecoptera	Perlidae		*Neoperla* sp.	4	
Coleoptera	Aspidytidae				1
	Dytiscidae				1
	Dytiscidae	Colymbetinae larva		1	
	Dytiscidae	Hydroporinae larvae		2	
	Dytiscidae		*Africophilus* sp.		1
	Dytiscidae		*Copelatus* sp.	6	
	Dytiscidae		*Laccophilus* sp.	24	
	Dytiscidae		*Philodytes* sp.		1
	Elmidae			2	3
	Gyrinidae			1	
	Hydrophilidae		*Helochares* sp.	5	
	Ptilodactylidae				1
	Scirtidae		*Cyphon* sp.		3
	Scirtidae		*Scirtes* sp.		1
Hemiptera	Belostomatidae		*Appasus* sp.	1	
	Corixidae		*Sigara* sp.	27	1
	Gerridae		*Gerris swakopensis*	14	10
	Notonectidae		*Anisops* sp.	1	
	Nepidae		*Borborophilus* sp.	1	
	Nepidae		*Ranatra* sp.	2	
	Pleidae		*Plea* sp.	6	1
	Veliidae				2
	Veliidae		*Microvelia* sp.		1
Diptera					1
	Athericidae			4	
	Athericidae		*Suragina* sp.		5
	Chironomidae			24	
	Chironomidae				2
	Chironomidae			77	7
	Chironomidae	Tanypodinae			8
	Culicidae			3	
	Culicidae		*Culex* sp.	10	8
	Simuliidae		*Simulium* sp.		5

Table 3. Relative abundance of aquatic macroinvertebrates surveyed at WCCA. The total abundance of each taxonomic group across all sampling events at different altitudes is recorded, along with common measures of diversity, namely the Shannon Diversity Index and Pielou's Evenness. The percentage of taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (%EPT) and Odonata (%EPTO) is calculated here, as these insects tend to be valuable indicators of good river health, with families in this order amongst the most sensitive to environmental changes and pollution (continued)

Phylum or Order	Family	Subfamily	Genus	Elevation (m a.s.l.)	
				Montane (1 700–2 100)	Alpine (>2 900)
	Tipulidae				1
Basommatophora	Planorbidae		*Bulinus* sp.	61	
Unidentified Nematoda					7
			Taxa relative abundance	538	109
			Taxa richness	37	31
			Pielou's Evenness	0.797	0.876
			Shannon Diversity	2.88	3.01
			Composition:		
			Ephemeroptera	185	27
			Odonata	65	1
			Coleoptera	41	12
			Hemiptera	52	15
			Diptera	118	37
			Mollusca	61	0
			Trichoptera	4	1
			Plecoptera	4	0
			EPT%	35.87	25.69
			EPTO%	47.96	26.60

to montane rock pools in the MD (Cornette et al. 2022). Three other related species of desiccation-tolerant chironomid species from the same genus are known from similar elevations in Namibia, Malawi and Nigeria (Cornette et al. 2017).

Preliminary results indicate that freshwater resources in WCCA are largely natural, with a high diversity of sensitive taxa like EPT (Dickens & Graham 2002; Odume et al. 2012). Nevertheless, the absence of some expected genera, such as the endemic Plecopteran genus, *Balinskycercella* Stevens & Picker, 1995, may point to increased disturbance in the region. Given the importance of these freshwater invertebrates as ecological indicators of ecosystem health, the above examples highlight the rich diversity of aquatic macroinvertebrates from WCCA and the urgent need for future studies to further unravel the hidden diversity that will inform evidence-based conservation and rewilding of the WCCA.

Plants

Combining various local projects, MSc (Lesego Malekana) and PhD (Mosiuoa Bereng) research, and BioBlitz records, 2 120 plant specimens were collected, representing 322 vascular flowering plant species in 59 families and 189 genera. The MIREN transect contributed 86% of the collection, with additional contributions from the PhD collection (6%), MSc project (4%), and general BioBlitz records (4%). Twelve non-native species were recorded. The GBIF database for the WCCA provided 549 records, with 260 plant species, 116 of which overlapped with the BioBlitz surveys.

The combined data from local projects and GBIF include 466 species from 66 families and 215 genera. This current checklist covers about 30% of the potential flora for the 7 000 ha Witsieshoek precinct, with notable gaps in woody habitats below 2 000 m a.s.l., comprehensive fern flora, and C_3 grasses above 2 600 m. Additional data sources yet to be incorporated include historical collections, extensive grass work in 2020 (e.g. Sylvester et al. 2020), SANBI's *Plants of the Free State* (Retief & Meyer 2017), published literature (e.g. Shezi et al. 2021), and data from the 7th Plant Functional Traits Course, which took place in the WCCA in December 2023 (https://plantfunctionaltraitscourses.w.uib.no/). As such, the current data are incomplete and preliminary and do not lend themselves to in-depth analyses at this point. Nevertheless, analyses of elevational patterns of the independently obtained species lists (GBIF and current study) indicate a high turnover between elevation zones in both datasets (Figure 5), with 82 species recorded as alpine-endemic at the scale of the current study (Figure 4).

The most diverse family in our study was Asteraceae (29%), followed by Poaceae (10%), Scrophulariaceae (6%), Iridaceae (6%) and Orchidaceae (4%). This dominance pattern is largely reflected in the total flora of the Drakensberg Mountain Centre (e.g., Carbutt & Edwards 2004). *Helichrysum* is the most diverse genus with 37 taxa, followed by *Senecio* with 16 taxa. Other significant genera include *Moraea*, *Erica* and *Disa*.

General discussion

The escalator to extinction

While most studies of climate change impacts on alpine biodiversity are situated in the northern hemisphere and focus on a single taxon (Freeman et al. 2018; Urban 2018; Watts et al. 2022), our study showed correlated responses across various plant and animal taxa to a montane–alpine gradient in southern Africa. Of 11 taxa for which data existed from both montane and alpine sites in this study, nine had alpine endemics (range 0–37%; mean 17.5%). This highlights the systematic biodiversity extinction risk for alpine endemics under climate change, especially small and flightless species. Species that are currently trapped within a narrow range of alpine habitat face a high extinction risk from further climate warming, especially for species that lack phenotypic plasticity or behavioural or physiological flexibility.

Predominantly in northern hemisphere mountain ranges like the European Alps and Himalayas, 227 000 km^2 of new lands will emerge by 2100 due to shrinking ice under the high emissions RCP8.5 scenario (Zimmer et al. 2022). Although this can be perceived as a benefit, there are many adverse effects of increased snow melt (Xu et al. 2009). This is not an issue in the Drakensberg Mountain Centre, which lacks current glaciers. Nevertheless, warming conditions may result in non-alpine plant and animal species from lower elevations being able to colonise higher elevation alpine habitats, possibly out-competing more specialised alpine congeners. For example, we were surprised to trap vlei rats *Otomys auratus* at 3 145 m a.s.l. in our study, occurring sympatrically with ice rats, *O. sloggetti*. No historical records for *O. auratus* exist from such a high elevation, and the animals captured were markedly smaller than individuals from lower elevations (Peter John Taylor, unpublished data), suggesting the possibility of phenotypic plasticity towards smaller size to save energy in a demanding cold environment that regularly experiences snow.

As expected and found also by Monadjem et al. (2023), we found that smaller and less mobile organisms such as insects and small mammals showed higher turnover and lower nestedness, than more mobile organisms like birds and bats. We can thus predict that the former are more vulnerable to global warming.

We demonstrated remarkable congruency between citizen science (GBIF, including iNaturalist, eBirds and the Southern African Bird Atlas 2 project) and our expert BioBlitz datasets (Figures 3, 5), validating the importance of mountain tourism-based citizen science in documenting species checklists and elevational patterns in the fauna and flora of imperilled alpine hotspots. Since mountain tourism is an important feature in alpine zones globally such as the Alps, Himalayas, Rockies and Andes, we advocate renewed exploration of citizen science datasets from these regions to document biodiversity at risk from the escalator to extinction.

Climate models may predict varying vulnerability of ecosystems to climate change. For example, the environmentally defined grassland floristic domains of the study area are considered mainly susceptible to climate-induced change according to the down-scaled HadCM2 climate model but robust to climate-induced change according to the downscaled GFDL2.1 climate model (Jewitt et al. 2015). Adaptation strategies vary based on climate model predictions (Mawdsley et al. 2009). For susceptible scenarios, conservationists should focus on expanding protected areas, managing ecosystem functions and land-cover change impacts, and designing climate-resilient protected areas. For robust scenarios, conservationists should focus on improving management of existing protected areas, regularly reviewing conservation policies, and increasing biodiversity representation and replication in protected areas (Jewitt et al. 2015). Future monitoring of our baseline data will help test climate models' predictive powers regarding the susceptibility of different assemblages, guiding appropriate conservation strategies.

Ecological indicators of ecosystem health and the potential for rewilding in WCCA

As they are highly sensitive to environmental conditions and disturbance, taxa such as aquatic invertebrates

(Mdidimba et al. 2021) and dung beetles (Botes et al. 2006) are excellent indicators of ecosystem health and biodiversity intactness. The functional and taxonomic diversity of aquatic invertebrates and dung beetles (and plants and animals generally) suggest that montane and alpine grassland ecosystems are largely intact. The almost complete absence of large mammalian herbivores and carnivores in the study area that occur in adjacent protected areas is therefore not due to habitat availability but rather mostly to hunting (Morake 2010) and/or competition with domestic grazers such as cattle, goats, donkeys and sheep. Although grassland ecosystems are currently largely intact, they are threatened by increasing alien invasion and bush encroachment (RangeX project; Mountain Invasion Research Network – RangeX, available online at https://www.mountaininvasions.org/rangex, accessed on 14 February 2024), as well as increasing grazing pressure by livestock of both South African and Basotho herders in the montane and alpine zones respectively (personal observation; Carbutt 2020; Kotzé et al. 2023). As they are dependent on specific shrub or grass plant species, leafhoppers are useful indicators of vegetation changes including shrub (bush) encroachment. In our study, leafhopper assemblages included both shrub and grass-dependent species, providing a good baseline for future assessments of rangeland condition.

Since these threats will impact the experience of, and revenues from, ecotourists, we advocate a mountain tourism and community-centred rewilding approach. Reintroduction of iconic species such as the common eland (*Tragelaphus oryx*), which has a strong cultural and spiritual connection with local communities (the municipality of '*Maluti-A-Phofung*' means 'The Place of the Eland' in the local Sesotho language), can considerably boost tourism revenue. Rewilding has been shown to be an effective strategy for protecting both charismatic large mammalian 'umbrella species' and entire ecosystems, but this requires mitigating conflicts between conservation stakeholders and livestock farmers (Freese et al. 2014). At present, rewilding is focused on large mammals because of the lack of data on what other taxa may be missing from the WCCA that might not be able to recolonise it naturally. In the WCCA, rewilding and reintroduction of large mammals can be achieved either by fencing and/or a community-based conservation plan, but these options need to be explored in partnership with local communities. Since the WCCA borders two countries, the Maloti-Drakensberg Transfrontier Conservation Authority (MDTFCA) is a critical player in conserving this area. Equally important is engaging with local communities and NGOs such as Meat Naturally Africa (https://www.meatnaturallyafrica.com/), to improve communal rangeland quality and sustainability, which directly benefits biodiversity and ecosystem services, as well as revenues from both livestock farming and biodiversity carbon credits (intact rangelands sequester more carbon than degraded rangelands; Preger et al. 2019). Since community conservation areas are critical to conserving alpine grasslands (Carbutt 2020), we propose that the WCCA is a test case that can provide solutions that are applicable to alpine grassland ecosystems globally.

Conclusions

Several groups, such as lepidopterans, were not comprehensively sampled during our expert BioBlitzes, suggesting that our species list will increase considerably as sampling gaps are filled. For example, the LepiMAP project database (Underhill & Navarro 2023) yielded 145 species of Lepidoptera from the 0.5 × 0.5° locus 2828D, which includes WCCA plus the two adjacent protected areas of RNNP and GGHNP, yet our study only recorded a few species, mainly incidentally, and GBIF yielded 29 species for the WCCA.

Area-based conservation requires a detailed understanding of local species, as well as ecosystem processes and should be underpinned by robust biodiversity inventories. Such inventories should be compiled from multiple sources, including field surveys by specialists, citizen science observations, public datasets and published studies. Each approach has its own limitations, and no single approach is comprehensive. There is no substitute for field-based surveys, but due to their costly and time intensive nature, these are often limited to rapid assessments (snapshots in time and space) such as BioBlitzes, carrying an inherent risk of limited data representation. To address this bias, we advocate multiple expert BioBlitzes that draw on a wide range of taxonomic expertise. In this study, we engaged a range of experts from such diverse fields as mammalogy, ornithology, herpetology, arachnology, entomology and botany, resulting in checklists for 14 diverse taxa. These experts also provided an understanding of local species, and corroborated local species lists obtained from public databases.

Data parity and data complementarity between approaches are essential to ensuring an accurate and comprehensive dataset to guide conservation management actions. In this study, we show that inventories obtained from the GBIF and from expert BioBlitzes were highly complementary; the combined species sums were considerably greater than those of either approach alone. Combining datasets resulted in a list of over 1 200 species.

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Declaration of competing interest

The authors declare that they have no known competing financial interests that could have appeared to influence the work reported in this paper.

Ethical considerations

Permission for scientific collecting was provided by Permit No. 202106000007056 of the Free State Province Department of Economic, Small Business Development, Tourism and Environmental Affairs (DESTEA) and from the landowners, the Batlokoa Royal House through a MOU between the ARU/UFS and Transfrontier Parks Destinations (TFD), who manage the Witsieshoek Mountain Lodge on behalf of the Royal Council. Ethical clearance was provided by the UFS Animal Research Ethics Committee (Project numbers: UFS-AED2021/0029/21 and UFS-AED2023/0037), UFS Environment and Biosafety Research Ethics Committee (Clearance no. FS-ESD2021/0233/22), and Section 20 permit from the Department of Agriculture, Land Reform and Rural Development (DALLRD) to conduct research in terms of Section 20 of the Animal Diseases Act, 1984 (Act No. 35 of 1984) [Reference no. 12/11/1/4 (2038 RJ)].

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Full list of authors and affiliations

Authors

[a] Peter J. Taylor
[a] Emile Bredenhand
[b,c] Ara Monadjem
[d,e] Adrian J. Armstrong
[a] Andrinajoro R. Rakotoarivelo
[a] Veli Monday Mdluli
[a] Alexandra Howard
[a] Serero Modise
[f] Samuel N. Motitsoe
[g,+] Pindiwe Ntloko
[g,h] Abigail P. Kirkaldy
[i] Dewald J. Kleynhans
[j] Astrid Jankielsohn
[a,p] Toka Mosikidi
[c,i] Maria K. Oosthuizen
[k] Stephanie Payne
[e] Thinandavha C. Munyai
[d,e] Clinton Carbutt
[a] Mpho Ramoejane
[l] Mosiuoa Bereng
[o] Michael Stiller
[a] Charles R. Haddad
[k] Sandy-Lynn Steenhuisen
[g,h,+] Musa C. Mlambo
[h,q] Sibusisiwe Moyo
[a] Nthatisi I. Nyembe
[a] Lehlohonolo Mofokeng
[a] Johann van As
[k,r] Lesego Malekana
[i,m,n] Gimo M. Daniel
[l] Onalenna Gwate
[a] Michelle van As
[f] James du Guesclin Harrison
[e] Nokubonga F. Thabethe
[a] Nozipho Kheswa
[k] Karabo Moloi
[a] Nkanyiso Sishange
[l] V. Ralph Clark

[+] Deceased

Affiliations

[a] Afromontane Research Unit and Department of Zoology and Ecology, University of the Free State, Qwaqwa Campus, Phuthaditjhaba, South Africa.
[b] Department of Biological Sciences, University of Eswatini, Private Bag 4, Kwaluseni, Eswatini.
[c] Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield, 0028, South Africa.
[d] Conservation Research & Assessment, Scientific Services, Ezemvelo KZN Wildlife, P.O. Box 13053, Pietermaritzburg 3202, South Africa.
[e] Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg, 3209, South Africa.
[f] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, Johannesburg, South Africa.
[g] Department of Freshwater Invertebrates, Albany Museum, Makhanda, 6139, South Africa.
[h] Department of Zoology and Entomology, Rhodes University, Makhanda, 6139, South Africa.
[i] Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield, 0028, South Africa.
[j] Agricultural Research Council-Small Grain, Crop Protection, Bethlehem, South Africa.
[k] Afromontane Research Unit and Department of Plant Sciences, University of the Free State, Qwaqwa Campus, Phuthaditjhaba, South Africa.
[l] Afromontane Research Unit and Department of Geography, University of the Free State, Qwaqwa Campus, Phuthaditjhaba, South Africa.
[m] Department of Terrestrial Invertebrates, National Museum, 36 Aliwal Street, Bloemfontein, South Africa.
[n] Department of Biological & Environmental Sciences, Walter Sisulu University, Mthatha, South Africa.
[o] Agricultural Research Council-Plant Health and Protection, Biosystematics, Queenswood, South Africa.
[p] The Expanded Freshwater and Terrestrial Environmental Observation Network, 56 Florence Street, Colbyn, Pretoria, South Africa.
[q] School of Life and Environmental Sciences, Bournemouth University, Fern Barrow, Poole, BH12 5BB, United Kingdom.
[r] Department of Environmental Systems Science, Institute of Integrative Biology, ETH Zürich, Universitätstrasse 16, Zürich CH-8092, Switzerland.

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Year-to-year changes in population density and site fidelity of psittaciform, coraciiform and piciform species in an acacia savanna, north-central Namibia

Authors

[1,2]Grzegorz Kopij

Affiliations

[1]Department of Vertebrate Ecology, Wroclaw University of Environmental & Life Sciences, ul. Koźuchowska 5b, 51-631 Wroclaw, Poland.

[2]Department of Integrated Environmental Science, University of Namibia, Ogongo Campus, Private Bag 5520 Oshakati, Namibia.

Corresponding Author

Grzegorz Kopij; e-mail: grzegorz.kopij@upwr.edu.pl

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Background: Bird species belonging to the orders of Coraciiformes, Psittaciformes and Piciformes may be regarded as good indicators of environmental quality. Since most species are fairly large and have distinctive plumage colouration, they attract human attention. Most of them are also strongly territorial and vocally conspicuous. However, not much is known about their population densities and virtually nothing about interannual population changes.

Objectives: The aims of this study were to: 1) estimate population densities; 2) assess interannual variations in population densities; 3) study site fidelity; 4) find preferences (or their lack) for natural or man-modified savanna of all coraciiform, piciform and psittaciform species breeding in a mosaic of natural and man-modified savanna; and 5) compare population densities of all these species recorded in the study area with those obtained in other regions of southern Africa.

Methods: Population densities of coraciiform, psittaciform and piciform species were assessed by means of the territory mapping method in an acacia savanna in the Cuvelai Drainage System, north-central Namibia. Studies were carried out in three separate years: 2012, 2017 and 2020.

Results: In total, 15 species representing these orders were recorded as breeding in the study plot (400 ha). In 2020, all three parrot species, namely Meyer's Parrot (*Poicephalus meyeri*), Rüppell's Parrot (*P. rueppellii*), and Rosy-faced Lovebird (*Agapornis roseicollis*), nested in a similar density of 0.50–0.75 pairs per 100 ha. The African Hoopoe (*Upupa epops*) was the most abundant coraciiform species reaching a density of 3.3 pairs per 100 ha in 2017. The second most abundant coraciiform species was the Lilac-breasted Roller (*Coracias caudatus*), which population increased from 0.5 pairs per 100 ha in 2012 to 1.4 pairs per 100 ha in 2020. Among the other coraciiform species, only the Common Scimitar-bill (*Rhinopomastus cyanomelas*) reached a density higher than one pair per 100 ha, in 2017. Among piciform species the most abundant was the Acacia Pied Barbet (*Tricholaema leucomelas*; up to 2.5 pairs per 100 ha).

Conclusion: Contrary to expectation, for most species and species groups studied, their population densities were negatively related to the precipitation. No other species of this order reached a density higher than 1 pair per 100 ha in any year. These population densities are compared with those obtained in 10 sites in Namibia and the South African Highveld. Lilac-breasted Roller, Common Scimitarbill, parrots and hornbills showed high, while barbets showed low site fidelity.

Keywords: *Agapornis roseicollis*, *Coracias caudatus, Upupa epops, Rhinopomastus cyanomelas*, *Poicephalus meyeri, Poicephalus rueppellii, Tricholaema leucomelas* population density, philopatry, population trends, urban ecology, acacia savanna.

Introduction

Bird species belonging to the orders of Coraciiformes, Psittaciformes and Piciformes may be regarded as good indicators of environmental quality (Mekonen 2017; Mariyappan et al. 2023), as they rely on tree holes for nesting sites, which are normally available in mature and well-preserved habitats. The order Coraciiformes is well-represented in southern Africa, where five roller (Coraciidae), nine bee-eater (Meropidae), and four hoopoe species (Upupidae, Phoeniculidae) occur. Also, the order Piciformes have numerous representatives in this region, among such families as woodpeckers (Picidae, 10 spp.), honeyguides (Indicatoridae, 6 spp.), barbets (Lybidae, 10 spp.) and hornbills (Bucerotidae, 10 spp.). The order Psittaciformes is represented by one family Psittaculidae in southern Africa, which includes three lovebird (*Agapornis*) and five parrot (*Poicephalus*) species (Hockey et al. 2005).

Members of these orders usually thrive in well-preserved savanna or forest biomes, but disappear from fragmented, disturbed or transformed environment (Juniper & Parr 2003; Hockey et al. 2005). Since most species are fairly large and have distinctive plumage colouration, they attract human attention. Most of them are also strongly territorial and vocally conspicuous (Del Hoyo et al. 1997, 2001, 2002; Hockey et al. 2005). Most of these species can be classified as fairly widespread and common in southern Africa. All these make them good objects for population studies. Martin et al. (2014) and Dueker et al. (2023) have summarised data on the distribution, population and range trends, and threats of larger parrot species and all African *Agapornis* species. Accurate estimation of population size is a starting point and a major theme of population studies. Despite this, not much is known about their population densities and virtually nothing about interannual population changes (Rowan 1983; Urban et al. 1986; Frey et al. 1988; Del Hoyo 1997, 2001, 2002; Hockey et al. 2005).

The aim of the study was to: 1) estimate population densities; 2) assess interannual variations in population densities; 3) study site fidelity; 4) find preferences or their lack to natural or man-modified savanna of all coraciiform, piciform and psittaciform species breeding in a mosaic of natural and man-modified savanna; and 5) compare population densities of all these species recorded in the study area with those obtained in other regions of southern Africa.

Methods

Study area

The study area was located on the University of Namibia (UNAM) Ogongo campus, Omusati Region, northern Namibia. It is situated in the Biodiversity Monitoring Transect Analysis in Africa (BIOTA) Observatory (in this project treated as a study area) called 'Ogongo', within the Cuvelai Drainage System, c. 50 km northwest of Oshakati, Outapi District, Omusati Region (17°42′00.0″S 15°18′36.0″E). It constitutes the final observatory of the BIOTA Transect (Hoffman et al. 2010; Jurgens et al. 2010; Schmiedel & Jurgens 2010).

The Cuvelai Drainage System, where the study area is situated, is a unique ecosystem comprising a network of water canals (*oshanas*), mopane and acacia savannas (Mendelsohn et al. 2000, 2009; Mendelsohn & Weber 2011). The study area is, however, devoid of these canals, and the natural vegetation comprises acacia savanna composed mainly of *Albizia anthelmintica, Boscia albitrunca, Colophospermum mopane, Combretum spp., Commiphora spp., Dichrostachys cinerea, Ficus sycomorus, Grewia spp., Hyphaene petersiana, Kigelia africana, Sclerocarya birrea, Senegalia fleckii, S. mellifera, Terminalia sericea, Vachellia erioloba, V. nilotica* and *Ziziphus mucronata* (Kangombe 2007). There is only small part of mopane savanna (composed almost entirely of young *Colophospermum mopane* shrubs) in the northeastern corner of study area. Both savannas are utilised as a pasture for cattle, sheep and goats.

The total surface of the study area was 400 ha. Most of it (70%) constitutes natural acacia savanna. The remaining 30% was man-modified acacia savanna, which includes built-up areas (yards with buildings and small gardens, 17.5%), arable fields (7.5%), orchards (2.5%), disturbed savanna (2.5%) and sport fields (0.5%) (Figure 1).

There are also numerous exotic trees planted in and around human settlements, such as *Moringa oleifera, Melia azedarach, Dodonaea viscosa* and *Eucalyptus camaldulensis*. There are several permanent water bodies with standing water, and the area borders with an artificial water canal to the north and an extensive *oshana* (natural grassy depressions filled with water in the rainy season) to the east.

Ogongo has a semi-arid climate. The summers are sweltering and partly cloudy; the winters are short, comfortable and clear (Mendelsohn et al. 2000; Mendelsohn & Weber 2011). In the 2019/2020 rainy season (September–April), the total amount of rain in nearby Ongwediva was 702 mm, in the previous rainy season it was 388 mm; and the long-term annual average is 724 mm (Figure 2) (https://weatherandclimate.com/namibia/oshana/ongwediva). The amount of rainfall in a given breeding season was correlated with the population density of particular bird species.

Data collection

Studies were conducted in three different years: 2012, 2017 and 2020. A territory mapping method

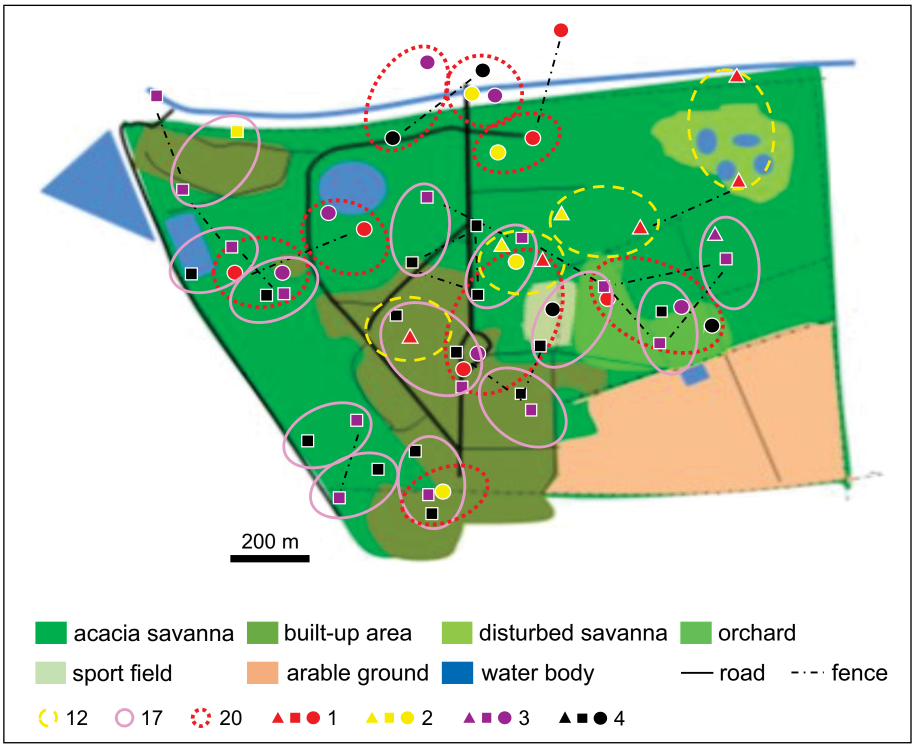

Figure 1. The study area with distribution of African Hoopoe territories in Ogongo in 2012, 2017 and 2020. Small triangles, quadrates and dots indicate mapped registrations of birds during the survey 1, 2, 3 and 4 in 2012 (12, yellow colour), 2017 (17, pink colour), and 2020 (20, red colour) respectively. At least two records in one clump were required to delineate occupied territory. Encircled are occupied territories in 2012 (yellow dotted circles), 2017 (pink circles) and 2020 (red dotted circles). Each occupied territory is the equivalent of one breeding pair.

(Sutherland 1996; Bibby et al. 2012) has been applied to assess the population densities of all coraciiform, piciform and psittaciform species breeding in the study plot. Field observations were conducted by the same observer throughout the years. Observations were aided with 10×50 binoculars. Surveys were conducted in early mornings by walking slowly, in all habitats, with a similar speed of about 1 km per 20–30 minutes.

During each survey all seen and heard birds (showing breeding or territorial behaviour) were mapped using GPS. The study area was traversed longitudinally or latitudinally on transects separated from one another by a space of about 70–100 m (GPS helped to keep the proper direction and distance). During each survey, the transects were differently set up in the field. Caution was taken to not register the same individuals by noting all movements in the field and by paying special attention to simultaneously calling birds.

Four surveys of the whole area were conducted in each year during the wet season (October–April). To cover the whole study area, each survey consisted of 4–5 counts conducted on different days in a fragment of the study area. In 2012 and 2020, the first surveys were conducted in the first half of November, second surveys in the second half of November, third surveys in the first half of December and fourth surveys in the second half of December. In 2017, the first survey in the first half of February, second survey in the second half of February, third survey in the first half of March, fourth survey in the second half of March. Slightly different seasons within a given year (stage of breeding) for counting birds in three different years may have resulted in some bias and inaccuracy in the comparison.

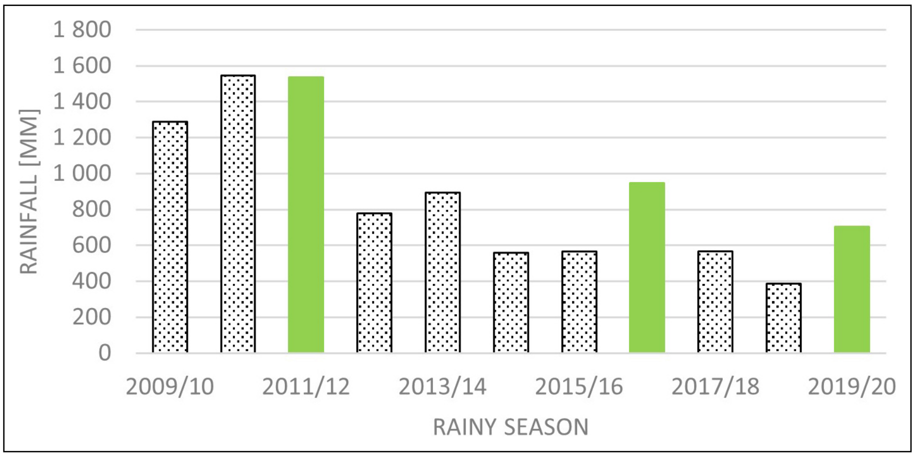

Figure 2. Annual rainfall in Ongwediva in rainy seasons (September–April) during the years 2009–2020.

Data analysis

Only calling/singing birds, and those showing other territorial or breeding behaviour, were plotted on the map 1:1000. Caution was taken to not register the same individuals by noting movements of counted birds in the field and by paying special attention to simultaneously calling birds. At least two records out of four in a clump were required to confirm an occupied territory (Bibby et al. 2012). However, if nest with eggs or chicks were found, one record was sufficient. The number of nests found may bias the sample, as species with easily detected nesting sites (parrots, rollers) had better detection rates than species with nests that are difficult to find (e.g., woodpeckers and wood hoopoes).

Population density was expressed as the number of breeding pairs per 100 ha. Nomenclature of species follow Chittenden et al. (2016). General habitat preference (natural vs partly transformed savanna) was measured by relating the number of territories established in natural savanna to the number established in partly transformed savanna in all studied years. The difference was tested with the ch^2-test. Site fidelity was assessed by relating the number of territories established exactly or partly in the same site in two or three studied years (2012, 2017 and 2020) to the number of territories established in different sites in each studied year. The x^2-test was also used to test the year-to-year differences in the number of breeding pairs of more common species and species groups.

Results

In total 3 psittaciform, 6 coraciiform and 6 piciform species were recorded as breeding residents in the study plot (Table 1; Appendix Figure 1A–O). The overall population density of parrots has increased from 1 to 2 pairs per 100 ha (Appendix Figure 1A–C). In 2020, Meyer's Parrot, Rüppell's Parrot and Rosy-faced Lovebird, nested in similar densities of 0.50–0.75 pairs per 100 ha (Appendix Figure 1A–C). All Rosy-faced

Table 1. Population densities of psittaciform, coraciiform and piciform species in the study area in Ogongo (400 ha) in 2012, 2017 and 2020. N – number of breeding pairs; D – density (pairs / 100 ha)

Species	**2012**		**2017**		**2020**	
	N	**D**	**N**	**D**	**N**	**D**
PSITTACIFORMES						
Meyer's Parrot (*Poicephalus meyeri*)	2	0.5	0	0	3	0.75
Rüppell's Parrot (*Poicephalus rueppellii*)	0	0	4	1	2	0.50
Rosy-faced Lovebird (*Agapornis roseicollis*)	2	0.5	2	0.5	3	0.75
Subtotal	**(4)**	**(1)**	**(6)**	**(1.25)**	**(8)**	**(2)**
CORACIIFORMES						
Lilac-breasted Roller (*Coracias caudatus*)	2	0.5	3	0.75	5.5	1.38
Little Bee-eater (*Merops pusillus*)	0	0	4	1	1.5	0.38
Swallow-tailed Bee-eater (*Merops hirundineus*)	0	0	2	0.5	1	0.25
African Hoopoe (*Upupa epops*)	4	1	13	3.25	7	1.75
Common Scimitarbill (*Rhinopomastus cyanomelas*)	3	0.75	6	1.5	3	0.75
Green Wood Hoopoe (*Phoeniculus purpureus*)	1	0.25	0	0	1	0.25
Subtotal	**(10)**	**(2.5)**	**(28)**	**(6.90)**	**(19)**	**(4.76)**
PICIFORMES						
Southern Red-billed Hornbill (*Tockus rufirostris*)	2	0.5	4	1	3	0.75
African Grey Hornbill (*Lophoceros nasutus*)	1	0.25	3	0.75	3	0.75
Acacia Pied Barbet (*Tricholaema leucomelas*)	10	2.5	5	1.25	10	2.50
Black-collared Barbet (*Lybius torquatus*)	2	0.5	3	0.75	3.5	0.88
Cardinal Woodpecker (*Dendropicos fuscescens*)	0	0	1	0.25	1	0.25
Golden-tailed Woodpecker (*Campethera abingoni*)	0	0	1	0.25	0	0.00
Subtotal	**(15)**	**(3.75)**	**(17)**	**(4.25)**	**(20.5)**	**(5.13)**
Grand total	**29**	**7.25**	**50**	**12.5**	**47.5**	**11.88**

Lovebirds nested in abandoned Red-billed Buffalo Weaver (*Bubalornis niger*) nests.

The order Coraciiformes was represented by 1 species of roller (Coraciidae) (Appendix Figure 1D), 2 species of bee-eaters (Meropidae) (Appendix Figure 1E–F), 1 species of hoopoes (Upupidae) (Appendix Figure 1G) and 2 species of wood hoopoes (Phoeniculidae) (Appendix Figure 1H–I). The African Hoopoe was the most abundant coraciiform species reaching a density of 3.3 pairs per 100 ha in 2017 in the whole study area (Appendix Figure 1G). This constituted almost half of all breeding coraciiform pairs (Table 1). Its density, however, fluctuates considerably from year to year. The number of Green Wood Hoopoe (*Phoeniculus purpureus*) territories refers to the territories of co-operatively breeding groups, where there is a reproducing pair and a number of non-reproducing helpers (Appendix Figure 1I). The second most abundant coraciiform species was the Lilac-breasted Roller, which population increased from 0.5 pair per 100 ha in 2012 to 1.4 pairs per 100 ha in 2020 (Appendix Figure 1D, Table 1). Among the other coraciiform species, only the Common Scimitarbill reached a density higher than 1 pair per 100 ha in 2017 (Appendix Figure 1H, Table 1).

The order Piciformes was represented by species belonging to three families: hornbills (Bucerotidae, 2 spp.), barbets (Lybidae, 2 spp.) and woodpeckers (Picidae, 2 spp.). Among the piciform species the most abundant was the Acacia Pied Barbet (up to 2.5 pairs per 100 ha). In 2012 and 2020 the Acacia Pied Barbet comprised more than half of all piciform breeding pairs (Appendix Figure 1L, Table 1). No other species of this order reached a density higher than 1 pair per 100 ha in any year.

All three parrot species and the Common Scimitarbill have shown preference for natural acacia savanna (Appendix Figure 1H). A preference for natural vegetation was also shown by woodpeckers (Appendix Figure 1N–O) and the Acacia Pied Barbet (Appendix Figure 1L). The Lilac-breasted Roller and Little Bee-eater (*Merops pusillus*) were equal in their choice of natural and man-modified savanna (Appendix Figure 1D, E). The Black-collared Barbet (*Lybius torquatus*) do not show any preferences (Appendix Figure 1M, Table 2). It should, however, be emphasised that all these differences are not statistically significant (Table 2).

Parrots and hornbills showed high site fidelity (most territories were held at the same site over years), while about half of Lilac-breasted Roller and Common Scimitarbill territories were at the same site year after year (Appendix Figure 1H). Barbets, however, appear to show low site fidelity (most territories were in different sites over years) (Appendix Figure 1L–M, Table 3). These results not necessary indicate site fidelity, as territories could have been held by different pairs in consecutive years. Birds were not colour-ringed or marked in any other way.

Discussion

The territory mapping method enables the estimation of population density of territorial bird species with a

Table 2. Number of territories of psittaciform, coraciiform and piciform species in acacia savanna with differential human modification

Species	Natural savanna		Human-modified savanna			
	n	%	n	%	n*	x^2
Acacia Pied Barbet	13	52	7	25	16.3	0.37
African Hoopoe	12	50	4	50	9.3	0.34
Common Scimitarbill	9	75	3	33.7	7.0	0.25
Lilac-breasted Roller	6	50	6	14.3	14.0	3.20
Red-billed Hornbill	6	66.7	3	0	7.0	0.08
Rosy-faced Lovebird	6	85.7	1	33.4	2.3	–
Little Bee-eater	6	100	0	66.7	0.0	–
Rüppell's Parrot	4	66.6	2	71.4	4.7	–
Black-collared Barbet	3	33.3	3	60	7.0	–
Grey Hornbill	2	28.6	3	71.4	7.0	–
Meyer's Parrot	2	40	3	50	4.7	–
Swallow-tailed Bee-eater	1	33.3	2	100	0.0	–
Cardinal Woodpecker	2	100	0	0	2.3	–
Red-billed Wood Hoopoe	1	50	1	50	2.3	–
Golden-tailed Woodpecker	0	0	1	100	2.3	–

Table 3. Site tenacity of psittaciform, coraciiform and piciform species in the study area (400 ha). T – territories the same; P – territories partly overlapped; N – territories separated.

Species	2012 vs 2015			2012 vs 2020			2015 vs 2020			2012/2017/2020		
	T	P	N	T	P	N	T	P	N	T	P	N
Meyer's Parrot	–	–	–	1	0	1	–	–	–	–	–	–
Rüppell's Parrot	–	–	–	–	–	–	–	–	2	–	–	–
Rosy-faced Lovebird	1	–	–	1	–	1	–	–	2	–	–	2
Lilac-breasted Roller	1	–	1	1	–	1	1	1	–	–	–	2
Little Bee-eater	–	–	–	–	–	–	–	–	2	–	–	–
Swallow-tailed Bee-eater	–	–	–	–	–	–	–	–	–	–	–	–
African Hoopoe	1	2	1	–	1	3	1	5	2	1	1	2
Common Scimitarbill	–	2	1	–	–	3	1	2	1	–	2	2
Red-billed Wood Hoopoe	–	–	–	–	1	–	–	–	–	–	–	–
Red-billed Hornbill	1	–	1	1	1	–	1	–	1	1	1	–
Grey Hornbill	1	–	–	1	–	–	1	2	1	1	–	–
Acacia Pied Barbet	–	3	2	1	2	7	–	2	3	1	2	3
Black-collared Barbet	–	–	2	1	1	–	1	–	2	1	–	1
Cardinal Woodpecker	–	1	–	–	–	–	–	–	–	–	–	–
Golden-tailed Woodpecker	–	–	–	–	–	–	–	–	–	–	–	–

high accuracy (Sutherland 1996; Bibby et al. 2012). For strongly territorial and vocal species, the estimated densities are close to the absolute values. In this study, such species were represented by the Lilac-breasted Roller, Common Scimitarbill, African Hoopoe and barbets. On the other hand, parrots are not strongly territorial (Meyer's and Rüppell's parrots) and may breed in small colonies (Rosy-faced Lovebird), posing problems in counting. The density of the Green Wood Hoopoe refers to the number of cooperatively reproducing groups rather than breeding pairs as such. The cooperative group is normally composed of the reproductive pair and 1–10 helpers (usually offspring from the previous breeding attempt of the actual reproducing pair), which although sexually mature, do not reproduce but help to rear offspring to the reproducing pair (Hockey et al. 2005).

Contrary to expectation, for most species and species groups studied, their population densities were negatively related to the precipitation. The interannual difference in population densities were, however, statistically significant only in the case of the African Hoopoe ($x^2 = 5.25$, $p<0.05$), coraciiform ($x^2 = 8.53$, $p<0.01$) and all the species taken together ($x^2 = 6.24$, $p<0.05$). Drier weather conditions appear to be especially conducive for coraciiform species (including the African Hoopoe). Possibly it is caused by migrating of these species from dry to more humid habitats in years with low precipitation. This phenomenon has been well-documented for the Lilac-breasted Roller and the Purple Roller (*Coracias naevius*) in Botswana (Herremans & Herremans-Tonnoeyr 1994). In the study area of Ogongo, coraciifoms nested in significantly lower densities in the year with high precipitation (2012) than in the years with much lower precipitation (2017 and 2020; Figure 2).

Site fidelity or philopatry can be proved with certainty only if birds are colour-ringed, marked with picric acid, also known as trinitrophenol or 2,4,6-trinitrophenol (used as a dye for textiles and other materials due to its bright yellow colour) or with other markers. In this study, birds were not marked, and site fidelity cannot be proved. However, high numbers of territories established in exactly the same site in three different years (2012, 2017 and 2020) suggest that the site fidelity may prevail in those species. This merits further investigation with marked birds.

Even in regard to such common and conspicuous species as those selected for this study, data on their population densities are scarce in literature (Frey et al. 1988, Del Hoyo et al. 2001, Hockey et al. 2005). The Lilac-breasted Roller bred at a density of 4 pairs / 100 ha in eastern Kenya (Brown & Brown 1973). The Little Bee-eater nested at a density of 2 pairs / 100 ha in a broad-leaved woodland in Limpopo, South Africa (Tarboton et al. 1987), being close to that in Ogongo. The Southern Red-billed Hornbill with 2 pairs / 100 ha in Limpopo, South Africa (Kemp 1976, Tarboton et al. 1987) and 2.3 pairs / 100 ha in Botswana (Herremans 1997) were twice higher than in Ogongo. The Black-collared Barbet nested in exceptionally high density of 9 pairs / 100 ha in a mixed woodland around Great Zimbabwe Ruins (Vernon 1985). Most of the values are higher than recorded in this study. Some of these figures may reflect local concentrations known in these species. This is a widespread error/bias in population studies often committed by researchers all over the world. However, it is also plausible that these habitats in the Limpopo province of South Africa and in Zimbabwe are more continuous, more compact (higher tree density) and natural than the fragmented and transformed more open (lower tree density) acacia savanna in the Ogongo area. Lower densities recorded in Ogongo might also be a result of interspecific competition. For the particular species, the densities were relatively low, but for all members of the order to which they belonged the overall density could have been higher, and the habitat could have been saturated with their territories, as coraciiform species often show interspecific competition (both for food resources and for nesting sites) and territoriality (Del Hoyo et al. 1997).

Parrots, especially the Rosy-faced Lovebird, are dependent on water, and when the precipitation is low they may migrate to other places (Ndithia & Perrin 2006; Ndithia et al. 2007). The Ogongo study had permanent water bodies in few sites and a water canal always filled with fresh water (Figure 1), which probably explains their constant presence irrespective of rainfall level.

Hoopoe population density appears to be much higher in the Cuvelai Drainage System than in other sites in Namibia. Possibly, it is one of the highest in southern Africa at large. Exceptionally high population density of the Black-collared Barbet has been recorded in Katima Mulilo (5.7 pairs / 100 ha), while that of the Acacia Pied Barbet is higher in Kasane (6.3 pairs / 100 ha). Both sites represent suburban areas with large numbers of fruit trees such as mangoes, papayas and figs, which may constitute a reservoir of food resources of these species. Green Wood Hoopoe, Common Scimitarbill and woodpecker species appear to breed in low population densities both in Namibia and in South African Highveld (grassland). Nowhere their densities were higher than 2 pairs / 100 ha (Table 4).

The above-mentioned bird species should be regarded as convenient objects of studies on environmental health and quality. Monitoring their numbers shall

Table 4. Population densities (pairs / 100 ha) of psittaciform, coraciiform and piciform species in an acacia savanna in southern Africa

	Study sites (see site names below)										
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Meyer’s Parrot	0.8	0.1	0	0	2.3	0	0	1.9	–	–	–
Rüppell’s Parrot	0.8	0	0	0	–	0	0	0	–	–	–
Rosy-faced Lovebird	0.8	0.4	2.3	0	–	–	–	0	–	–	–
Lilac-breasted Roller	1.4	0.5	2.3	1.0	2.5	2.9	0.7	1.3	0.1	–	–
Little Bee-eater	1.0	0.4	0	1.5	1.3	0.6	1.1	0.6	0.0	–	–
Swallow-tailed Bee-eater	0.5	0.1	0	0	0	0	0	0	0.2	<0.1	–
African Hoopoe	3.3	3.5	5.4	3.5	0	0	0.7	0	<0.1	0.8	2.0
Common Scimitarbill	1.5	0.5	0	0	1.3	1.2	0.4	0	<0.1	<0.1	0.0
Red-billed Wood Hoopoe	0.3	0.3	0	0	0.2	0.6	1.1	1.9	0.0	–	–
Red-billed Hornbill	1.0	3.0	0	0	–	0	0	0.6	0.0	–	–
Grey Hornbill	0.8	0.4	0	0	1.3	0	0	2.5	0.1	–	–
Acacia Pied Barbet	2.5	1.0	1.2	2.0	0	0	0	6.3	0.8	1.0	<0.1
Black-collared Barbet	0.9	0.1	3.1	3.0	2.6	2.4	5.7	1.9	0	<0.1	<0.1
Cardinal Woodpecker	0.3	0	0	0	0	0	0.4	0	0.1	0.1	0
Golden-tailed Woodpecker	0.3	0.2	0	0	0	0	1.1	0	0	–	–

1: Ogongo Campus, Namibia, 400 ha (this study).
2: Ogongo Game Park, Namibia, 3 000 ha, Kopij (2023).
3: Outapi, Namibia, Kopij (2019a).
4: Ongwediva, Namibia, 100 ha, Kopij (2021a).
5: Katima Mulilo, Namibia, 4 plots pooled: 476 ha, 2013–2015; Kopij (2019b, 2020a).
6: Katima Mulilo, Namibia, 2014/15, 85 ha, Kopij (2020b)
7: Zambezi forests near Katima Mulilo, Namibia, 2015: 280 ha, Kopij (2019).
8: Kasane, Botswana, 2014–2016, 160 ha, Kopij (2018b).
9: Windhoek, Namibia, 2014–2019, 50 km^2, Kopij (2022b).
10: Bloemfontein, South Africa, 1992–2002, 50 km^2, Kopij (2001a, 2015).
11: Roma Valley, Lesotho, 50 km^2, Kopij (2001b).

constitute integral parts of conservation projects. Some of them (hornbills, wood-hoopoes, honeyguides and woodpeckers) appear to be prone to habitat modifications, others, like the Rosy-faced Parrot, Lilac-breasted Roller, African Hoopoe or Swallow-tailed Bee-eater appear to be well adapted to human-modified environments. The Rosy-faced Lovebird may even reach high population densities in some Namibian towns and cities (Kopij 2021b, 2022a, 2022b).

The population densities, with their year-to-year variations recorded for 15 bird species in acacia savanna may constitute a basis for assessing population size of these species on larger areas through an extrapolation. Such assessments are especially valuable for species included in the Red Data Books and Red Lists. Information of site tenacity may also be used to assess the status of environmental quality, as declining site tenacity may indicate declining environmental quality.

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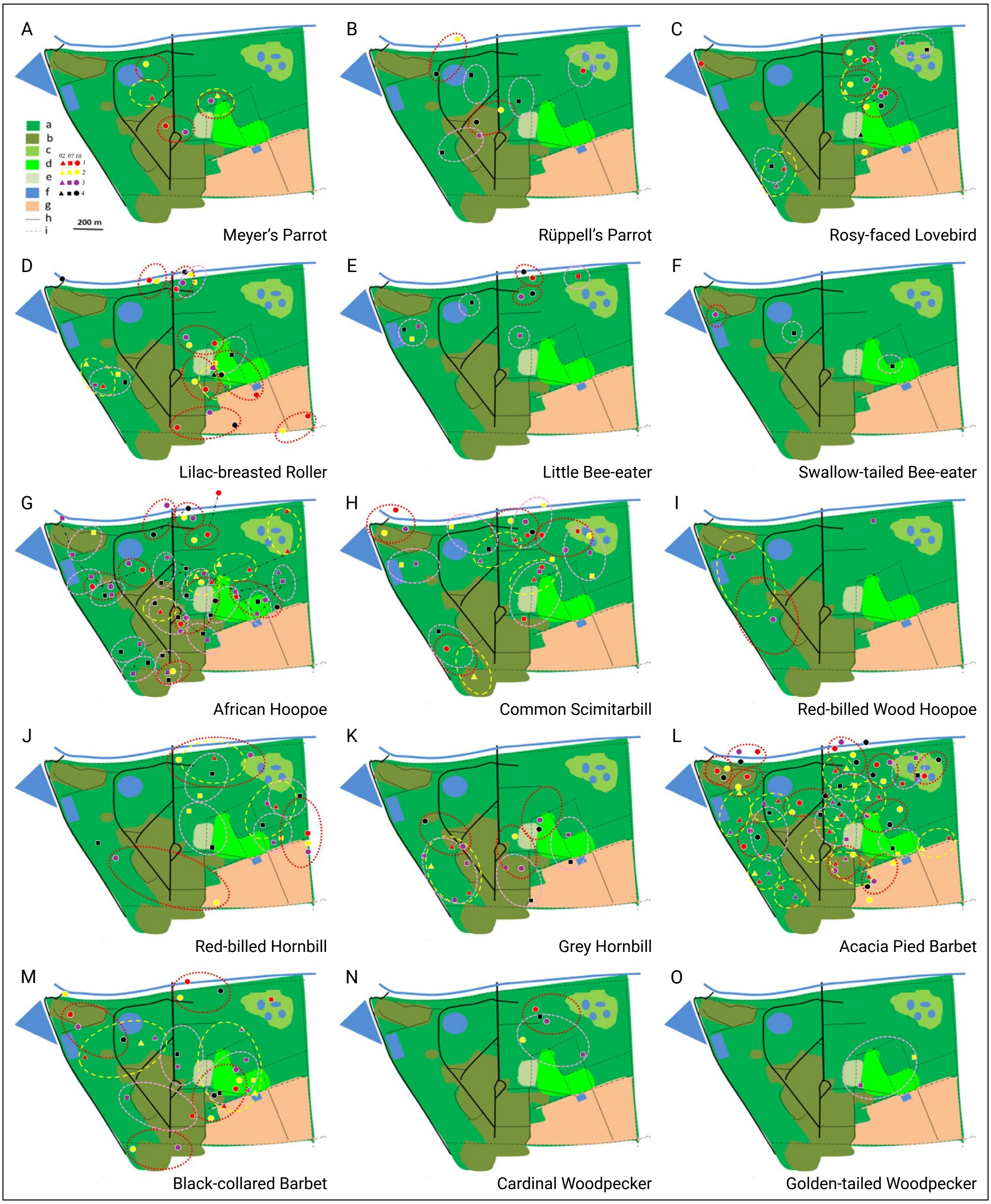
Appendix 1



Distribution of territories of psittaciform, coraciiform and piciform species in Ogongo in 2012, 2017 and 2020. Small triangles, quadrates and dots indicate mapped registrations of birds during the survey 1, 2, 3 and 4 in 2012 (12, yellow colour); 2017 (17, pink colour); and 2020 (20, red colour) respectively. At least two records in one clump were required to delineate occupied territory. Encircled are occupied territories in 2012 (yellow dotted circles), 2017 (pink circles) and 2020 (red dotted circles). Each occupied territory is an equivalent of one breeding pair.

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Western Barn Owl (*Tyto alba*) diet analysis to assess small mammal populations in two regions of Kenya

Authors

[1] Veronicah Onduso
[2] Nathan Gichuki
[2] Evans Mwangi
[3] Anna K. Behrensmeyer
[4] Frederick K. Manthi
[1] Ogeto Mwebi

Affiliations

[1] Osteology Section, Zoology Department National Museums of Kenya, Museum Hill, Kipande Rd, P.O. Box 40658 00100, Nairobi, Kenya.
[2] Department of Biology, University of Nairobi, Chiromo Campus, Riverside Drive, off Chiromo Road, P.O. Box 30197-01000, Nairobi, Kenya.
[3] Department of Paleobiology, MRC 121, Smithsonian National Museum of Natural History, P.O. Box 37012, Washington, DC, 20013-7012, USA.
[4] Department of Antiquities, Sites and Monuments, National Museums of Kenya, Museum Hill, Kipande Rd, P.O. Box 40658 00100, Nairobi, Kenya.

Corresponding Author

Dr Ogeto Mwebi; e-mail: email. omwebi@museums.or.ke / ogeto_mwebi@yahoo.com

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Background: Avian predators are known to take prey in proportion to their availability in different ecological settings, but additional causes of variation in species representation remain unclear. Species recorded in predator diets may reflect both novel predator adaptive strategies as well as the composition of prey communities. Assemblages of regurgitated owl pellets typically contain diverse species of small vertebrates, and analysis of their contents provides a way to document changes in both prey populations and predator strategies over time. Furthermore, pellet assemblages can provide valuable information on species (including cryptic species) not captured using conventional trapping methods.

Objectives: The study aimed to compare historical and current small mammal prey diversity in Western Barn Owl pellets and trapping surveys in Nairobi Urban Environment (NUE) and Tsavo East National Park (TENP) to assess patterns of prey selection in relation to two different habitats and evaluate the potential for using owl diets to monitor changes in ecosystem health over time.

Methods: This study conducted dietary analysis of the Western Barn Owl [*Tyto alba* (Scopoli, 1769)] in the NUE and TENP. We compared prey composition in Western Barn Owl pellets residing in these two localities and assessed small mammal populations through trapping in the same areas. A total of 795 complete and previously disintegrated Western Barn Owl pellets retrieved from both localities were analysed. The NUE dataset consisted of two nest sites, which included 371 complete pellets collected in 2020–2021 and disintegrated pellets collected in 2005, as records of recent and past diversity to compare with trap results. For TENP we analysed 424 Western Barn Owl pellets from four nests collected in 2020–2021. Trapping surveys for small mammals were conducted for two seasons between December 2020 and August 2021 across suspected owl foraging habitats and around the nest sites in both locations.

Results: Small mammals formed the principal prey for all owls across the sites, with other taxa such as birds, reptiles, invertebrates and amphibians present in lower abundance. Variation in diet was significant between the two sites, which we infer was primarily determined by prey availability. Comparison of pellet and trapping data showed significant differences in recorded species diversity across habitats.

Conclusions: Our study involved understanding how different environmental conditions affect Western Barn Owl diet. The results demonstrate dietary variation across biogeographical regions with both urban and natural habitats, suggesting that small mammal communities co-existing in a given ecological region can adapt to local environmental conditions. Species richness in the owl diet was greater in the urban habitat, likely because of increased prey diversity as well as the adaptability of Western Barn Owls as predators in this environment.

Key words: Western Barn Owl, small mammals, pellets, trapping, habitat, species, prey, diet.

Introduction

Understanding dietary niche is a fundamental part of developing a conservation scheme, which in turn depends on understanding the role of a species in biological communities (Beever et al. 2016). Raptors are apex predators in their relevant food chains; they occur in small numbers and have low reproductive rates relative to their prey (Donázar et al. 2016). Their feeding behaviour makes them useful for sampling small vertebrate biodiversity because they generally track the abundance of their prey populations in the ecosystem (Natsukawa & Sergio 2022). Western Barn Owl [*Tyto alba* (Scopoli, 1769)] diets are widely studied because of the species' cosmopolitan distribution, usefulness as a biocontrol agent for rodent populations worldwide, vulnerability to rodenticides, as well as the ease of identifying prey remains recovered from regurgitated pellets (Abd Rabou 2020). Western Barn Owls exhibit dietary plasticity that is greater than many other species of raptors (Donázar et al. 2016). Their flexible hunting strategy allows them to adapt to various environments, contributing to their success as predators and also explaining their varied diet and wide geographic distribution (Moysi et al. 2018).

Western Barn Owls generally require large territories, and their home range varies significantly depending on the landscape structure and prey availability (Thomsen et al. 2014). During the breeding season they hunt in a 1 km radius around the nest and up to an average distance of 28.5 km at other times (Hindmarch et al. 2017). Their conservation becomes more difficult when wild populations must cope with anthropogenic expansions that limit habitat areas (Renuka Balakrishna 2023). Urbanisation leads to restructuring of faunal communities that live in close proximity to humans (Xu et al. 2018). Tolerance of Western Barn Owls and other avian species to urban environments is connected to plasticity in diet and nest site availability (Latorre et al. 2022).

Owls living in urban environments adapt by using wider home ranges compared to those in natural habitats (Dykstra 2018). This allows them to better exploit more fragmented habitats and less-developed areas (Lövy & Riegert 2013). However, urban areas also act as an ecological trap in which animals occupy habitats where their fitness may be lower, especially when confronted by rapid habitat change, subjecting them to the possibility of local extinction (Hale & Swearer 2016).

Western Barn Owls are primarily predators of nocturnal small mammals (7–24 g), but also feed on other small animals such as invertebrates, amphibians, birds and reptiles (Hindmarch & Elliot 2015). They swallow whole prey, and pellets contain undigested prey remains such as bones, fur, feathers, teeth, claws and exoskeleton (Saufi et al. 2020). Prey remains in pellets can be identified to genus or species level, allowing accurate assessments of diet breadth or prey diversity. Pellet analysis provides evidence of prey species and quantitative data on local populations of small vertebrates (Marsh 2012; Wright 2019). Owl pellets can be an efficient and cost-effective biodiversity sampling method across broad spatiotemporal scales, but owls may also bias their diet towards mammal species that are more available as prey (Paniccia 2019).

Quantifying small mammal presence and abundance with Western Barn Owl pellets can be used to investigate the influence of climate factors and humans on community structure and abundance in different landscapes (Horváth et al. 2018). Western Barn Owl diets vary considerably among habitats and regions, and between seasons and years, and all such factors interact with prey population dynamics. A change in habitat can lead to changes in the small vertebrate fauna of any given area (Baroni et al. 2021). Habitat preferences also affect the composition and abundances of prey taxa, which may co-vary with the habitat exploited by the predators (Kenchington et al. 2013). Changes in Western Barn Owl prey selection in relation to habitat indicate that they can be either opportunist or selective hunters (Castaneda 2018). Changing of feeding behaviour is a strategy for adapting to changing environmental conditions (Cavalli et al. 2014).

Documenting small mammals in the wild is customarily conducted using various trapping methods. Conventional trapping is expensive and time-consuming and constrains small mammal monitoring to limited spatiotemporal scales as well as introducing biases associated with baits and trap types (Mwebi et al. 2019). The simultaneous use of live trapping and pellet collection provides complementary data sets for analysis, leading to more comprehensive information on small vertebrate species diversity (Guimarães et al. 2016).

Data on owl prey dynamics through dietary analysis and field trapping of potential prey are limited in tropical Africa, and Kenya in particular (Grande et al. 2018). The goal of this study was to compare historical and current small mammal prey diversity in Western Barn Owl pellets and trapping surveys in Nairobi Urban Environment (NUE) and Tsavo East National Park (TENP) to assess patterns of prey selection in relation to two different habitats and evaluate the potential for using owl diet to monitor changes in ecosystem health over time. Comparisons of data obtained from Western Barn Owl regurgitates and trapping are important for understanding predator–prey relationships. This also provides a framework for evaluating Western Barn Owl prey selection, factors affecting their distribution and accessibility of the prey, and how their diet reflects prey species in foraging habitats. Comparisons of Western Barn Owl diets between the NUE and TENP allowed us to examine the influence of habitat on prey selection as a potential adaptive strategy under changing environmental conditions. We used additional data from pellets collected in 2005 from NUE – Muthangari Estate to increase the understanding of any changes in species or community trends in the urban landscape, thus providing a longer-term perspective on the direction and magnitude of ecological changes affecting owl diet.

Materials and methods

Study site

This research took place in two locations, Nairobi Urban Environment (NUE) and Tsavo East National Park (TENP), which are approximately 340 km apart. Dry and wet season data were collected from the months of December 2020 to August 2021, and their geographical locations are described in (Table 1). The Nairobi region has a subtropical highland climate with a bimodal rainfall regime, an annual rainfall of between 300 mm to 900 mm, and an average daily temperature between 15 °C (night) and 29 °C (day). Samples of owl pellets from NUE were collected from two different sites, Ondiri Swamp and Muthangari Estate. Ondiri Swamp, approximately 10 km from Nairobi Central Business District (CBD), is a highland bog with major vegetation consisting of reeds (*Phragmites* sp.), cattails (*Typha latifolia*) and water grass (*Vossia* sp.). The swamp is surrounded by farmlands with pasture and crops as well as scattered bushes and agro-forestry trees, and by development from Kikuyu town. Additional data were collected from Muthangari Estate, located 5 km from Nairobi CBD. Muthangari was previously covered by indigenous trees, which provided favourable roosting and nesting habitat for Western Barn Owls. The pellet assemblage used in this study (here termed Muthangari) was collected in 2005. This area is currently dominated by residential buildings, infrastructure networks, public and private offices, with limited natural owl nesting or roosting sites. The remaining vegetation includes a few undeveloped areas of bushland dominated by *Lantana camara*, numerous farmlands consisting of perennial and annual crops, fields (grasslands) and scattered woodlands of eucalyptus trees along riverbanks and in residential compounds.

The second study location was TENP, Kenya's largest and oldest protected area, covering 13 747 km^2 in Taita Taveta County, southeastern Kenya. Tsavo has a warm and dry climate, rainfall is often low and erratic; the annual average rainfall ranges between 200 mm and 700 mm (Spinage 2012), and average daily temperatures fluctuate between 20 °C (night) and 31 °C (day). The Rhino Sanctuary and Trailer nest sites were located in grassland habitats towards the southern part of the park, and two other nest sites were located in woodland habitats (named Motor Vehicle Workshop) and a residential building (here referred to as Rangers Camp), in the administration offices near Voi Gate (Figure 1).

Pellet collection

Sampling of pellets was limited to identified Western Barn Owl roost/nest sites, which therefore determined the choice of our sampling sites. These were located through inquiries and information given by locals, rangers and scientists, as well as follow-ups from previous collections preserved at the National Museums of Kenya.

At Ondiri Swamp, complete and compact pellets were collected where a pair of Western Barn Owls were nesting inside a ceiling of a two-story residential building close to the swamp. For Muthangari, disintegrated pellets were obtained in 2005 by FKM and curated at the National Museums of Kenya (NMK). No owl roosting or nesting sites were detected during the 2020–2021 surveys in Muthangari, therefore trapping in this area provides the only recent data for comparative purposes.

At TENP, Western Barn Owl pellets were collected from inside four watch towers at the Rhino Sanctuary; these consisted of intact and disintegrated pellets accumulated over multiple years. We observed a Western Barn Owl flying off (thereby assuring the identity of the owl). Complete and compact pellets were also recovered from inside a tree cavity at the area referred to as 'Trailer' (Table 1).

Inside the motor vehicle building/workshop, we collected pellets dropped on the floor by a pair of Western

Table 1. Data collection localities within NUE and TENP study sites

Locality	Site	Sampling dates	Latitude	Longitude
Nairobi (NUE)	Ondiri Swamp	12/2020, 4/2021	01.2507430 S	36.6594320 E
	Muthangari	2005	01.26576 S	36.7770 E
		12/2020,4/2021		
Tsavo East (TENP)	Rhino Sanctuary	4/2021, 8/2021	03.1280 S	38.8934120 E
	Trailer	4/2021, 8/2021	03.1051560 S	38.88905900 E
	Motor Vehicle Workshop	4/2021, 8/2021	03.3546130 S	38.5977910 E
	Rangers Camp	4/2021, 8/2021	03.3603220 S	38.5977070 E

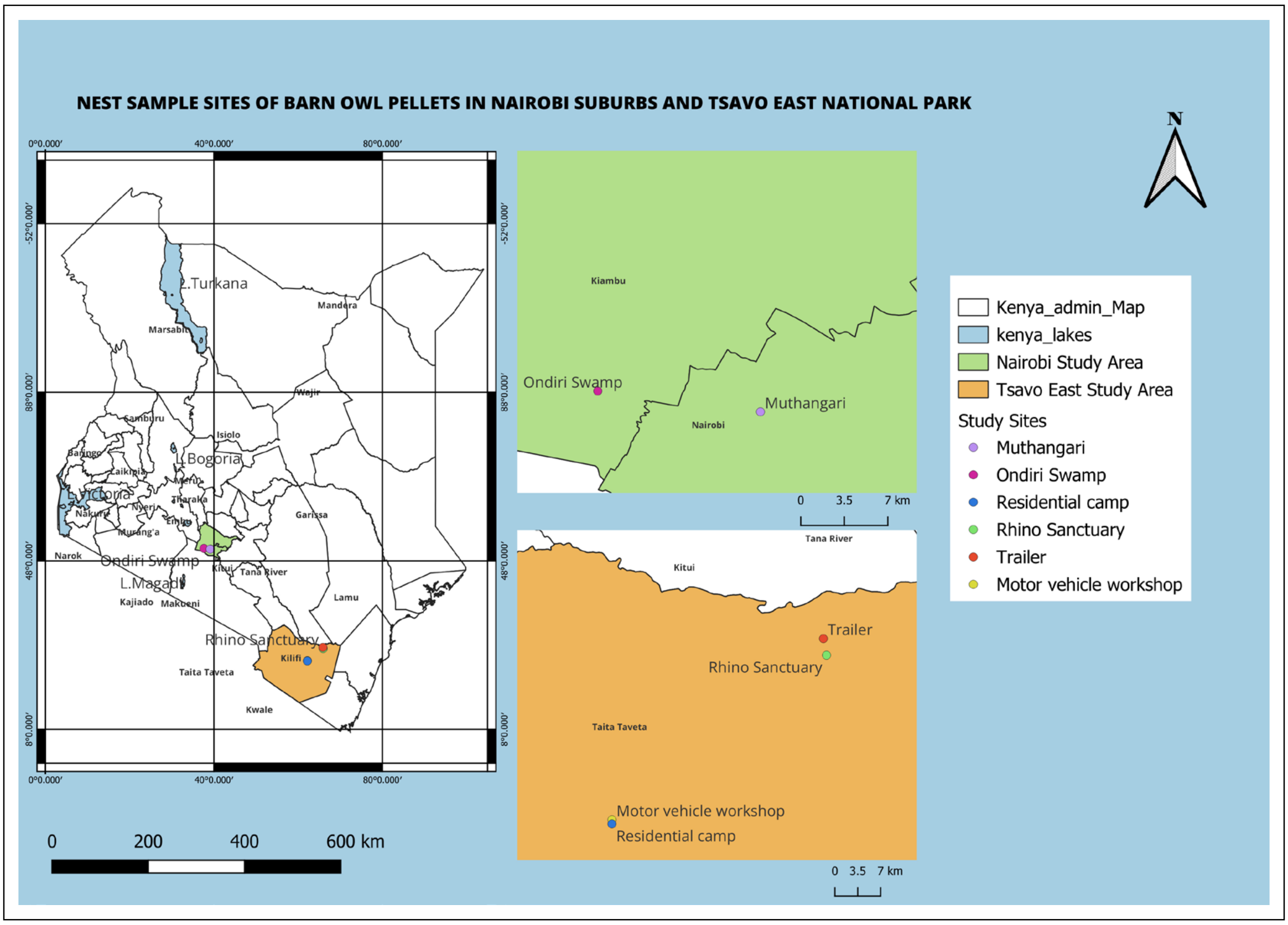

Figure 1. Map of Kenya showing sampling sites within the two study localities, Nairobi Urban Environment (NUE) and Tsavo East National Park (TENP).

Barn Owls nesting inside hidden ledges, and from another nest inside a chimney in a residential building (Table 1). Pellets were collected in two seasons determined by the prevailing weather patterns of the two study locations, packed in zip lock bags, transported to the NMK Osteology laboratory, and stored at room temperature before undergoing processing and analysis.

Pellet analysis

In the laboratory, complete pellets were given unique numbers, photographed and morphometric data recorded using sliding callipers. A total of 795 pellets were collected from the two study sites; 371 from NUE and 424 from TENP, ranging in size from 5.8 ×12.8 mm to 82 × 41.7 mm in NUE and from 21.3 ×12.3 mm to 119.2 × 46.4 mm in TENP. Pellets were soaked individually in a jar containing water mixed with alcohol for a day to kill pathogens and disintegrate the pellets. Disintegrated pellets were passed over a 2 mm sieve and spread on a tray to dry. Prey remains compacted in hair were isolated manually using forceps. Identification of prey remains was based on comparative material available in the Osteology laboratory, NMK, aided by skeletal element (cranial and post cranial) morphology.

Determination of Minimum Number of Individuals (MNI) was based on paired elements and similarities observed in skeletal size to determine taxonomic abundances. Where one of the paired elements was missing (which may be due to complete digestion or errors during sorting), the highest number right or available left elements was used to calculate the MNI. Most vertebrate prey remains were identified to genus. Small mammal (rodent and shrew) identification to species based on skeletal material is challenging because of morphological similarity and lack of diagnostic features. Identification beyond the genus level was not possible for most specimens, with the exception of vertebrate prey species with conspicuous and unique features (Tables 2 & 3, Appendices 1 & 2). Invertebrates were identified to order level based on exoskeleton morphology, the only remains recovered from the pellets.

Trapping and species identification

Trapping was conducted across all habitats within a 2–5 km radius surrounding the Western Barn Owl nest sites. In NUE, we obtained specimens from the habitats along the edge of Ondiri Swamp, i.e., bushland, grassland and woodland, and from habitats in Muthangari surrounding the building where pellets were collected

Table 2. Small mammal prey composition in pellets and trapping from all sites in NUE and TENP, (numbers are counts of individuals MNI and F%)

	NUE				**TENP**			
Taxon	**Pellet**		**Trap**		**Pellet**		**Trap**	
	MNI	**F%**	**F**	**F%**	**MNI**	**F%**	**F**	**F%**
Rodent								
Acomys sp.	147	6.3	0	0	12	1.67	13	39.39
Arvicanthis sp.	3	0.1	0	0	115	16.02	3	9.09
Dendromus sp.	42	1.8	0	0	0	0	0	0
Gerbilliscus nigricaudus	0	0	0	0	0	0	1	3.03
Gerbilliscus sp.	0	0	0	0	82	11.42	14	42.42
Grammomys sp.	2	0.1	3	1.9	0	0	0	0
Lemniscomys sp.	235	10.0	30	18.7	0	0	0	0
Lophuromys sp.	69	8.7	60	37.5	0	0	0	0
Mastomys sp.	384	16.3	34	21.3	53	7.38	0	0
Mus sp.	188	8.0	15	9.4	76	10.58	1	3.03
Oenomys sp.	1	0.0	0	0	0	0	0	0
Otomys sp.	151	6.4	0	0	0	0	0	0
Rattus rattus	399	17.0	7	4.4	0	0	0	0
Rhabdomys sp.	4	0.2	0	0	16	2.23	0	0
Tachyoryctes sp.	165	7.0	0	0	0	0	0	0
Thamnomys sp.	9	0.4	0	0	0	0	0	0
Shrew								
Crocidura olivieri	344	14.6	0	0	0	0	0	0
Crocidura sp.	207	8.8	11	6.9	364	50.7	1	3.03
Total F	**2 350**		**160**		**718**		**32**	
Total species (N = 18)	**16**		**7**		**7**		**6**	

in 2005, including edges of farmlands, bushlands and grazing fields. In TENP, two habitats were trapped, the southern grassland and woodland.

Trapping at both NUE and TENP occurred during two different seasons of the year. In each sampling period, a 100 m transect line consisting of 20 trap stations was laid in the selected habitats at two study localities. A combination of Sherman traps and snap traps were set in each trap station (one Sherman and one snap trap), positioned 5 m apart, a total of 40 traps per transect line. Traps were baited with a mixture of oats, cyprinid fish (*Rastrineobola argentea*) and peanuts; inspected once a day early in the morning; left open for three consecutive days; and moved to the next habitat until all areas were sampled (Halliday et al. 2015*)* – a total trapping effort of 120 trap nights for each habitat and locality. Animals trapped were sedated using intravenous (IV) Ketamine followed by cervical dislocation (Linsenmeier et al. 2020). Morphological data were recorded, i.e., head–body length, hind foot length, tail length, ear length and body mass, for purposes of data accuracy, consistency and uniform comparisons with owl pellets. Seven small mammal species represented by 100 individual skins and skeletal remains were prepared as scientific voucher specimens, accessioned and preserved in the NMK's reference collection.

Statistical analyses

The frequency (F%) of each prey species in the Western Barn Owl diet was determined by calculating the percentage contribution of each species to the total MNI (Minimum Number of Individuals) for all species in a set of pellets. Data are recorded as MNI for pellets, F for trapping and F% for all methods of surveys.

The Levin's Food Niche Breadth (FNB) of Western Barn Owls at all the sites was calculated to determine the dietary diversity in each habitat according to Levin's

(1968) formula: $1/\Sigma pi^2$, where p*i* denotes contribution of a given prey group to the diet.

Differences in prey diversity recorded in pellets at different habitats and sites were calculated using the Shannon-Wiener diversity index: $H' = -\sum pi \ln(pi)$; where H′ represents the index of species diversity, p*i* is the proportion of species *i* in the owl diet, and ln is the natural logarithm. This index reflects both the species richness in the diet and the number of individuals (MNI) in each taxon.

Comparisons of prey items from pellets versus trapping were computed using the chi-squared test for independence. Overall variation in prey taxa in different habitats and sites was tested using one-way ANOVA and a chi-square test. Levels of significance for all tests conducted were set at $p = 0.05$, and test results were considered statistically different if $\alpha < 0.05$. All statistical analyses were carried out using the PAST statistical program for Windows.

Table 3. Small mammal richness (species present) and abundance for combined data from two sites in NUE and four sites in TENP, Kenya; numbers are counts of individuals (MNI) from pellet and trapping data (2005 and 2020–2021 samples)

SPECIES	NUE (Nairobi)	TENP (Tsavo)
Acomys sp.	42	15
Arvicanthis sp.	3	62
Cardioderma cor	2	1
Crocidura olivieri	20	0
Crocidura sp.	529	103
Dendromus sp.	42	126
Gerbilliscus nigricaudus	0	1
Gerbilliscus sp.	0	31
Grammomys sp.	11	0
Hipposideros sp.	2	0
Lemniscomys sp.	265	0
Lophuromys sp.	129	0
Mastomys sp.	398	0
Mus sp.	202	77
Nycteris thebaica	0	1
Oenomys sp.	1	0
Otomys sp.	151	0
Rattus rattus	406	0
Rhabdomys sp.	4	2
Tachyoryctes sp.	165	0
Tadarida lobata	0	1
Thamnomys sp.	9	0
Total = 22 species	2 381 (18 sp.)	420 (11 sp.)
H′ (Shannon-Wiener Diversity Index)	2.169	1.681
Evenness	0.4862	0.537

Ethical considerations

Permissions and procedures dealing with animal subjects adhered to the wildlife research laws of Kenya and guidelines for use of wild mammal species in research and education (Sikes & The Animal Care Use Committee of the American Society of Mammologists 2016). Permit application was reviewed and approved by the Research and Ethics Committee of the Kenya Wildlife Service (permit number: KWS-0001-01-21).

Results

Western Barn Owl dietary composition

A total of 4 508 individuals representing 50 species were identified from all sites in NUE and TENP localities. These were derived from a total of 795 pellets and disintegrated pellets. The 371 pellets collected from Ondiri Swamp and disintegrated pellets from Muthangari-2005 yielded 3 018 individuals of 32 species, while 424 pellets from TENP yielded 1 490 individuals representing 31 species (Appendix 1).

Prey items were classified into five broad taxonomic units: small mammals, birds, reptiles, amphibians and invertebrates. Based on F%, small mammals, particularly rodents, were the principal food source in Western Barn Owl diets at both study localities, constituting 78% (17 species) in NUE and 85.8% (12 species) in TENP. In NUE, birds comprised 17.7% (8 species) while 4.2% (2 species) of amphibians were detected. Invertebrates and reptiles each recorded negligible proportions (1 species) of prey items consumed in NUE. Invertebrates were the second most important major taxonomic group in the Western Barn Owl diet of TENP, with F% = 10.5% (3 species) followed by birds 3.7% (12 species) and amphibians 0.3% (3 species) while reptiles recorded 0.1% (1 species) (Appendix 1).

The range of variability in prey taxa consumed by Barn Owl in NUE and TENP was significantly different (ANOVA F = 2.357, df (1, 48), P = 0.02). Consequently, the actual diets differed significantly ($\chi^2_=$ 3161.3, df = 1, P = 0). Levin's food niche breadth of the resource categories consumed by owls revealed a broader niche breadth (FNB = 0.373) in the NUE than in TENP (FNB = 0.123) (Appendix 1)

Comparisons of owl pellets and trapping surveys

A total of 193 individuals consisting of 11 small mammal taxa (rodents and shrews) were recorded using traps in the two study localities; 160 individuals representing 7 taxa from two sites in NUE and 33 individuals representing six taxa from two habitats in TENP (Figure 2). Based on the traps employed and the need for accurate comparisons of taxa across sites and localities, we excluded chiropterans (bats), which were present in pellets. When the two sampling methods were combined (pellets and trapping), this yielded a total of 18 small mammal taxa at both localities for the 2020–2021 samples, with the 2005 Muthangari pellets included. The diversity of small mammals in owl pellets was significantly higher than in traps. All mammal species captured in traps were also identified in the pellet samples. More small mammal species (16 species) were recorded at NUE than at TENP (7 species) based on the two combined sampling methods (Table 2).

In the NUE, *Lophuromys* sp. occurred more frequently in trapping samples (37.5% Table 2), but *Rattus rattus* was more frequently consumed by Western Barn Owl (17.0%, Table 2). *Crocidura* sp. was the dominant prey for TENP Western Barn Owl diet (50.7%) contrasting with a higher frequency of *Gerbilliscus* sp. in trapping samples (42.4%). Diversity indices show higher diversity of small mammals in pellets (H′ = 2.29, 1.47) than trapping (H′ = 1.63, 1.27) in NUE and TENP, respectively. A chi-square test confirmed significant difference between prey species in pellets versus taxa recorded in trapping surveys at different habitats in NUE ($\chi^2 = 460$, df = 1, P = 0) and TENP ($\chi^2 = 200.9$ df = 1, P = 0).

Small mammal dynamics-change through time

Analysis of the 2005 disintegrated pellet sample from Muthangari revealed 2 220 individuals representing 19 species. Small mammals (10 species) were the principal prey, comprising 70.6% of MNI (1565 individuals). The remaining specimens were birds (527 individuals of 7 species) and amphibians (128 individuals of 2 species) (Appendix 2). Note that traps used in 2020–2021 were only suitable for capturing rodents and shrews, thus limiting taxonomic comparisons.

The relative frequency of each small mammal species differed significantly between pellets collected in 2005 and trapping in 2020–2021, although the 15 years separating the collection of Muthangari owl pellets from the time of trapping results likely affects species representation and abundance in these two samples.

Trapping of small mammals at Muthangari yielded 5 small mammal species – 4 species of rodent (21 individuals) and 1 species of shrew. Three (3) small mammal taxa identified in the pellets (*Otomys* sp., *Tachyoryctes* sp. and *Crocidura olivieri*), were not captured by trapping (Figure 3). However, we recorded *Tachyoryctes* sp. through direct observation of a living specimen, suggesting that our traps were not appropriate to capture this species and maybe many others.

Small mammal species richness and relative abundance

We combined data for the pellet and trapping samples from 2005 and 2020–2021 to obtain an overview of small mammal biodiversity represented in the two regions (Table 3). For all pellet samples combined, a total of 2 801 individuals representing 22 small mammal species were recorded in NUE (Ondiri plus Muthangari) and four sites in TENP. With the two sampling methods (trapping and pellets) combined for 2020–2021, the total is 2 381 individuals representing 18 small mammal species in NUE and 420 individuals representing 11 small mammal species in TENP (Table 3). The Shannon-Wiener biodiversity index shows a higher diversity of small mammals in NUE (H′ = 2.169 evenness = 0.4862) compared with TENP (H′ = 1.681, evenness = 0.537).

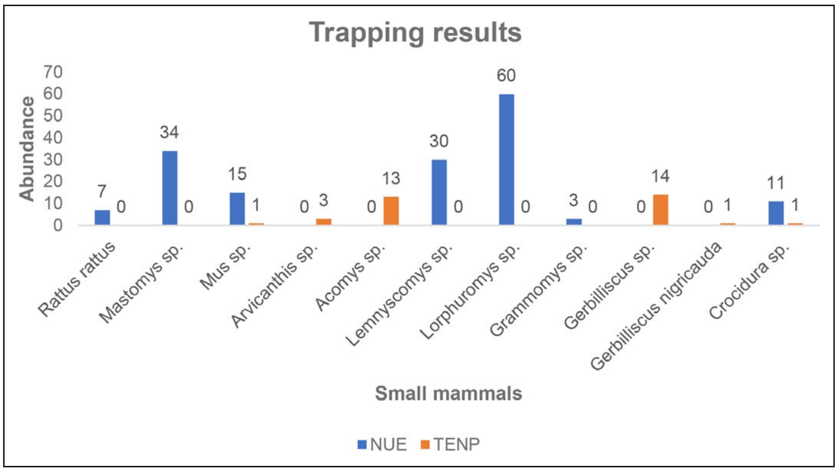

Figure 2. Small mammal trapping survey from Nairobi Urban Environment and Tsavo East National Park shown as abundance for each taxon captured.

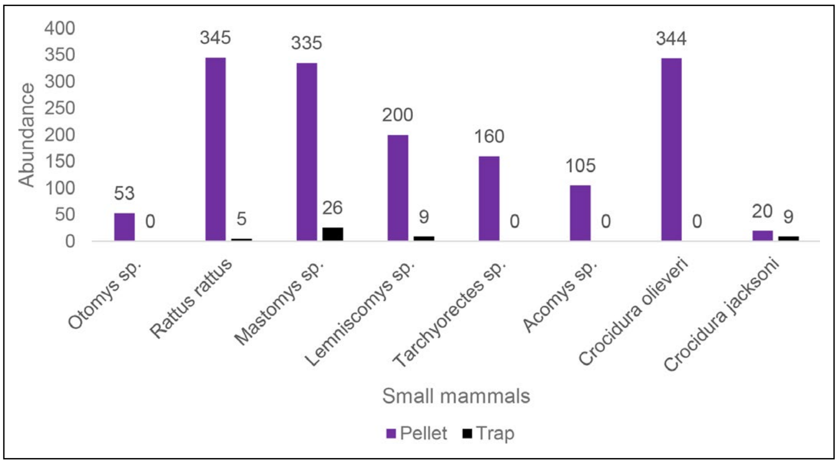

Figure 3. Comparisons of small mammals identified from Muthangari 2005 pellets versus 2020–2021 trapping survey.

Discussion

Western Barn Owl diet composition

Barn Owl diet has been extensively studied worldwide. However, it is still unclear if these owls normally consume prey in relation to abundance or preference (Fernández-Jalvo et al. 2016). Based on pellets from NUE and TENP, it is apparent that owls consumed a wide variety of small taxa in four vertebrate classes (mammals, birds, reptiles and amphibians) and also invertebrates. Small mammals were the principal vertebrate prey across the two study localities (Appendix 1). Our findings are comparable with others that have reported small mammals as the dominant prey group in Western Barn Owl diets (Milchev 2015; Horváth et al. 2018). Other prey items such as birds, invertebrates and amphibians are taken opportunistically in low numbers (Nadeem et al. 2012). Few bats were eaten at either location, which suggests greater difficulties in capturing bats compared to other mammalian prey, or low preference for them as prey. A similar study reported no bats in Western Barn Owl diet (Moysi et al. 2018). Consumption of bats by Western Barn Owls in both of our study areas suggests opportunistic feeding. Obuch et al. (2016) reported that Western Barn Owls' prey on chiropterans when they are abundant or easy to catch.

Birds were the second most preferred prey group in NUE. In contrast, TENP Western Barn Owls consumed more invertebrates as their second prey group. Greater consumption of birds suggests that Western Barn Owls may resort to eating birds to complement their food preference when small mammal populations are relatively low. Another study also concluded that Western Barn Owls may take a smaller share of birds when populations of small mammals increase (Ali & Santhanakrishnan 2012). Likewise, consumption of greater proportion of invertebrates for TENP Western Barn Owls explains their abundance as food resource when rodent populations fluctuate (Dickman et al. 2011).

A smaller proportion of invertebrates was recorded in the diet of NUE Western Barn Owls in contrast to TENP, similar to findings in Uganda urban landscapes (Kityo 2001). Research conducted in relatively humid areas as well recorded a small proportion of invertebrates in Western Barn Owl diet (Moysi et al. 2018). Our results differ from a previous study in the Nairobi suburbs near our study area, which reported a significantly higher consumption of amphibians by Western Barn Owls and lower numbers of shrews (Gichuki 1987). A broader food niche breadth was detected in NUE than in TENP, associated with high species richness. This is consistent with another study in urban landscapes (Milana et al. 2016), which reported high small mammals species richness.

The ability to utilise a broad prey base, via an opportunistic feeding strategy, enables the Western Barn Owl to be a successful predator across a wide distribution range, and this also allows them to occupy a variety of habitats/territories despite declining populations of their main prey species (Tores et al. 2005). The behavioural plasticity of Western Barn Owls enables them to maintain their fitness via a strategy that balances energy gained over energy disbursed during foraging (Elder 2022).

Western Barn Owl feeding habits are strongly affected by the abundance and distributions of prey in any given region (Fernández-Jalvo 2016). Western Barn Owls thus are bio-indicators of habitat stability and ecosystem health and can provide evidence for changing environmental conditions. However, it is important to keep in mind that other variables may affect the prey evidence in pellets, such as owl preference for foraging habitat and prey size, and possibly competition with sympatric owl species (Wiens et al. 2014). If Western Barn Owls take prey in terms of preference, this may lead to underestimating overall taxonomic composition of an ecosystem based on data from pellets (Hindmarch & Elliott 2015). Furthermore, Western Barn Owl diets vary considerably among regions, seasons and time of year. In our 2020–2021 surveys, seasonal data were not adequately captured due to unpredictable weather conditions. Future research should focus on seasonal and long-term monitoring of prey dynamics to clarify the seasonal and spatial foraging traits of the Western Barn Owls and other sympatric owl species within the two study locations.

Comparisons of owl pellets and trapping surveys

The comparison between trapping and pellet sampling methods revealed significant differences in small mammal species composition. Owl pellets are confirmed as an informative method for sampling small mammals, recording a higher diversity of prey than trapping surveys. This concurs with other studies that have reported owl pellets to be a more efficient and informative sampling tool than traditional live-trapping, due to lower effort and fewer species-specific sampling biases (Torre et al. 2015), although expertise in bone identification is also required. Relying solely on traditional live-trapping would have led to a misrepresentation of the small mammal composition and taxonomic diversity at each of our localities. Conversely, Western Barn Owls may preferentially target certain prey species, resulting in biases in documenting small mammal composition in a given ecological region (Janžekovič & Klenovšek 2020). Therefore, combined sampling strategies along with long-term monitoring with owl pellets are needed to improve the accuracy of biodiversity monitoring of small vertebrate communities.

We confirmed that species predominantly documented by trapping in the NUE were not frequently preyed upon by the Western Barn Owls in the same area. For instance, *Lophuromys* sp. was the most abundant prey in trapping samples, but Western Barn Owls preyed more on *Rattus rattus*. Though infrequently recorded in pellets, the consumption of *Lophuromys* sp. and other diurnal prey species suggests that Western Barn Owls may sometimes hunt during the day. Changing activity patterns and diurnal hunting may indicate that the Western Barn Owls are struggling to get enough food. Western Barn Owls are mostly nocturnal, but in some cases, they adapt to daytime activity to improve fitness (Palmstrøm 2024). Factors such as human proximity, changing climate (e.g., precipitation patterns) and brooding behaviour can influence Western Barn Owl diurnal feeding (Elder 2022; Glåmseter 2021).

Prey selection for TENP Barn owl appeared to have been influenced by abundance and/or ease of capture. For instance, *Gerbilliscus* sp. was frequent prey and likewise predominated in the trap captures. *Gerbilliscus* sp. is a dry land and nocturnal species, and its high frequency in the TENP Western Barn Owl diet was expected. Western Barn Owl food selection in both study localities appears to be highly correlated with habitat structure (Séchaud et al. 2021). These inferences for TENP and NUE are also supported by a similar study (Horváth et al. 2018), which documented that diet composition and food-niche breadth of the Western Barn Owl may differ depending on habitat structure.

Low frequency of some species in traps might result from biases in the bait, or because some small mammals may be trap shy, avoiding traps altogether (Byers et al. 2019). The traps we used might be the cause of low shrew captures. Furthermore, trapping in the Nairobi and Tsavo localities occurred only for a few days, whereas the owl pellets accumulated over many seasons and covered a larger area sampled for small mammals and other taxa by the owls. Prey remains logically should reflect wider spatial and temporal patterns of species abundance than seasonal trapping efforts from a relatively small area of the owl's hunting range. Our study demonstrates that owl pellets and trapping survey can be complementary methods for inventorying small mammals and are most informative if used together. Future research should involve long-term seasonal trapping with additional types of traps, changing of bait and a larger sampling area, all of which likely would expand the small mammal species list.

Evidence of change over time in small mammals

The study of Western Barn Owl diet in NUE reported here (Appendix 1) provides interesting comparisons with a previous study of Western Barn Owls conducted in Nairobi's Karen suburb (Gichuki 1987). The genera *Mus* sp., *Acomys* sp., *Lophuromys* sp. and *Thamnomys* sp. identified in NUE in the present survey were not reported by Gichuki (1987). Further, the genera *Pelomys* sp., *Dasymys* sp. and *Gerbilliscus* sp. (formally *Tatera* sp.) previously identified in Western Barn Owl diet in Nairobi (Gichuki 1987) were not identified in our study. Also of note are the larger numbers of amphibians documented in Gichuki's pellet samples. Since diet composition for Western Barn Owls is shaped by prey availability, habitat type and hunting techniques (Ali & Santhanakrishnan 2012), diet variation between 1987 and 2021 are likely due to differences in foraging habitats and environmental change over 33 years and could also be affected by microhabitat variation in the two sites, which are 10 km apart.

Comparisons of the 2005 Western Barn Owl pellets collected from Muthangari Estate and the 2020–2021 trapping, revealed discrepancies in small mammals in the older pellet sample compared with the trapping survey (Figure 3). These comparisons tested whether small mammal species preyed upon by Western Barn Owls in 2005 still occur after 15 years in the same habitat. This period should be long enough to detect significant change or stasis in small mammal communities with respect to environmental or habitat shifts (Balčiauskas & Balčiauskienė 2021). Species such as *Otomys* sp., *Tachyoryctes* sp. and *Crocidura olivieri* were not detected in the trapping survey. However, we detected *Tachyoryctes* sp. through physical observation, evidence that the traps were unable to sample some species. The absence of *Otomys* sp. and *Crocidura olivieri* in the traps could be due to trapping biases, or as a result of their actual disappearance from the sampled areas. If this indicates disappearance, our results are consistent with a long-term study that concluded some species termed 'urban avoiders' disappear along with urbanisation (Patankar et al. 2021). The 2005 Muthangari pellets revealed *Rattus rattus* to be the most frequent species preyed upon by the Western Barn Owl, while the 2021 trapping survey revealed *Mastomys* sp. as the most common taxon (Figure 3). These taxa are closely associated with human habitation because of their adaptability to different environments provided by man.

Land-use changes in urban landscapes are considered the key drivers of biodiversity change through impacts on species distribution, especially at local scales (Simkin et al. 2022). Previous studies have documented a decline in community biodiversity (number of taxa) with increased abundance of common synanthropic species in human disturbed habitats (Torre et al. 2015). Anthropogenic activities favour certain species to increase in abundance, while at the same time species richness is expected to decrease, with urbanisation also making way for non-native species (Storch et al. 2022).

The collection of pellets at Muthangari pre-dated the trapping survey by 15 years and biases associated with the two different sampling methods deter precise inferences regarding changes of small mammal species richness and relative abundance over time. Lack of owl nests during the 2021 survey and low numbers of small mammals in traps suggests human impact and a need for long-term monitoring to be conducted in the same area, including landscape modelling, more intensive search for Western Barn Owl nests, and comprehensive seasonal trapping surveys using different kinds of traps and baits.

Small mammal species richness and relative abundance

Our results documented a higher species richness and diversity of small mammals in the NUE than in the TENP using two sampling methods and including the 2005 Muthangari sample (Table 3). We infer that Western Barn Owls in Tsavo consumed more from non-mammal prey categories due to low availability of small mammal prey. Carmona and Rivadeneira (2006) reported a study in one of the arid regions with low small mammal diversity as being connected with the extreme dry spells and low primary productivity in the ecosystem, limiting the abundance and species richness of Western Barn Owls' preferred prey. A similar study documented that those owls occurring in unproductive, hot and dry parts of the globe tend to rely less on small mammals, while those from moist temperate zones tend to specialise on them (Taylor 2003) . However, the TENP Western Barn Owl diet did include over 85.8% small mammals, suggesting greater dependence on these taxa at local scales.

The Western Barn Owl is normally considered to be an opportunistic predator (Moysi et al. 2018), therefore, we infer that most if not all of the variation of prey species in the diet between the NUE and TENP pellet samples likely reveals environmental conditions rather than hunting preferences.

Conclusion

Our study indicates that the opportunistic predation method of Western Barn Owls enables them to survive in highly anthropogenic urban centres and adapt to changing climatic conditions in the tropical regions of Africa. Their diet of small mammals differed significantly with differing habitat structure at the two study localities. Owl pellets, therefore, provided a representative measure of local small mammal communities and can be used to track changes in ecosystem health along with simultaneous trapping surveys. Relying solely on traditional trapping survey could have led to a misrepresentation of the small mammal composition and taxonomic diversity at local scales. The 2005 Muthangari pellet data suggests species change over 15 years, but this could not be confirmed at the same site because only trapping data are available for 2020–2021 (no pellets).

Future research will focus on regular collection of pellets to assess the seasonal and inter-annual dietary shifts and conduct landscape mapping to investigate the extent of owl foraging areas and factors leading to owl survival in relation to environmental changes.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

NG and EM (Department of Biology, University of Nairobi) were responsible for experimental and project design. AKB (Department of Paleo-biology, Smithsonian National Museum of Natural History) provided research funds and assisted with research design, FM (Department of Sites and Monuments, National Museums of Kenya) provided 2005 pellets for the study, OM and VO (Department of Zoology National Museums of Kenya) collected the 2020–2021 data, and all the authors contributed to developing and refining the manuscript.

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Appendices

Appendix 1. Western Barn Owl diet composition based on pellet analysis from all sites in Nairobi Urban Environment (NUE) and Tsavo East National Park (TENP), Kenya (MNI – Minimum Number of individuals and F%)

Groups	Family or Order	Species	(NUE) Nairobi		(TENP) Tsavo	
			MNI	F%	MNI	F%
Mammals	Hipposideridae	*Hipposideros* sp.	2	0.1	0	0
	Megadermatidae	*Cardioderma cor*	2	0.1	7	0.5
	Molossidae	*Tadarida lobata*	0	0	2	0.1
	Muridae	*Acomys* sp.	147	4.8	12	0.8
		Arvicanthis sp.	3	0.1	115	7.7
		Dendromus sp.	42	1.4	548	36.8
		Gerbilliscus nigricaudus	0	0	1	0.07
		Gerbilliscus sp.	0	0	82	5.5
		Grammomys sp.	2	0.1	0	0
		Lemniscomys sp.	235	7.8	0	0
		Lophuromys sp.	69	2.3	0	0
		Mastomys sp.	384	12.7	53	3.6
		Mus sp.	188	6.2	76	5.1
		Oenomys sp.	1	0	0	0
		Otomys sp.	151	5	0	0
		Rattus rattus	399	13.2	0	0
		Rhabdomys sp.	4	0.1	16	1.1
		Tachyoryctes sp.	165	5.5	0	0
		Thamnomys sp.	9	0.3	0	0
	Nycteridae	*Nycteris thebaica*	0	0	1	0.1
	Soricidae	*Crocidura olivieri*	344	11.4	0	0
		Crocidura sp.	207	6.9	364	24.4
Birds	Acrocephalidae	*Acrocephalus griseldis*	0	0	1	0.1
	Alaudidae	*Mirafra* sp.	0	0	8	0.5
	Apodidae	*Apus caffer*	0	0	1	0.1
	Coliidae	*Colius striatus*	86	2.8	4	0.3
	Columbidae	*Columba larvata*	0	0	6	0.4
		Oena capensis	0	0	1	0.1
	Cuculidae	*Cuculus solitarius*	9	0.3	0	0
	Estrildidae	*Mandingoa nitidula*	210	7	0	0
	Fringillidae	*Crithagra mozambica*	0	0	1	0.1
		Crithagra striolata	118	3.9	0	0
	Laniidae	*Eurocephalus anguitimens*	76	2.5	0	0
	Leiothrichidae	*Turdoides hypoleuca*	29	1	0	0
	Muscicapidae	*Muscicapa* sp.	0	0	1	0.1

Groups	Family or Order	Species	(NUE) Nairobi		(TENP) Tsavo	
			MNI	**F%**	**MNI**	F%
	Nectariniidae	*Cyanomitra olivacea*	1	0	0	0
	Passeridae	*Pseudonigrita arnaudi*	2	0.1	0	0
		Plocepasser mahali	0	0	4	0.4
	Ploceidae	*Ploceus castaneiceps*	0	0	3	0.2
	Pycnonotidae	*Phyllastrephus terrestris*	1	0	0	0
		Pycnonotus sp.	2	0.1	14	0.9
	Turdidae	*Turdus* sp.	0	0	7	0.5
Reptiles	Lacertidae	*Adolfus jacksoni*	1	0	1	0.1
Amphibians	Hyperoliidae	*Hyperolius sheldricki*	0	0	1	0.1
	Pipidae	*Xenopus laevis*	127	4.2	0	0
	Pyxicephalidae	*Pyxicephalus edulis*	0	0	2	0.1
	Rhacophoridae	*Chiromantis petersii*	1	0	1	0.1
Invertebrates	Coleoptera		0	0	15	1
	Decapoda		0	0	76	5.1
	Orthoptera		1	0	66	4.4
Total		**50 taxa**	**3 018**	**100**	**1490**	**100**
			***FNB* = 0.373**		***FNB* = 0.123**	

Appendix 2. Western Barn Owl diet composition based on pellet analysis from pellets collected at Muthangari in 2005

Group	Species	MNI	F%
Mammals	*Acomys* sp.	105	4.73
	Cardioderma cor	1	0.05
	Crocidura jacksoni	20	0.9
	Crocidura olivieri	344	15.5
	Hipposideros sp.	2	0.09
	Lemniscomys sp.	200	9.01
	Mastomys sp.	335	15.09
	Otomys sp.	53	2.43
	Rattus rattus	345	15.54
Birds	*Tachyoryctes* sp.	160	7.21
	Colius striatus	85	3.83
	Crithagra striolata	118	5.32
	Cuculus solitarius	9	0.41
	Cyanomitra olivacea	1	0.05
	Eurocephalus anguitimens	76	3.42
	Mandingoa nitidula	209	9.41
	Turdoides hypoleuca	29	1.31
Amphibians	*Chiromantis petersii*	1	0.05
	Xenopus laevis	127	5.72
Total	**19 Species**	**2 220**	**100.07**

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Collaborating for conservation: the first five years of implementation of the Biodiversity Management Plan for Pickersgill's Reed Frog, *Hyperolius pickersgilli*

Authors

[1,2]Adrian J. Armstrong, [3]Ian du Plessis, [3]Piet Lesiba Malepa, [4,5]Antoinette Kotze, [1]Felicity Elliott, [1]Sharon L. Louw, [6]Cherise Acker-Cooper, [6,7,8]Lauren Waller, [6,9,10]Jeanne Tarrant

Affiliations

[1]Scientific Services, Ezemvelo KZN Wildlife, P.O. Box 13053, Cascades 3202, Pietermaritzburg, South Africa.
[2]Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa.
[3]Johannesburg City Parks and Zoo, Johannesburg Zoo, Jan Smuts Ave, Parkview, Randburg, Johannesburg 2122, South Africa.
[4]Department of Genetics, University of the Free State, P.O. Box 339, Bloemfontein 9300, South Africa.
[5]South African National Biodiversity Institute, P.O. Box 754, Pretoria 0001, South Africa.
[6]Endangered Wildlife Trust, 27 & 28 Austin Road, Glen Austin AH, Midrand, 1685, South Africa.
[7]Department of Biodiversity & Conservation Biology, University of the Western Cape.
[8]IUCN SSC Conservation Planning Specialist Group, c/o Auckland Zoo, 12101 Johnny Cake Ridge Road, Apple Valley, MN 55124, USA.
[9]Anura Africa NPC, 34 Springside Road, Hillcrest, 3610, Durban, South Africa.
[10]Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa.

Corresponding Author

Adrian J. Armstrong; Adrian.Armstrong@kznwildlife.com

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A Biodiversity Management Plan for Species (BMP-S) is a legislated plan provided for by the South African National Environmental Management: Biodiversity Act, 2004 (Act no. 10 of 2004). The aim of such plans is the long-term survival of a species in the wild through co-ordinated implementation of actions by entities and organisations to meet the objectives and goals of the plan. This paper reports on the strengths and weaknesses of the BMP for Pickersgill's reed frog, *Hyperolius pickersgilli*, as ascertained by implementers of the plan at the end of the first five-year period. The plan must be revised after that period, and the Opportunities and Threats potentially facing the next iteration are also presented. The first five years of implementation has resulted in many achievements, which would not be possible without the strong collaboration between organisations that was afforded by the plan, as well as the dedication of individuals within those organisations. The development and implementation of this plan is an example of how species conservation planning can assist to focus and co-ordinate contributions of a variety of stakeholders to successfully guide conservation action for a threatened species, in turn benefitting the habitat of the species and co-occurring species. By this paper, we hope to encourage stakeholders working to improve the conservation status of other threatened species to consider the development and implementation of BMPs to achieve co-ordinated actions.

Keywords: threatened amphibian, SWOT analysis, conservation planning, species recovery, inclusive participation.

Introduction

Preventing species extinctions and ensuring the recovery and conservation of species is included in Target 4 of The Biodiversity Plan for Life of the Earth (now known as the Kunming–Montreal Global Biodiversity Framework) of the Convention on Biological Diversity (2022). Achieving this is difficult, with increasing proportions of threatened species and future extinctions likely, especially with respect to Class Amphibia (González-del-Pliego et al. 2019; Grant, Miller & Muths 2020; Luedtke et al. 2023). Forty-one per cent of amphibian species are currently considered at risk of extinction according to the second Global Amphibian Assessment (GAA2; Luedtke et al. 2023), with an even higher proportion experiencing significant population declines. The main factor causing amphibian declines globally is habitat modification (Green et al. 2020; Harfoot et al. 2021; Luedtke et al. 2023), which exacerbates the impact of other threats including pollution (Hayes et al. 2010; Boyero et al. 2020), disease (Fisher & Garner 2020), climate change (Li, Cohen & Rohr 2013), invasive species (Falaschi et al. 2020) and exploitation through trade (Warkentin et al. 2009; Hughes, Marshall & Strine 2021). Many amphibian species have limited distribution ranges and high habitat specificity, making them particularly prone to extinction risks (Sodhi et al. 2008).

Pickersgill's reed frog, *Hyperolius pickersgilli* Raw (1982), is a habitat specialist endemic to a narrow coastal strip in KwaZulu-Natal, South Africa (Figure 1). It is a small (body length ≤ 29 mm) hyperoliid reed frog with variable colouration (Raw 1982; Figure 2). The behaviour and call of this species are cryptic, and it is often overlooked in the presence of other larger-bodied and louder hyperoliids. The Red List status of *H. pickersgilli* is Endangered (IUCN SSC Amphibian Specialist Group & SA-FRoG 2016), having previously been listed as Critically Endangered in 2010, because of its limited extent of occurrence (4768 km²), small area of occupancy (12 km²), the severe fragmentation of its habitat, the continuing decline in its area of occupancy, and the extent and quality of its habitat. The main threats to the survival of this species are habitat loss due to urbanisation, sylviculture,

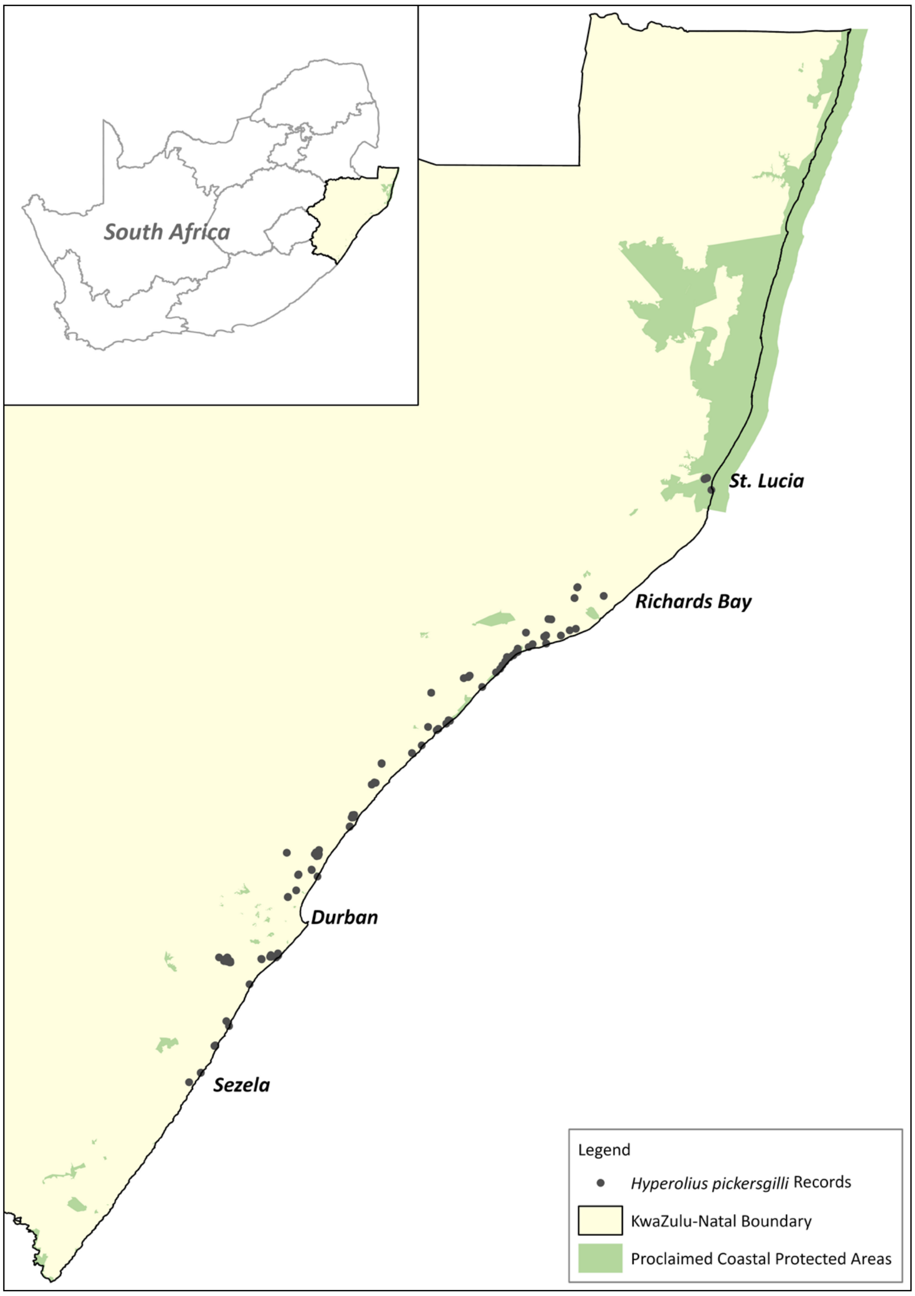


Figure 1. Occurrence records of Pickersgill's Reed Frog, *Hyperolius pickersgilli*, as of 14 July 2023 indicating its coastal distribution.

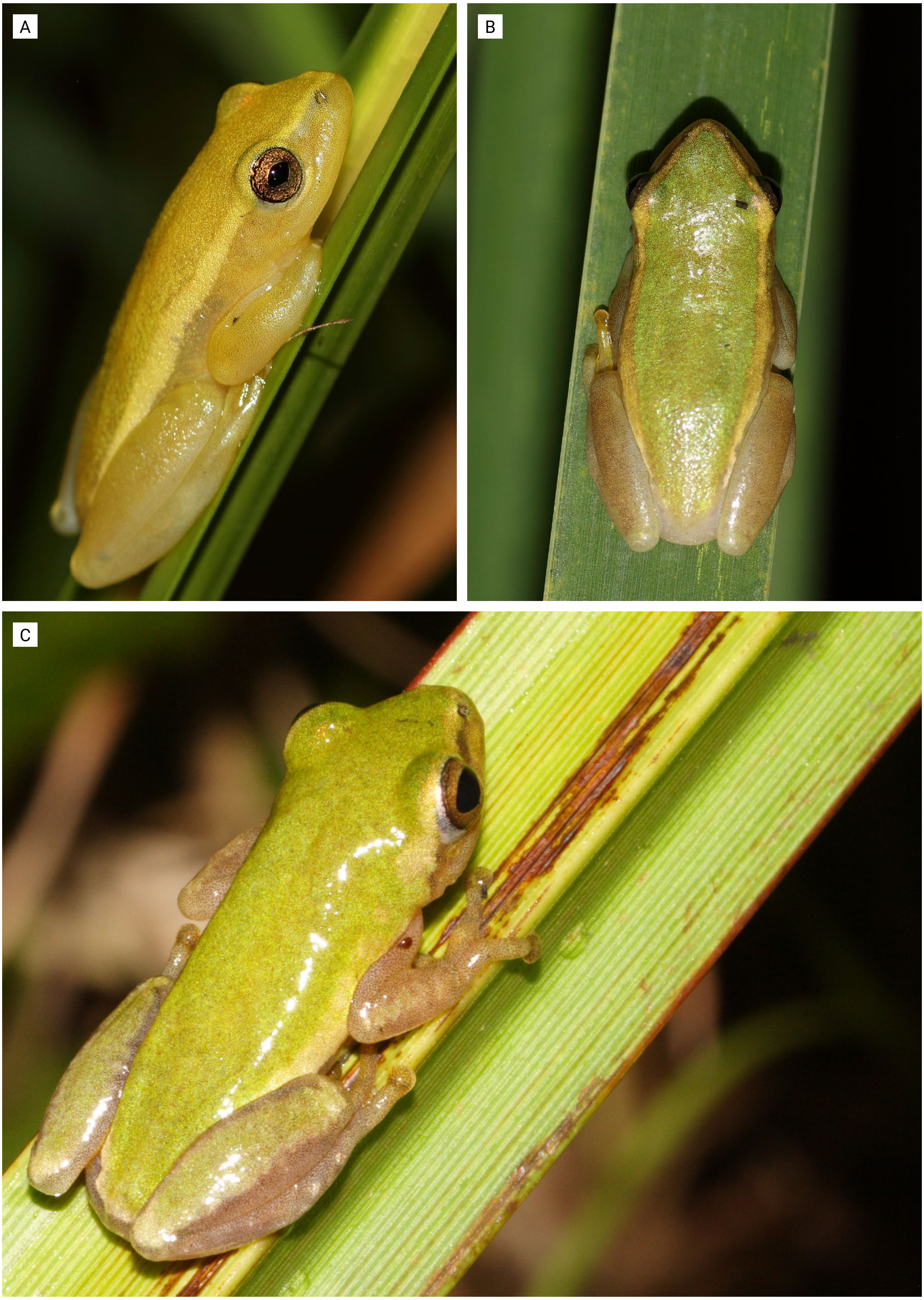


Figure 2. Pickersgill's reed frog, *Hyperolius pickersgilli*, adult males showing colour variations (A, B) and adult female (C). Photographs: A.J. Armstrong.

dune mining, large-scale industrial development, drainage of wetlands for agricultural and urban development, and degradation of habitat by alien invasive plants (Minter et al. 2004). Large extents of natural habitat in the species' range have been transformed (Jewitt 2018), and the species no longer occurs at its type locality (Avoca; Raw 1982; Tarrant & Armstrong 2017). A study by Tarrant and Armstrong (2013) indicated that at least four wetland sites known to have hosted *H. pickersgilli* previously no longer had extant populations, and 44.6% of the wetlands visited where the species was predicted to occur had been either degraded (14.1 %) or transformed (29.5%). While population estimates have been conducted for two subpopulations using audio transects (Bowman 2011; Trenor 2015), the overall population size of *H. pickersgilli* remains unknown. Given these threats and the perceived declining population, a conservation action plan for the species was recommended following the 2010 assessment of *H. pickersgilli* as Critically Endangered (Measey 2011). The species was prioritised for conservation research, including monitoring, and was the first threatened frog species in South Africa to be used in a captive breeding programme (Measey 2011).

Strategic conservation planning is critical for ensuring positive outcomes for species. Participatory planning guides effective, collaborative conservation actions, and is supported through the IUCN Species Survival Commission's (IUCN SSC) Conservation Planning Specialist Group (CPSG). A review of conservation action plans from 23 countries found that for the 35 species assessed, threatened species declines gradually slowed, and then reversed, with an upward trend of recovery within 15 years (Lees et al. 2021). No species became extinct and projected outcomes would have been worse without the planning intervention. In South Africa, Biodiversity Management Plans for Species (BMP-S) are formal mechanisms supported by government recognition and approval, normally targeted at threatened species where threat mitigation requires commitment by multiple stakeholders. Twenty-six of these BMP-S exist under the auspices of the Department of Forestry, Fisheries and the Environment (DFFE; Humbu Mafumo, pers. comm. 14 September 2023). A BMP-S was initially identified as a useful means of coordinating conservation efforts for the then Critically Endangered *H. pickersgilli* in 2009 (Tarrant 2012), with the first official stakeholder meeting held in October 2013. This BMP-S was gazetted in 2017 (Tarrant & Armstrong 2017), with multiple coordinated actions initiated in the interim. With *H. pickersgilli* being a species of conservation importance in KwaZulu-Natal (Armstrong 2001), only two populations were known from formally protected areas at the commencement of the implementation of the BMP. The need to identify, manage and protect remaining breeding *H. pickersgilli* sites was crucial, particularly considering the immense development pressure on the KwaZulu-Natal coast (Jewitt et al. 2015b; Jewitt 2018).

The first iteration of the BMP (2017–2022) for Pickersgill's reed frog (PRF) (*Hyperolius pickersgilli*) has been completed. A BMP-S should be revised every five years, and in preparation for this first revision, our aim here is to consider the strengths and weaknesses and report on progress made against the 16 actions identified for the 2017–2022 iteration of the BMP for *H. pickersgilli*, and to consolidate the achievements of the BMP to date. The Pickersgill's Reed Frog Forum meets annually to track and evaluate BMP actions and report progress and challenges to the Department of Forestry, Fisheries and the Environment. Before meeting to discuss the BMP revision, the Forum, through the chairs, requested that the IUCN SSC Conservation Planning Specialist Group (CPSG) assist in running a workshop with Forum members to complete a Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis for the Biodiversity Management Plan for Pickersgill's reed frog (BMP-PRF) and to review the revised threats table, which had been circulated via email previously to Forum members for their input. The outcomes are reported below.

Methods

A virtual workshop was held with 36 representatives of Pickersgill's Reed Frog Forum (PRFF) members (see Acknowledgements) on 27 October 2023 to conduct the SWOT analysis. Participants were asked to consider matters internal to the Pickersgill's Reed Frog Biodiversity Management Plan, or projects within their control, when determining the strengths of the BMP-PRF. For the weaknesses, the participants were asked to consider internal factors within their control; these might be obstacles, barriers, etc., that obstruct their ability to meet their goals. Regarding opportunities, participants were asked to consider the systemic human and environmental factors that could influence the revised BMP-PRF. These are external factors that the BMP-PRF should (or could) consider, including the: political, economic, social, technological, legislative and environmental domains. Finally, in terms of threats, participants were asked to consider external factors that may negatively impact the next iteration of the BMP-PRF. These are beyond participants' control but are good to be aware of because of the potential risk to successful BMP implementation. These are aspects related to, but not limited to, political, economic, social, technological, legislative and environmental issues. The methods used to produce the various outputs of the implementation of the BMP mentioned below that have not been published in peer-reviewed scientific journals are presented in Supplementary Material 1.

Results and discussion

Figure 3 summarises the results of the SWOT analysis.

Strengths identified for the 2017–2022 BMP-PRF

Establishment of a forum

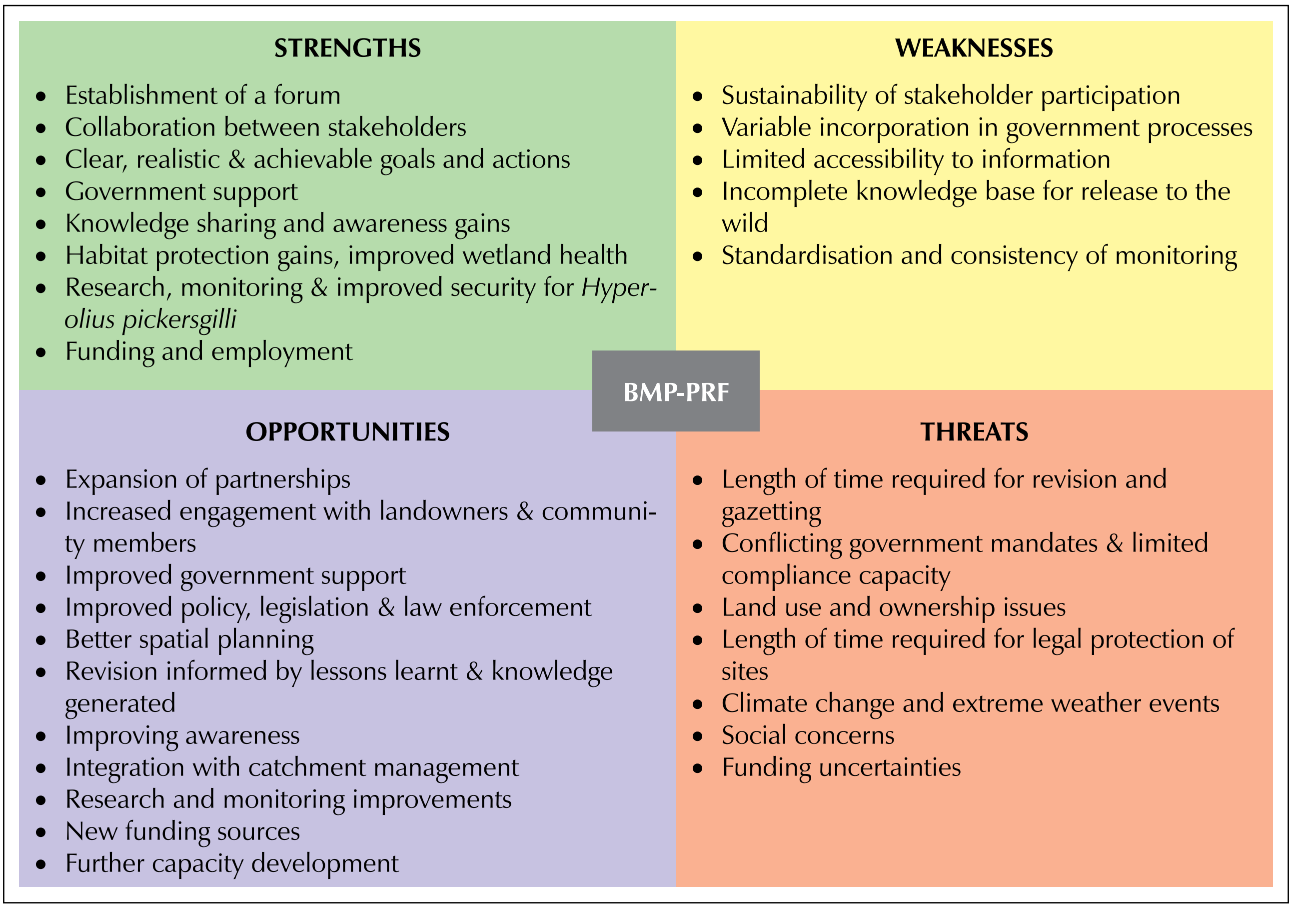
The Pickersgill's Reed Frog Forum (PRFF) was constituted on 20 April 2018 at Twinstreams Environmental Education Centre, Mtunzini, KwaZulu-Natal. Seventeen organisations were represented and each of these member organisations had one or sometimes two representatives. By 2022, the institutional membership had increased to twenty-four, with most members having representatives present at each annual forum meeting (see Acknowledgements).

Collaboration between stakeholders

This was the first and, to date, only example of a BMP for an amphibian species in South Africa. The four-year process to identify and include stakeholders and the collaboration and sharing of resources was identified as being critical to the success of the implementation of the BMP. Strong collaboration was forged between local, provincial and national government entities, land managers, a zoo, private organisations, NGOs, research institutions, universities, as well as with the public. Having consistent organisational champions behind the BMP throughout the 13+ years since the BMP process was proposed has been key to its success. The level of executive support from many organisations made participation in the implementation of the BMP easier. Effective implementation of actions resulted from enthusiastic communication, interaction and collaboration between stakeholders that brought together the required skills and capacity.

Process of developing and implementing the BMP-PRF

The process followed to develop the BMP ensured that the goals and objectives were clear, realistic and achievable. Documentation drafted as annual reports in the implementation of the BMP allowed the progress



STRENGTHS

- Establishment of a forum
- Collaboration between stakeholders
- Clear, realistic & achievable goals and actions
- Government support
- Knowledge sharing and awareness gains
- Habitat protection gains, improved wetland health
- Research, monitoring & improved security for *Hyperolius pickersgilli*
- Funding and employment

WEAKNESSES

- Sustainability of stakeholder participation
- Variable incorporation in government processes
- Limited accessibility to information
- Incomplete knowledge base for release to the wild
- Standardisation and consistency of monitoring

BMP-PRF

OPPORTUNITIES

- Expansion of partnerships
- Increased engagement with landowners & community members
- Improved government support
- Improved policy, legislation & law enforcement
- Better spatial planning
- Revision informed by lessons learnt & knowledge generated
- Improving awareness
- Integration with catchment management
- Research and monitoring improvements
- New funding sources
- Further capacity development

THREATS

- Length of time required for revision and gazetting
- Conflicting government mandates & limited compliance capacity
- Land use and ownership issues
- Length of time required for legal protection of sites
- Climate change and extreme weather events
- Social concerns
- Funding uncertainties

Figure 3. Summary of the results of the analysis of the Strengths and Weaknesses of the first five years of implementation of the Biodiversity Management Plan for Pickersgill's reed frog, *Hyperolius pickersgilli* (BMP-PRF), and of the Opportunities for, and potential Threats to, the revision of this plan (SWOT analysis). Each of the strengths, weaknesses, opportunities and threats are discussed in detail in the following sections.

made to be collated and presented clearly. All identified actions were connected and implemented in relation to five objectives, and led to downstream benefits, e.g., the management of habitat of *H. pickersgilli* and local employment needs. Also, many of the actions identified in the BMP are ongoing (and indeed some commenced before the BMP was gazetted). Actions resulting from the BMP were also implemented by landowners in the context of a variety of land use types and using a diversity of approaches.

Government support

The BMP was gazetted by the then Minster of Environmental Affairs and thus had government support. The BMP enabled government departments (at local, provincial and national levels) that otherwise would not have worked together, to be involved with the implementation of actions. The inclusion of *H. pickersgilli* data into municipal and national spatial planning processes (e.g., municipal spatial development frameworks and the DFFE's Environmental Impact Assessment (EIA) species tracking tool [Department of Forestry, Fisheries and the Environment 2021]) has assisted with protecting *H. pickersgilli* habitat. Municipalities have started to manage or purchase land specifically to protect *H. pickersgilli*. The priority habitat for *H. pickersgilli* falls within one metropolitan area, four district municipalities and four local municipalities (with priorities for inclusion in planning processes shown in Figure 4). Table 1 indicates progress in including priority areas for *H. pickersgilli* in district and local municipal and other governmental planning processes. Potential

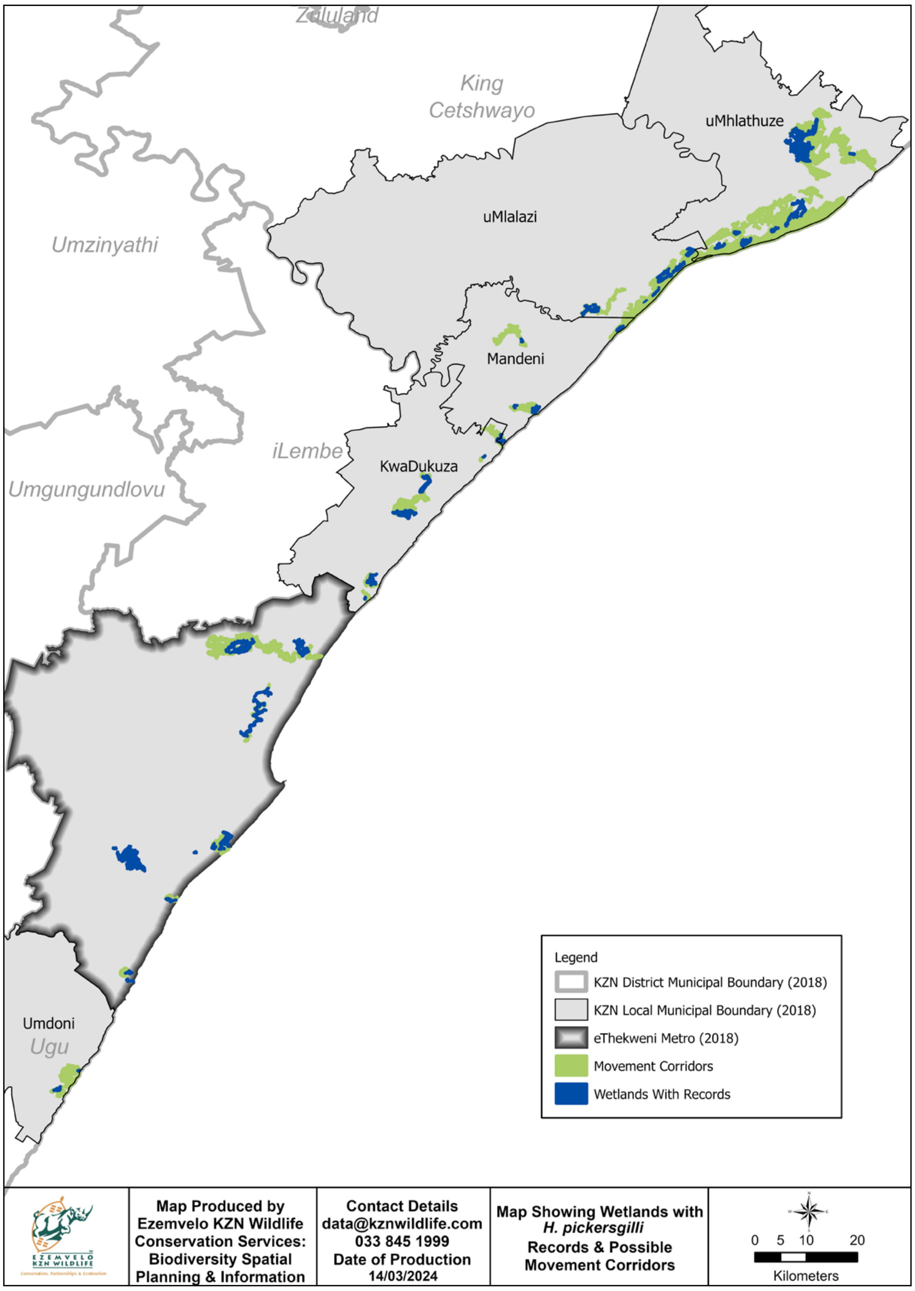


Figure 4. Map of priority habitat for Pickersgill's reed frog, *Hyperolius pickersgilli*, for inclusion in municipal spatial planning tools.

Table 1. Progress in including priority areas for Pickersgill's reed frog, *Hyperolius pickersgilli* (*Hp*), in district (DM) and local (LM) municipal and other governmental planning processes

Municipality or Department	Attribute	Planning tool	Year(s)
King Cetshwayo DM	Wetlands holding *Hp*	Environmental Management Framework	2018
eThekwini Metro	Priority *Hp* areas that are included in the Durban Metropolitan Open Space System	Durban Metropolitan Open Space System coverage; used to inform all spatial planning	2018
KwaDukuza LM	Areas of known and potential (modelled) *Hp* habitat	Biodiversity and Open Space Management Plan, used to inform the Spatial Development Framework and the Integrated Development Plan	2019
uMhlathuze LM	Information on the *Hp* Biodiversity Management Plan	Spatial Development Framework	2020
uMlalazi LM	Wetlands known to contain *Hp*	Spatial Development Framework	2020
National Department of Forestry, Fisheries and the Environment	Localities at which *Hp* occurs; distribution model for *Hp*	Natural Resource Management Programme: Working for Wetlands five-year Strategic Plan; Environmental Impact Assessment Screening Tool	2020
All DMs and LMs within the distribution range of *Hp*	Geographic Information System spatial layers defining the wetland sites where *Hp* has been recorded, potential sites for this species, linkages between such sites, as well as buffers to these areas	Municipal planning systems	2021
iLembe DM, Mandeni LM, King Cetshwayo DM, uMlalazi LM	Priority *Hp* habitat information	Spatial Development Framework documents	2022–2023

corridors between wetlands for *H. pickersgilli* were mapped, totalling 17 140 hectares (Figure 4). The updated predicted distribution map, which includes wetlands and linkages between them that may be suitable for *H. pickersgilli*, is indicated in Figure 5.

Knowledge sharing and awareness gains

Collaboration between PRFF members and stakeholders allowed information gathered to benefit both *H. pickersgilli* habitat management and the broader community. This knowledge sharing contributed to a greater general awareness of the plight of the species and its habitat, and of methods to counter the decline of its population. Increased engagement and exposure through articles, newspapers, televised and social media, etc., has reached people both inside and outside of the conservation sector. Media articles reached local people directly, so land managers were more easily convinced that they needed to protect *H. pickersgilli*. Each year more than 400 000 people visit the Johannesburg Zoo and the public were made aware of the Johannesburg Zoo ARP's biosecure breeding facility and the captive-breeding programme.

Research emanating from the 2017–2023 BMP-PRF has enabled collaborative research, including with local and international universities. Three publications in peer-reviewed scientific literature (Kotze et al. 2019; Measey et al. 2019, Du Plessis et al. 2022b) made information accessible to the scientific community. Other scientific outputs and human capacity development included four Honours projects and two MSc studies. Research findings have been presented at 12 conferences, university lectures and other forums. Four data collection apps were developed and research collaborations with Nature Metrics and EdgeAcoustics were initiated. The Zimbali Estate Management Association supported the development of an in-house frog field guide that includes *H. pickersgilli*.

The Biodiversity Database of Ezemvelo KZN Wildlife holds records for *H. pickersgilli* (increasing from 120 records from 30 localities as of 1 June 2017 to 239 records from 46 localities as of 31 December 2022). Recordings from passive acoustic monitoring (PAM) are maintained in the Endangered Wildlife Trust's Biodiversity Databank. Data on the social aspects of the project and ecological data are also stored by the Endangered Wildlife Trust (EWT) in its Conservation Science Unit. Forty-one *H. pickersgilli* tissue samples and many DNA samples have been banked at the South African National Biodiversity Institute's (SANBI) biobank at the National Zoological Garden, Pretoria.

Habitat protection gains

Three sites qualified for the Protected Environment category through the Biodiversity Stewardship process, potentially increasing the area under formal protection by 633 hectares, should all these sites be declared. A Protected Area Management Plan (PAMP) was drafted for one of these sites (Umgavusa) and approved by landowners and was subsequently declared a Protected Environment. A metropolitan municipality wetland has been rezoned to 'Conservation Reserve' and its rehabilitation agreed to by the municipality. Habitat loss caused by development was mitigated through commenting on development applications at five sites. One site under threat has been bought for conservation.

Improved wetland health

Invasive alien clearing and wetland health monitoring were implemented at four sites in the eThekwini area and three in the iLembe District (Supplementary Material, Table S6). Wetland health assessments conducted over periods of five years indicate that some wetland systems, e.g., at Mt Moreland, have been relatively stable despite flooding events and pollution runoff into the system. Continuous management and monitoring are, however, critical. For example, invasive alien plant (IAP) clearing was discontinued, and this should be consistently implemented. There are positive gains through IAP clearing, e.g., improved hydrology and decreased invasion by IAPs due to increased inundation. Clearing of IAPs is important for

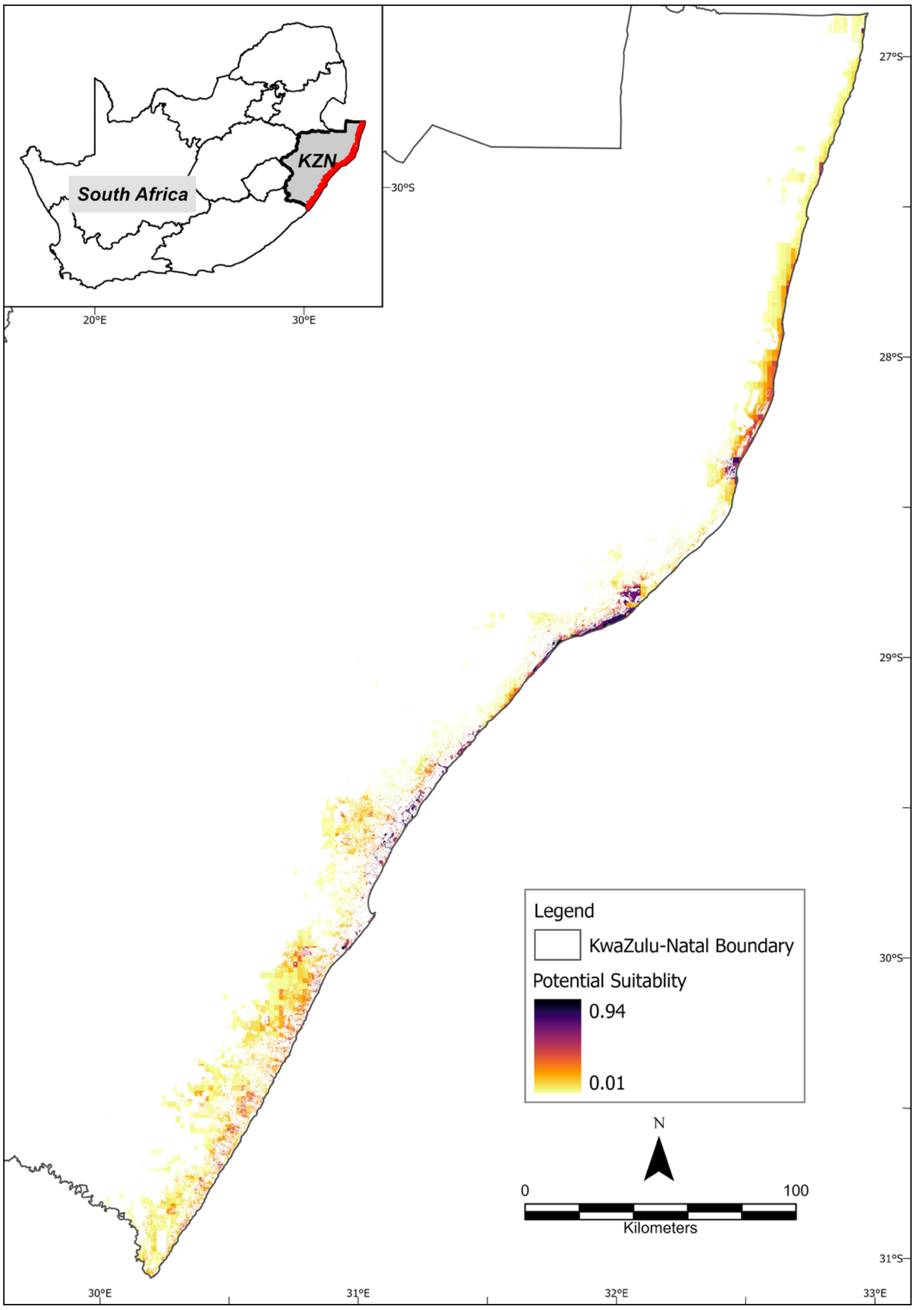


Figure 5. Predicted distribution of Pickersgill's reed frog, *Hyperolius pickersgilli*, in KwaZulu-Natal (KZN). Transformed areas have been removed from the map.

maintaining buffer zones and protection of the core of a given wetland. Monitoring is key to gauging effectiveness of interventions and determining wetland health over time. Gains in wetland health at Adams Rural, Widenham and Gingindlovu through IAP clearing, monitoring and adaptive monitoring are important indicators of the success of the BMP.

Solid waste surveys showed that disposable diapers are a significant waste problem in watercourses at Adam's Rural (Supplementary Material, Table S6). The Adams Rural site is regularly patrolled by EWT's Biodiversity Protection and Environmental Control Officers (BPOs and ECOs), and environmental transgressions are reported. A purpose-developed Environmental Legislation Audit ECO application is used to collect data on transgressions. A workshop was held with 98 traditional leaders from eighteen traditional authorities in KwaZulu-Natal to highlight and explain the importance of environmental legislation and compliance with it.

Controlled harvesting of wetland plants such as *Juncus kraussii* Hochst., *Cyperus latifolius* Poir. and *Phragmites australis* (Cav.) Steud. in the wetlands next to the Mlalazi Estuary at Umlalazi Nature Reserve, Mtunzini, by large numbers of harvesters (approximately 2 000) from various regions of KwaZulu-Natal has occurred 26 times in the period 1988 to 2022 (Supplementary Material, Table S6). The harvesting is managed by controlling access to various sections of the wetlands where *J. kraussii* stands dominate. The monitoring of wetland plant stocks through fixed point photography, resource stock assessment and harvesting off-take records has detected a vegetation shift, with *P. australis* dominating previous monospecific *J. kraussii* stands. This has contributed to the expansion of suitable *H. pickersgilli* habitat in Umlalazi Nature Reserve. The implementation of appropriate management to secure the habitat of *H. pickersgilli* during wetland plant harvesting was successful during the 2022 harvesting event and will continue in the future (Figure 6).

Both Simbithi Eco-Estate and Zimbali Estate have *H. pickersgilli* as a specific management target for the estates' environmental management teams and are good examples of conservation management of *H. pickersgilli* and its habitat within golf and residential estates (Supplementary Material, Table S6). These actions serve not only to benefit *H. pickersgilli*, but also other co-occurring species.

Research, monitoring and improved security for H. pickersgilli

Molecular genetic analysis indicated that *H. pickersgilli* has a single genetic population owing to sufficient gene

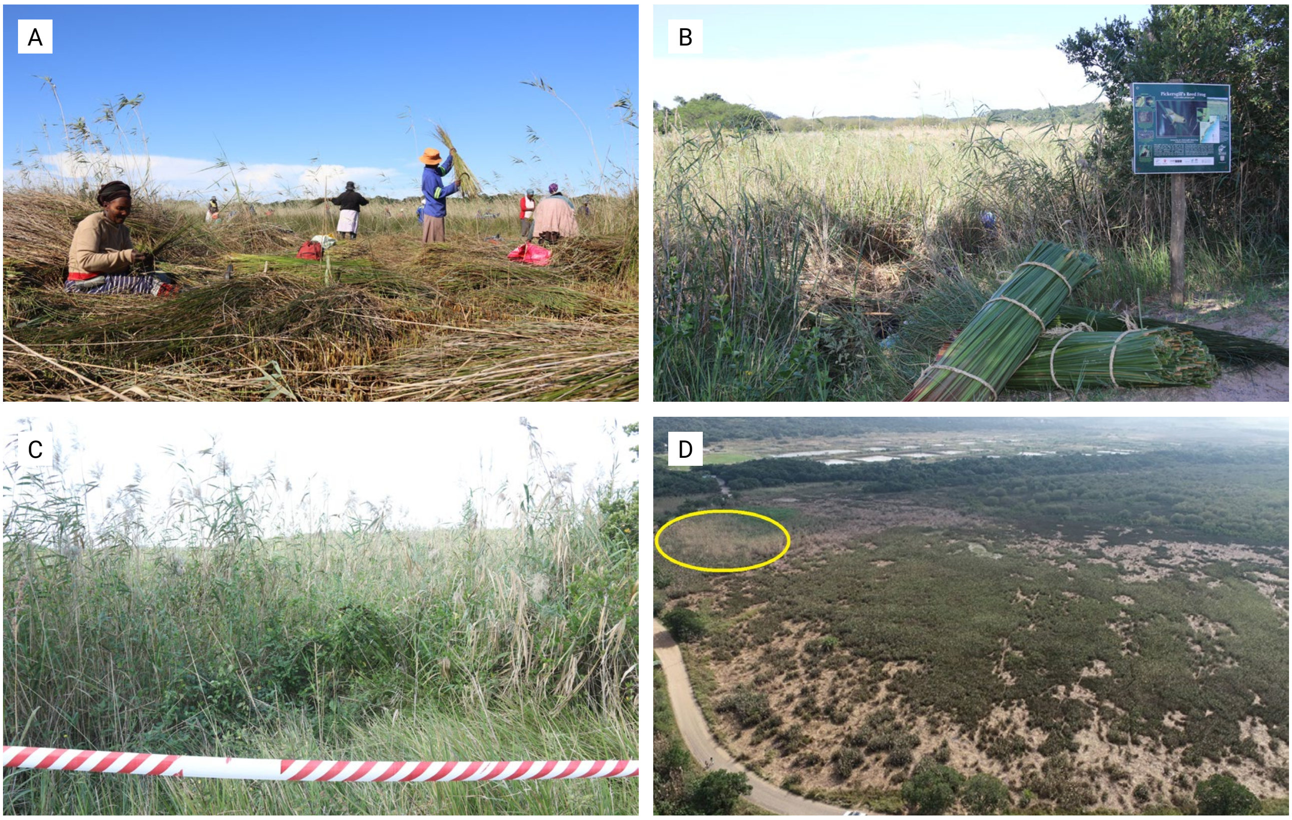


Figure 6. A, harvesters cutting and sorting *Juncus kraussii* in the Umlalazi Nature Reserve wetland; with B, bundles lying next to the Pickersgill's reed frog, *Hyperolius pickersgilli*, information board; C, barrier tape marks the edge of the wetland exclusion plot that protects *Hyperolius pickersgilli* microhabitat in the harvested area; and D, intact vegetation within the *H. pickersgilli* exclusion plot (yellow ellipse) in comparison to harvested areas within the wetland.

flow in the past between localities (Kotze et al. 2019). Genetic markers revealed moderate to high levels of genetic diversity throughout the remnant sites and absence of specific phylogeographic structure among individuals sampled across twelve localities throughout the range of the species (Kotze et al. 2019). Where suitable habitat exists, *H. pickersgilli* in neighbouring areas might connect and spread through dispersal between sites.

Climate change resilience was considered in the conservation importance ranking of existing sites for *H. pickersgilli* in 2019 (Supplementary Table S1). According to the downscaled HadMC2 model and the vulnerability framework, 2.6% of the localities are classified as 'Susceptible' and 97.4% are classified as 'Vulnerable'. This indicates that *H. pickersgilli* may be affected severely by climate change. Management responses, which have already been initiated, should include ex situ conservation, conservation translocations, monitoring of populations, and reduction of other threats to the species (Jewitt et al. 2015a). The scores for variables and the final ranking for each of the 38 wetlands known to have *H. pickersgilli* as of 25 April 2019 are indicated in the Supplementary Table S3. This ranking allows for informed decision-making in terms of where resources should be allocated to ensure the long-term survival of *H. pickersgilli* but does not mean that wetlands known to have *H. pickersgilli* and that are low ranked are unimportant. The provincial ecosystem status of Indian Ocean Coastal Belt Wetland habitat in which *H. pickersgilli* occurs is Critically Endangered (Jewitt 2018). All remaining habitat for this species should be protected in perpetuity to achieve the goal of having the species downlisted to Least Concern in accordance with the IUCN Red List process.

The use of acoustic technology for monitoring and research improved BMP action implementation. Monitoring was important for informing adaptive management. During the five-year period, a total of 870 hectares of habitat for *H. pickersgilli* was under observation through various project activities. Monitoring and surveillance of *H. pickersgilli* has been implemented at 17 sites using PAM (Supplementary Table S6) and Visual Encounter Surveys (VES) including of released captive-bred frogs marked using Visual Implant Elastomers (VIE). Previously unknown *H. pickersgilli* subpopulations were discovered at various protected or secure sites.

The Johannesburg Zoo managed the only breeding programme for the reintroduction of captive-bred individuals of the species to secure rehabilitated or created sites and to maintain a captive insurance population (Supplementary Material). This is a novel approach for a threatened amphibian species in South Africa. The *ex-situ* life cycle of *H. pickersgilli* has been elucidated, the captive-breeding of the species to F2 generation accomplished, and a captive assurance population established (Du Plessis et al. 2022a, 2022b). A detailed husbandry manual has been compiled (Du Plessis et al. 2022a). A study that forms part of the implementation of the BMP found that the *H. pickersgilli* skin microbial community includes various anti-chytrid fungus bacterial lineages (Mnisi et al. 2024) which may have played an important role in ensuring that all tests of the captured breeders, and the offspring prior to release to the wild, were negative for chytrid fungus.

Funding and employment

Long-term and short-term access to funding, including for collaborative work, was facilitated by the BMP. Funding grants were secured for specific objectives and activities outlined in the BMP (Supplementary Table S6). More than 140 local people were employed and upskilled for the removal of invasive alien plants. The EWT employed 12 people in positions related to implementation of BMP activities, e.g., Biodiversity Protection Officers. Four community youths from Adam's Rural were trained as local Nature Site Guides.

Weaknesses identified for the 2017–2022 BMP-PRF

Sustainability of stakeholder participation

Some inefficiencies with regards to stakeholder collaboration were experienced. The setting up of a working group might have assisted role players to harness opportunities more efficiently, and through this to assist PRFF members to be more active in the implementation of the BMP and to maximize opportunities (Supplementary Material, Table S6).

Insufficient outreach and landowner involvement

There was inadequate outreach to the commercial sector. The limited involvement in the implementation of the BMP of some PRFF members representing commercial stakeholders tapered off and their direct involvement with the BMP was not sustained or meaningful. The causes of this need to be ascertained and addressed in the next iteration of the BMP.

Variable incorporation of the BMP-PRF in government processes

The success of the BMP-PRF in land use decision-making and conservation processes in the three tiers of government (local, provincial and national) varied, thus affecting overall government buy-in. The annual reporting to the Minister of the Department of Forestry, Fisheries and the Environment was reliant on the report passing through the office of the Member of the Executive Committee (MEC) responsible for Environmental Affairs in KwaZulu-Natal. The high turnover of MECs during the first five years of the implementation of the BMP may have contributed to the reports not reaching the Minister's office during the first three years. It is not clear if this channel must be maintained by protocol.

Limited accessibility to information

A lack of communication in terms of access to information was raised by some members. Greater accessibility to data and educational information, especially for rural areas, was required. Strategic planning and communication with respect to site prioritisation should be strengthened, with a focus on the conservation and management of higher priority sites.

Incomplete knowledge base for release of H. pickersgilli *to the wild*

Potential climate change impacts and other threats were not sufficiently addressed during the selection of the first rehabilitated site for the release of captive-bred *H. pickersgilli*. Flooding and other factors prevented the successful establishment of captive-bred *H. pickersgilli* at the River Horse Valley release site, situated less than 5 km downstream of the (no longer existent) Type Locality of the species. A total of 516 captive *H. pickersgilli* were released at River Horse Valley (Supplementary Material), the results of the monitoring are presented in Supplementary Table S5. Monitoring shows that the *H. pickersgilli* have not successfully bred at the site where they were released. This indicates that the criteria used to choose the release site, the process to prepare the captive-bred *H. pickersgilli* for release, and the number of captive-bred frogs required for release to in situ sites need refining (Supplementary Table S6). An experimental release of a small number of captive-bred *H. pickersgilli* at a wetland in the Buffelsdraai Landfill Site buffer zone did not lead to a sustained population at the site (Armstrong et al., unpublished data).

Standardisation and consistency of monitoring

Standardisation of monitoring techniques and monitoring effort across sites is required. Monitoring of *H. pickersgilli* at some localities was neglected where it may have been necessary (e.g., at wetland sites with sewage inflow), while in other areas monitoring was inconsistent because the availability of the required resources varied over time. PAM devices should be positioned and configured using standardised methods for specific monitoring objectives to optimise data collection. Similarly, the labelling and management of acoustic data needs to be standardised. The use of the current systems and technology in wetland monitoring is time consuming. Improved data storage, analysis skills and funding are needed.

Opportunities identified for the revision of the BMP-PRF

Partnership development

Expansion of partnerships to include additional stakeholders based on lessons learnt will be important. Partnerships can develop into alliances, e.g., forming an alliance with residential estates to tackle environmental concerns that are broader than specifically *H. pickersgilli* and its habitat. Stakeholder champions are critical for the successful implementation of the revised BMP. Opportunities for expanding the captive breeding programme to facilities in the geographic range of *H. pickersgilli* should assist with adaptation of the captive-bred offspring to the wild environment.

Increased engagement with landowners and community members

Access to land ownership information, particularly for state, municipal and communal land, and to information on where wetlands are situated, would assist considerably toward facilitating conservation actions on the ground and in packaging information and messaging when approaching specific landowners. Continued engagement with landowners and occupants of land with priority *H. pickersgilli* wetland sites would assist with opportunities for further implementation of the BMP.

Improved government support

The BMP was gazetted in 2017 and therefore has indirect government endorsement. However, the BMP needs to be adopted and supported across the three tiers of government. Opportunities exist and need to be taken to inform key people within various government departments of the BMP to facilitate the further incorporation of the BMP and outputs from it into local conservation and land-use planning.

Improved policy, legislation and law enforcement

Wherever possible, the inclusion of measures to conserve *H. pickersgilli* and its habitat in policy or legislation should be effected. An example is in the Department of Water and Sanitation's ecological state of water systems analysis, where information relating to

H. pickersgilli could be used. Opportunity to improve legislation should be harnessed. For example, protocols to prevent the transmission of zoonotic diseases through import or movement of amphibians do not exist. The inclusion of other effective conservation measures (OECMs) should be considered as part of habitat protection approaches. Stewardship benefits and incentives should be investigated to encourage landowners to formally protect *H. pickersgilli* habitat. Non-compliance reporting to municipalities and other government agencies responsible for enforcement of laws should continue to be supported at a local level to assist with local environmental improvement for the benefit of people and wildlife, including *H. pickersgilli*.

Better spatial planning

Opportunity exists to have additional information about *H. pickersgilli* incorporated into spatial planning as part of the next iteration of the BMP. Since risks to *H. pickersgilli* remain significant and are cumulative, mitigating impacts are crucial to the species survival. A regional priority wetland map may assist with identification of habitat for biodiversity offsets. Some government departments (e.g., eThekwini Municipality) have a land acquisition programme, which would be valuable in terms of expansion of habitat for the species.

Revision informed by lessons learnt and knowledge

Lessons learnt from implementation of the first iteration of the BMP can inform the next five years of implementation. Knowledge generated from different projects and initiatives can help with improving the conservation of *H. pickersgilli* and other amphibians. The revision of the BMP provides opportunities for it to be aligned with other new conservation initiatives, to try to increase synergistically its impact in conservation planning and implementation.

Improving awareness

Opportunities to build awareness about *H. pickersgilli* and its habitat requirements and management include: erection of signage at secure wetlands with *H. pickersgilli*; more effective use of social media to spread information and garner support for action on the ground; getting more youth involved in implementation of the BMP; development of a website for the BMP; focusing awareness around the ecosystem benefits of the wetlands where *H. pickersgilli* occurs; introducing *H. pickersgilli* into local schools through curricula such as EWT's 'Frogs in the Classroom' programme; make institutions aware of regional wetland priorities; continuation of education programmes in and outside of the Johannesburg Zoo; encouraging and advertising the adoption of wetlands and sponsoring of projects by schools and societies; the establishment of a communications subcommittee; embracing the keenness of people in the general public; and creating awareness of the soft call of *H. pickersgilli* and its distinction from noisy frogs such as the Painted reed frog, so that *H. pickersgilli* is not lumped together with other frog species by residents unhappy about the noise of frog choruses.

Integration with catchment management

Wetlands are complex and are part of broader catchments that play an integral role in maintaining the integrity of wetlands. A catchment management approach rather than a site-specific approach should be pursued where possible. This approach is not being implemented widely in South Africa, and new information on how to implement such an approach would be useful. Integration with other catchment management initiatives would be beneficial, as would integration with projects such as the Transformative River Management Programme of the eThekwini Municipality. Lee et al. (2022) developed an urban amphibian conservation framework approach and applied it to the city of Calgary in Canada. This type of approach could be applied to catchments in which *H. pickersgilli* occurs, and a fairly similar approach was implemented at a larger scale as part of the BMP-PRF (Figure 4; Table 1). Although wetlands have been lost, it is possible to restore or create wetlands in large flat areas, particularly in terms of offsetting developments, which would provide opportunities to expand *H. pickersgilli* reintroduction efforts and achieve *H. pickersgilli* population stabilisation. Protection of input water sources and prioritising wetlands where *H. pickersgilli* occurs needs to be addressed through formal and informal engagement with stakeholders.

Research and monitoring improvements

The impacts of climate change, particularly extreme weather events that result in flooding, and the role that wetlands play in ameliorating floods should be considered in the implementation of actions of the next iteration of the BMP.

The availability of relatively low-cost acoustic monitoring devices allows for monitoring on a larger scale, especially where there are budget constraints or where the use of expensive equipment is not required. Short-term spot surveys on a wide geographic scale could assess potential locations for long-term acoustic monitoring with hi-end equipment. The acoustic data already collected from *H. pickersgilli* sites contains large amounts of data for other species, which could be studied by students. Collection of environmental acoustic data is an opportunity to share resources and costs with other projects. A new method or tool to monitor captive-bred *H. pickersgilli* released to the wild would assist in more efficiently determining the success of colonisation. A population viability analysis should be conducted to guide the captive breeding and re-introduction of *H. pickersgilli* to the wild. The continued development of a generic framework of habitat requirements of *H. pickersgilli* is recommended to inform habitat management and rehabilitation. The development of defined conservation evidence objectives, e.g., monitoring to better understand *H. pickersgilli* population fluctuations or density, and the use of artificial intelligence for detection of calls in the soundscape would strengthen the outcomes of this BMP. A combined database will assist in improving data access for all stakeholders.

New funding sources

Access to sustainable long-term funding is vital and so traditional and new sources of funding should be explored, particularly to support new objectives. Some potential sources include credit funding systems (carbon/biodiversity) and funding to protect endangered species from extinction. Efficient management of funding should be a priority. Partnerships between people with ideas and those with funding should be developed. Incentives to encourage the protection of *H. pickersgilli* habitat should be explored and pursued. Building ownership models and adopt-a-spot-type initiatives could be considered. An investigation into opportunities afforded by offsetting and mitigation banking might be fruitful, considering the very transformed nature of the landscape in the species' range.

Further capacity development

Local community members have been trained to implement environmental management on the ground at several sites, and this capacitation needs to continue and be expanded if possible. Opportunities for clearing invasive alien vegetation in urban areas where communities live adjacent to *H. pickersgilli* habitat need to be investigated and where possible developed into employment opportunities.

Threats to the successful implementation of the revised BMP-PRF

Matters relating to the BMP process

Some participants were uncertain whether the BMP is the most appropriate tool for species conservation. BMPs may not feed effectively into the Environmental Impact Assessment process, particularly in relation to protecting *H. pickersgilli* habitat, and some decision makers were not aware of the BMP-PRF. Once the BMP process commences, the time taken to complete the draft BMP and the timeframe for the approval process and gazetting of the BMP can take several years. This could impact the timeous implementation of conservation actions on the ground.

Matters relating to government

Opportunities exist for political agendas to be positive for frogs as this BMP was the first for a frog species, but uncertainty exists as to the government's view of amphibian conservation and associated environmental concerns. Securing habitat in the face of government-driven development is a concern. Barriers at the provincial government level to the annual reporting on progress in the implementation of the BMP to national government were encountered, and although these barriers were removed during the latter years of the five-year cycle, political instability can disrupt continuation of established reporting channels. Change of ward counsellors can affect the progress of individual projects. The slow rate of formalisation of outputs of the BMP in local government administrative systems and the lack of formal implementation of spatial plans in some local government areas and in traditional areas hampered the effectiveness of the implementation of the BMP. Corruption and decisions that are not made in the interest of *H. pickersgilli* were also seen as threats. Complexities in navigating the local administrative process to protect or rehabilitate land and get access to resources to secure *H. pickersgilli* sites, e.g., the Isipingo Wetland site, were encountered.

Conflicting mandates within local municipal departments, e.g., social, environmental and economic, need to be navigated; the status of the BMP needs to be known and accepted by a variety of departments to leverage support for initiatives relating to *H. pickersgilli* conservation on municipal land. Five municipalities still didn't explicitly reference priority *H. pickersgilli* habitat in their Spatial Development Framework documents by the end of 2022. Response to climate and other emergencies by government is usually reactive. These issues undermined the implementation of some aspects of the BMP. Certain rural communities supported the BMP on the ground (e.g., at Adams Rural, 497 households agreed to Protected Environment status for the wetland system where *H. pickersgilli* occurs) but there were difficulties working with the Ingonyama Trust Board, who effectively own this land.

Government compliance and enforcement capacity is limited, and the relative lack of enforcement of environmental legislation, including the BMP, weakens the impact of the implementation of the BMP. Incomplete understanding of municipal bylaws can make implementation of some of the BMP difficult.

Land use and ownership issues

Land claims are currently not an issue at sites where *H. pickersgilli* occurs, but land grabs have had some impact, and conflict around development initiatives has been and may be experienced. Expropriation of land is a potential threat to securing sites with *H. pickersgilli*. Attempts to formally protect certain areas of *H. pickersgilli* habitat, especially within traditional authority areas, e.g., Adams Rural, were prolonged and did not come to full fruition. The question of how processes can be streamlined to protect land in rural and residential areas is still open. Ongoing management challenges were experienced at some protected sites caused by illegal cattle grazing and concomitant burning of vegetation. Proper town planning was not implemented in some areas where developments took place within environmentally sensitive areas, including *H. pickersgilli* habitat. Approval of some developments took place without thorough consideration of the environmental impacts on *H. pickersgilli*. Also, some areas with *H. pickersgilli* were compromised through lack of awareness and of appropriate habitat management or through a lack of compliance and law enforcement.

The cumulative effects of unregulated and unlawful development within wetlands and their buffer areas where *H. pickersgilli* occurs, within both the formal and informal sectors, threaten the overall effectiveness of implementation of the BMP. These include the selling of communal land within wetland areas and development without environmental authorisation. Rapid urban expansion and human settlement and concomitant change in land use from agriculture to residential will likely cause the loss of habitat for *H. pickersgilli*. Opportunities have been missed with the conversion of sugar cane lands to residential land. Land on which sugar cane is grown is perceived as having no value as a biodiversity asset, although some of this land could be rehabilitated to a natural system including potential habitat for *H. pickersgilli*. Inappropriate management of catchments also threatens the long-term sustainability of habitat for *H. pickersgilli* through siltation of wetlands, etc. Poor upper catchment management negatively impacts the integrity of wetlands over time, especially in relation to climate change and extreme weather events that damage wetlands in poor condition, which leads to further degradation of social-ecological resilience.

Time delays

Long and extensive formal protection processes can lead to time delays before formal gazetting of protection for sites. The length of time taken is influenced by several factors (e.g., political issues) that are outside the control of parties implementing the BMP, and progress may be stymied. Time delays in securing sites with *H. pickersgilli* for conservation may have consequences such as degradation of sites through alien plant invasion, pollution, drainage, etc., leading to the unsustainability of the sites for *H. pickersgilli* so that formal protection of the site is no longer pursued. A quicker turnaround timeframe is required for the implementation of conservation management actions to ensure the long-term sustainability of sites for *H. pickersgilli*. Accessing funding can be a long process. Delays caused by government procurement processes affect the implementation of wetland projects aimed at conserving *H. pickersgilli*.

Climate change and extreme weather events

Climate change needs to be considered in the next iteration of the BMP, and actions that enhance resilience to climate change included. Such actions may include searching for habitat expansion and offset opportunities. Climate change is likely to impact coastal wetlands and knowing what these changes might be is necessary to ensure that resources to manage wetlands accordingly are available. Potential flooding of areas currently occupied by *H. pickersgilli*, with resultant erosion and/or sedimentation, is a risk. Flood risk increases with the drainage of wetlands, and mitigation of human impact on wetland habitat will indirectly impact the success of the implementation of the BMP.

Social concerns

These include environmental lawlessness and the inability of municipalities to service the growing human population, leading people to find their own solutions, which can negatively impact *H. pickersgilli* wetland habitat, e.g., waste disposal into wetland areas, erection of informal housing in wetlands, harvesting of wetland plant materials for domestic use and grey water discharge into wetlands. Poor sewage and domestic waste management is apparent in various parts of the range of *H. pickersgilli*. This, as well as agricultural pollution, impacts *H. pickersgilli* and its habitat directly and indirectly. As an example, 30 *H. pickersgilli* adult individuals collected at Adams Rural south of Durban in 2021 to form part of the captive-breeding and insurance population were found during quarantine to be infested with endoparasites and ectoparasites. Although treated, half the number of collected adults succumbed to the severity of the infection, perhaps exacerbated by the stress of being captured and transported hundreds of kilometres to the Johannesburg Zoo. Water sample analysis indicated greatly elevated levels of *Escherichia coli*, manganese, arsenic, iron and lead in the wetland water compared to levels that are safe for drinking water. The other cations analysed (calcium, magnesium, copper and mercury) were in safe concentrations and no elevated levels of pesticides were recorded.

The impact of unpredictable social dynamics, e.g., riots, and how these influence the environment, and *H. pickersgilli* habitat in particular, is a concern. Security issues prevent stakeholders from getting involved in the management of certain areas. In some areas there is the risk of theft of acoustic monitoring equipment, particularly in publicly accessible locations and where the devices are clearly visible. Getting community ownership of, and participation in, projects implemented within some areas may be difficult where there is lack of support from the community or where there are misconceptions and superstitions about frogs (Tarrant et al. 2016). Socio-cultural breakdown, socio-ecological and economic decline, and lack of understanding of the importance of appropriate management of the environment are threats to the implementation of a revised BMP-PRF. Stakeholders need to be cognisant of all these difficulties moving forward.

Uncertainty of sustainable funding

The initial development of the BMP was novel for funders and received support from the Mohamed Bin Zayed Species Conservation Fund, Disney Conservation Fund and Rand Merchant Bank, but sustaining support for development of future iterations, and the implementation of actions therein may prove more difficult. Global and local issues influence access to funding. For the Umgavusa Protected Environment, proclaimed in May 2023, additional funding is needed for the long-term maintenance and protection of the site. Protection may be better afforded by using OECMs in certain cases.

Conclusion

The BMP for *H. pickersgilli* was the first of its kind to be gazetted for an Endangered frog species in South Africa. The first five years of implementation of this BMP has resulted in many achievements, which would not be possible without strong collaboration between organisations, taking place over more than a decade, as well as the dedication of individuals within those organisations. This collaborative implementation is a good example of how species conservation planning can assist to focus and co-ordinate contributions of a variety of stakeholders to successfully guide conservation action for threatened species, which may also act as flagships for co-occurring species. The importance of having a BMP to guide stakeholders who are involved with the conservation of *H. pickersgilli* to improve its threat status is evident by what is reported in this article. The number of localities at which the species had been documented increased from 30 to 46 between 1 June 2017 and 31 December 2022. The area of habitat that has been legally protected because of work conducted during this five-year period is 127 ha, and other sites totalling 506 ha were in the process that leads to legal proclamation. Other areas of habitat are being better managed (e.g., at housing estates) because of the BMP. The first trial re-introductions of a threatened amphibian species in South Africa were conducted. Many thousands of people have been directly influenced by BMP-related project activities. We hope that this paper will encourage stakeholders working to improve the conservation status of other threatened species to consider development and implementation of BMPs for their taxa to achieve co-ordinated action in this regard. As work starts on the next iteration of this BMP, it was valuable for the PRF Forum members to come together and critically evaluate the successes and failures of the first iteration of the BMP-PRF, and to consider the future opportunities and threats. This evaluation will be useful in the compilation of the next iteration.

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Competing interests

The authors declare no competing interests.

Authors' contributions

JT and AJA conceived the draft Biodiversity Management Plan. All authors contributed to the finalisation of the plan and/or to the writing of the paper and/or to the outcomes of the plan. AJA, AK, CA, IduP, PM, SLL and JT carried out field and/or laboratory and/or ex situ work. LW ran the SWOT analysis workshop.

Ethical considerations

Ethical clearance was received from the Endangered Wildlife Trust Ethics Committee (EWT_EC) for monitoring released captive-bred *H. pickersgilli* using Visual Implant Elastomers (VIE) (clearance number: EWTEC2018_006), as well as by the South African National Biodiversity Institute (SANBI) for the BioBlitz project in 2022: Species composition and microhabitat of Pickersgill's reed frog (*Hyperolius pickersgilli*) (ethics clearance number: P2022/05). The Johannesburg City Parks and Zoo ethics committee granted permission for the Conservation Project for Pickersgill's Reed Frog in a Captive Environment to carry out breeding and release (Clearance number: JHBZOOESC - 21/017).

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Supplementary Material

Materials and methods

Habitat and connectivity map for inclusion in municipal spatial planning systems

A map was produced as a Geographic Information System (GIS) spatial coverage for use in municipal planning processes that indicated the most important areas for the conservation of *H. pickersgilli*. Wetlands in which *H. pickersgilli* have been recorded [as per the records in the Ezemvelo KZN Wildlife (EKZNW) Biodiversity Database] and linkages between these and between them and other potentially suitable wetlands for the species were delineated using ESRI World Imagery (2015–2020) and Google Earth imagery (various dates) in ArcGIS Pro Version 2.8 (Environmental Systems Research Institute, Inc., 2021, Redlands, California, USA). This delineation was guided by the wetlands identified in the EKZNW vegetation map (Scott-Shaw & Escott 2011) and by information presented in Tarrant and Armstrong (2013), in particular: (1) the position and extent of the wetlands that had a relative suitability of 0.5 ('typical habitat') or higher for *H. pickersgilli*, as determined by the model (see Figure 2 of Tarrant & Armstrong 2013), and (2) the friction map produced in accordance with the friction classes presented (see Table 1 and the example of Figure 4 of Tarrant & Armstrong 2013). These wetlands were buffered where possible by 400 m width (providing the landcover was suitable for the dispersal or foraging of *H. pickersgilli*), to ensure that the ecological functionality of the wetlands and the microhabitats for the frog species are maintained (Semlitsch & Bodie 2003). Some of the wetland extents had to be edited because those wetlands were extensively modified. Untransformed areas were identified for each linkage (of a minimum of 200 m in width where possible) and were the most suitable landcover classes present for the dispersal or foraging of *H. pickersgilli* (in accordance with Table 1 of Tarrant & Armstrong 2013). Site-specific information from a variety of sources was used to modify the map for those sites if necessary. The coverage (map) was divided into sections in accordance with the boundaries of the various municipal areas in which *H. pickersgilli* occurs and instructions on how to use the coverage provided for each of these divisions.

Ranking of wetlands where *H. pickersgilli* was known to occur in 2019

A prioritisation exercise was conducted to rank sites where *H. pickersgilli* occurred (as of 25 April 2019) in terms of conservation importance. Values for a range of variables (Table S1) were assigned to each of these wetlands. The scores for each wetland were averaged to give a final score per site and the wetlands were ranked from highest to lowest score.

Updating the predicted distribution map for *H. pickersgilli*

The predicted distribution map of Tarrant and Armstrong (2013) was updated to include new distribution records. One hundred and fourteen accurate (within 250 m) occurrence records for *H. pickersgilli* were extracted from the EKZNW Biodiversity Database on 24 February 2020. Literature was consulted to assess which environmental predictors would be most likely to influence the distribution of the species (Raw 1982; Armstrong 2001; Elith et al. 2011; Tarrant & Armstrong 2013; IUCN SSC Amphibian Specialist Group, South African Frog Re-assessment

Table S1. Scores for variables included in the ranking scheme for conservation intervention at wetlands with Pickersgill's reed frog, *Hyperolius pickersgilli*, subpopulations to ensure their long-term viability (NEMPAA = National Environmental Management: Protected Areas Act)

Variables	Categories	Score (out of four)
Protection status	NEMPAA protected	4
	Conservation zonation	2
	Conservation influenced	1
	Not protected	0
Management	Continuous directed management	4
	Continuous general management	3
	Intermittent directed management	2
	Intermittent general management	1
	No management	0
Habitat size (ha)	> 100 ha	4

Table S1. Scores for variables included in the ranking scheme for conservation intervention at wetlands with Pickersgill's reed frog, *Hyperolius pickersgilli*, subpopulations to ensure their long-term viability (NEMPAA = National Environmental Management: Protected Areas Act) (continued)

Variables	Categories	Score (out of four)
Habitat size (ha) (continued)	> 10 to 100 ha	3
	> 1 to 10 ha	2
	≤ 1 ha	1
Land use context	Mining	0
	Commercial agriculture	1
	Commercial sylviculture	1
	Subsistence agriculture	2
	Low density residential	3
	High density residential	1
	Intact natural	4
	Modified natural	3
	Industrial	1
	Transport infrastructure	1
Ownership	Private	3
	Traditional authority	2
	State	4
	Commercial	2
	Municipal	2
Threats	Habitat destruction extent	1–4
	Habitat fragmentation extent	1–4
	Pollution extent	1–4
	Climate change resilience	1–4
	Siltation extent	1–4
	Alien plants coverage	1–4
Connectivity	Isolated	0
	Poorly connected	2
	Well connected	4
Vegetation integrity (present ecological state)	Poor	1
	Fair	2
	Moderate	3
	Good	4
Other fauna of conservation importance present?	Yes	4
	Likely	3
	Unknown	1
Stakeholder willingness to implement	Yes	4
	Unknown	1
	No	0
	Uncertain	2

Group (SA-FRoG) 2016; Du Plessis et al. 2022a, 2022b). The continuous variables (Schulze 2007) chosen for use in developing a distribution model for *H. pickersgilli* and the reasons were as follows: average summer and average winter, mean daily minimum temperature (°C; Ezemvelo KZN Wildlife 2014f, 2014h; *H. pickersgilli*, especially the tadpole, is sensitive to low temperatures, and temperature and regulation of water loss are important for amphibian biology); average summer and average winter, mean daily maximum temperature (°C; Ezemvelo KZN Wildlife 2014a, 2014d; *H. pickersgilli* breeds in summer and is a small frog so may be susceptible to high temperature, or in winter, low maximum temperatures, and regulation of water loss is important for amphibian biology); average summer and average winter, mean daily average relative humidity (%; Ezemvelo KZN Wildlife 2014b, 2014c; *H. pickersgilli* requires fairly high relative humidity for survival, especially in summer when it breeds, for regulation of water loss); mean annual precipitation (mm; Ezemvelo KZN Wildlife 2014e; *H. pickersgilli* requires fairly deep water for reproduction and the tadpole is aquatic); number of days with rainfall greater or equal to 10 mm (Ezemvelo KZN Wildlife 2014g; *H. pickersgilli* requires fairly deep water for reproduction and the tadpole is aquatic). Summer was defined as October to March and winter as from April to September. The environmental space of *H. pickersgilli* was defined using a mask. *Hyperolius pickersgilli* is a coastal species confined to the Indian Ocean Coastal Belt (IOCB). Therefore, the IOCB in KwaZulu-Natal (IOCB extract from Scott-Shaw & Escott 2011) defined the mask, even though this region is larger than the currently known distribution range of *H. pickersgilli*. The projection of the coverages was the Transverse Mercator lo31 central meridian on the WGS84 datum, and the pixel size was 20 × 20 m.

MaxEnt version 3.4.1 (Phillips, Anderson & Schapire 2006; Phillips & Dudik 2008) was used to develop the distribution model. Five cross-validate replicates were run with the maximum number of iterations set at 1 000 to ensure algorithm convergence; the logistic output type was selected, and the default settings were used for all the other relevant parameters except that the regularisation multiplier was varied. The regularisation parameter was given the following values: 0.5, 1, 1.5, 2, 3, 4, 5, 6, 10, 15. The default feature classes were used due to the number of data points per fold being relatively few (Phillips & Dudik 2008). Post-processing of the output was conducted in TerrSet® Version 19.0.4 Idrisi Geographical Information System (Eastman 2020). The KwaZulu-Natal 2017 landcover coverage (Ezemvelo KZN Wildlife 2020) was used to classify landcover classes into two categories: (1) landcover classes that were suitable for the feeding and/or dispersal of *H. pickersgilli* and (2) unsuitable land cover classes. The areas of landcover unsuitable for *H. pickersgilli* were removed from the distribution model output.

Assessments of health and biodiversity and management efficacy at selected wetlands where *H. pickersgilli* occurs

Wetland health and biodiversity assessments were conducted to determine the state of priority wetlands for *H. pickersgilli* and determine relevant site-specific management activities. Annual wetland assessments have been conducted at four sites (Adam's Rural, Isipingo, Mount Moreland and Widenham) since 2016, providing a measure of habitat health and function, and providing a basis from which to develop rehabilitation plans for *H. pickersgilli* habitat (Edwards, Pike & Mncwabe 2023). The WETHealth tool was used to assess the health of priority wetland sites, combining indicators of three components, namely hydrology, geomorphology and vegetation, which make up an overall impact score (Macfarlane et al. 2009). All the components add up to a total score of 10, where a score of 0 indicates that the wetland has not been modified and is in a natural state, and a score of 10 means that the wetland has been completely modified. These impact scores were then used to assign the wetland to an ecological category or present ecological state (PES), as shown in Table S2.

Table S2. Wetland present ecological state (PES) categories (Macfarlane et al. 2009)

Impact score	Ecological category	Description
0–0.9	A	Natural state
1–1.9	B	Largely natural with a few alterations
2–3.9	C	Moderately modified but the basic ecosystem functions are still unchanged
4–5.9	D	Largely modified. A large loss and change in the habitat, biota and basic ecosystem functions
6–7.9	E	Seriously modified. The loss and change of habitat, biota and basic ecosystem functions are extensive
8–10.0	F	Critically modified. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota

Further to this, the Management Effectiveness Tracking Tool (METT-4; Stolton, Dudley & Hockings 2021) was used to assist with the development of site-specific management plans for sites where habitat protection processes have been undertaken. The METT methodology is a rapid assessment based on a scorecard questionnaire. The scorecard incorporates six components of management including: site context, planning, inputs, process, outputs and outcomes. The needs, constraints and priority actions to improve management of priority wetlands for *H. pickersgilli* were determined through the METT and the WET Health Assessments and formulated into site management plans.

The efficacy of management activities was monitored using Ecological Goods and Services (EGS) Quality Assessments conducted through locally employed community members who, through a participatory science approach, conducted continuous assessments on the quality of EGS. Data were collected through an application, which automatically provided a quality score of between 1 (poor) and 5 (good) according to specific indicators, including indigenous and invasive alien vegetation, faunal diversity, soil erosion and land disturbance, and these scores were used to determine the quality of EGS within priority sites (Acker-Cooper et al. 2019).

An environmental compliance monitoring system (Acker-Cooper, Little & Roxburgh 2021) was used to determine state of environmental compliance within priority sites and to track changes in non-compliance. Non-compliance incidents were categorised according to a theme, e.g., agriculture, water, which relate to specific restricted activities as specified in environmental legislation. Records were given geographic tags and used to assess and verify the extent of an activity. The site-specific databases provided an inventory of compliance issues and assisted towards prioritising non-compliance issues for investigation and enforcement action by the mandated authority. A waste monitoring system (Acker-Cooper & Roxburgh 2022) was used to track changes in illegal waste dumping incidents in wetlands and watercourses within priority sites.

Management of natural resource harvesting at a wetland with *H. pickersgilli* in a protected area

Certain natural resources associated with wetland habitats outside of protected areas in KwaZulu-Natal have declined because of the lack of management of the wetlands and harvesting of the resources and because of land transformation. As a result, pressure has been put on protected areas to meet the natural resource needs of local communities. Vocalisations and sightings of *H. pickersgilli* were recorded in a major wetland plant harvesting area at Umlalazi Nature Reserve early in 2022. Prior to the harvest event in May 2022, the harvest area was surveyed for *H. pickersgilli*. A refuge area for *H. pickersgilli* of 2500 m^2 (100 × 25 m) was demarcated by barrier tape to ensure that the harvesters did not enter this refuge during the weeklong harvest.

Assessment of the vulnerability of *H. pickersgilli* to climate change

The potential vulnerability of *H. pickersgilli* to climate change was assessed by using Google Earth® and plotting the accurate *H. pickersgilli* occurrence records as of 25 April 2019 on a coverage derived from downscaling of the HadCM2 climate model of the environmentally defined floristic domains of Jewitt et al. (2015), ranked in terms of vulnerability to climate change according to a vulnerability framework [see Jewitt et al. (2015) for further details]. The downscaled HadCM2 model predicted an average 2.1 °C mean annual temperature increase and a mean annual precipitation decrease of 90 mm by 2050 (Jewitt et al. 2015). The four categories of the vulnerability framework were 'Robust' (high Climate Stability Index and high Habitat Intactness Index), 'Susceptible' (low Climate Stability Index and high Habitat Intactness Index), 'Constrained' (high Climate Stability Index and low Habitat Intactness Index) and 'Vulnerable' (low Climate Stability Index and low Habitat Intactness Index). The number of the 38 localities where *H. pickersgilli* occurred that fell into each category of the vulnerability framework could then be determined and the vulnerability of the species to climate change until 2050 assessed according to the downscaled HadCM2 climate model.

Monitoring of *H. pickersgilli* at selected priority wetlands

Frog calls are species-specific, and observers can use calls to locate and identify different species of frogs easily and reliably within a study area (Tarrant 2021). Most species of frogs use calls to attract mates and establish breeding habitats (Du Preez & Carruthers 2009). The implementation of the protocol developed in 2013 and refined in 2020 (Tarrant & Armstrong, unpublished), took place over several years and at several wetland sites, including at Mount Moreland, Simbithi Eco-Estate, Adam's Rural, Widenham and Gingindlovu (Umgavusa Protected Environment), as well as at sites at which captive-bred *H. pickersgilli* were released [River Horse Valley (Durban) and Buffelsdraai]. PAM allows for the automated recording of the soundscape at set times and intervals using equipment designed for biodiversity monitoring (Browning et al. 2017). Recordings taken between 2016 and 2020 produced more than 8 000 hours of call data, subsamples of which were initially listened to manually to confirm the presence of

H. pickersgilli, as well as to identify other frog species that share habitat with *H. pickersgilli*. The data were stored digitally and analysed as part of three UKZN Honours projects in 2020 (Tarrant 2021).

Releases of captive-bred *H. pickersgilli* to the wild within its geographical range

Two standard operating protocols were developed and implemented before any captive-bred *H. pickersgilli* were released to the wild. The first was a risk assessment before release and the second was a release protocol. The breeding and releases were done under a Memorandum of Agreement signed between Ezemvelo KZN Wildlife and the Johannesburg Zoo. Sampling for chytrid fungus testing by SANBI National Zoological Garden staff was done in the field at the site of capture of breeder adults, when the breeders first arrived at the Johannesburg Zoo, and a month prior to release of captive-bred *H. pickersgilli* to the wild. A faecal float was done weekly by Johannesburg Zoo staff for six weeks before release to check for internal parasites. Only frogs that passed these health checks could be released to the wild. Between 6 and 8 weeks prior to the release of the frogs to the wild, the captive environmental conditions and food were changed to more closely simulate that of the natural receiving environment (e.g., the food was changed from crickets to free-living fruit flies and feeding was skipped from time to time, additional lighting was provided for irregular periods, temperature and humidity were varied but maintained within the ranges in their natural habitat during the current season). These pre-release methods were used to prepare the captive *H. pickersgilli* for, and to improve their chances of survival in, the wild. Further details can be found in Du Plessis et al. (2022a). The genetics study (Kotze et al. 2019) indicated that individuals from any subpopulation could be released at any suitable site within the native distribution range of the species.

Marking of frogs to be released was by visible injectable elastomer (VIE). The VIE was premixed and less than 1 ml was subcutaneously injected by a veterinarian in the inner side of the hind thigh. A period of two weeks was provided for the skin to heal before the specimens were handled in preparation for the transport to the release site. Two colours were used in combination with the injection site being the left or right hind leg to identify the generation and year of hatching. Transportation by road of the captive-bred specimens from the Johannesburg Zoo to the release site was done at night because the frogs would be less stressed owing to the cooler temperatures, lower carbon dioxide levels and the darkness. The captive frogs were transported in clear plastic 5-litre jars with perforated screw-on lids. Paper towel dampened with reverse osmosis (RO) water was placed in the jars to maintain adequate humidity of no less than 65% and temperatures of between 15 °C and 18 °C. Each jar housed more than 15 adult specimens or 20 subadult specimens. The dampened paper towel was replaced every three hours when the jars were wiped down inside and misted with RO water. All jars were placed in carton boxes to ensure stability of the jars.

Monitoring of the *H. pickersgilli* individuals released to the wild was based on the calling of released males at sites where no *H. pickersgilli* calls had been recorded prior to the release, by sightings of released *H. pickersgilli* marked using VIE, and through metabarcoding analysis of two water samples from River Horse Valley by NatureMetrics (United Kingdom). Monitoring was conducted by the observers listening for calls and by actively searching for and sighting *H. pickersgilli* adults, as well as by setting up SongMeters (SM3, Wildlife Acoustics, Inc., Maynard, USA) in suitable positions to record the soundscape and by analysing the recordings using Kaleidoscope Pro software (version 5.1.2, Wildlife Acoustics, Inc., Maynard, USA) to detect calls of *H. pickersgilli*.

A release site was identified at River Horse Valley, Durban, based on the rehabilitation of the habitat to include some suitable for *H. pickersgilli* and the proximity of the site to the destroyed type locality for the species, located upstream less than 4 km away in a northeasterly direction as the crow flies (Figure S1). No *H. pickersgilli* were present at this recently rehabilitated site immediately before the release. An advantage of releasing the captive-bred frogs at the River Horse Valley site was that the released frogs would be easy to monitor by listening for their calls and searching for them, and any *H. pickersgilli* calling in the wetland would be released frogs. We hoped that eventually other *H. pickersgilli* would be attracted to this site by the calling of the released frogs and so increase the population size at the site. Fifty captive *H. pickersgilli* were released there at night on 5 March 2019. Seventy more *H. pickersgilli* (including 20 tadpoles) were released at River Horse Valley on 18 February 2020. At the latter release, in the early afternoon the frogs were evenly divided between two netted enclosures. Each enclosure was suspended just above the water surface amongst the emergent reeds at two places in suitable habitat to acclimatise for some hours. All the tadpoles were confined to one plastic tadpole enclosure with a perforated lid to allow gaseous exchange so that the tadpoles could breathe, as they had lungs at that stage of their development. The enclosure was semi-submerged in the water at one of the release places and tethered to the vegetation. This enclosure was left in situ for some hours for the tadpoles to acclimatise to the release environment. Water quality readings were taken, and the water quality shown to be ideal for *H. pickersgilli*. The team returned to River Horse Valley after dusk and

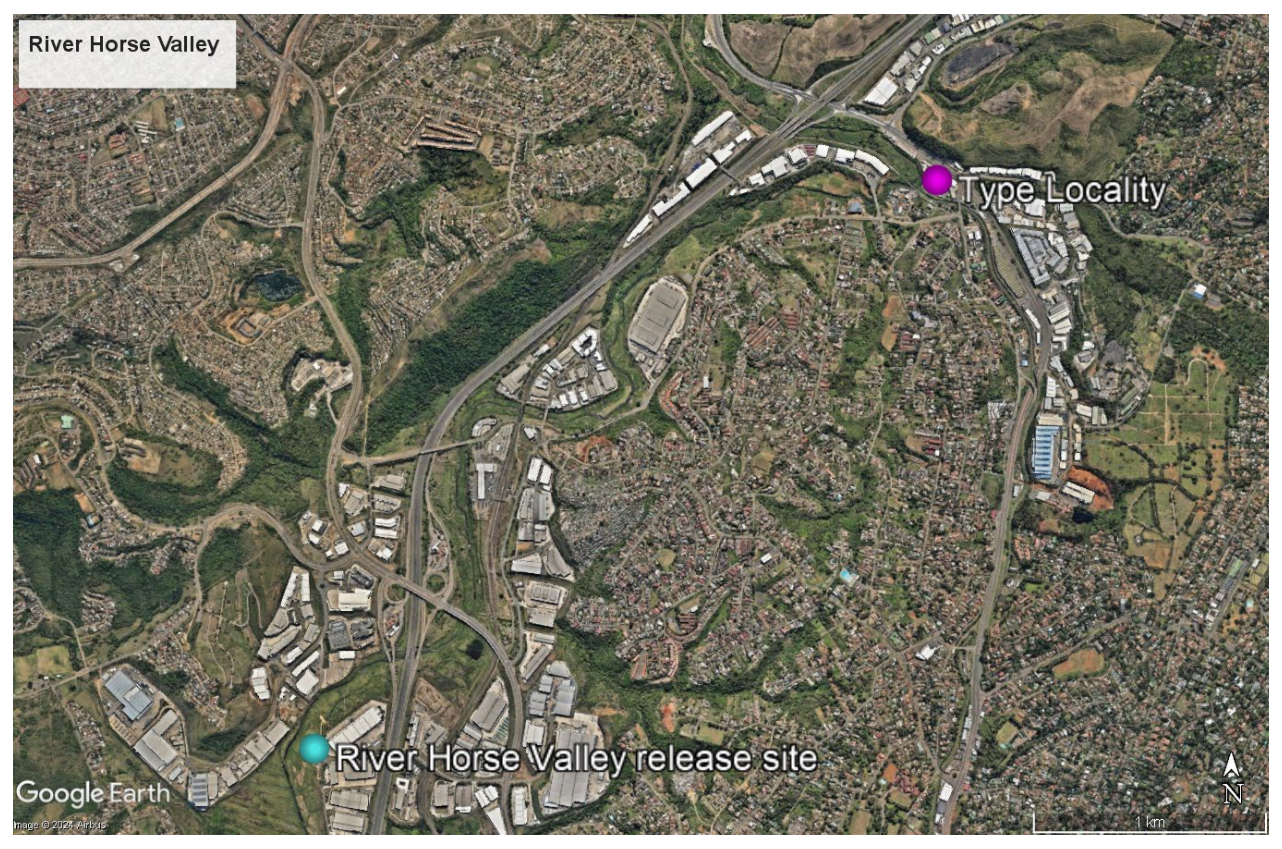

Figure S1. The site (cyan dot) at River Horse Valley, Durban, South Africa, where captive-bred Pickersgill's reed frogs *Hyperolius pickersgilli* were released in relation to the type locality (magenta dot).

released the 50 frogs into the habitat and started the acclimation process for the tadpoles by slowly mixing the purified (RO) water in which they were contained with the wetland water. After half an hour the process was complete, and the tadpoles were seen to be acclimated to the water. The plastic enclosure was perforated at the sides to allow water flow through the enclosure and left semi-submerged as before. A further 396 adult *H. pickersgilli* were released at the River Horse Valley site on 10 November 2020.

Awareness campaign and education programme about *H. pickersgilli*

An integrated education system was developed by the EWT to inform various community sectors within *H. pickersgilli* priority sites. Efficacy of environmental education was measured through formal knowledge assessments and environmental attitude assessments. A functionalist approach was used to determine the attitudes of people towards their environment (Drews 2002). A questionnaire was compiled including 42 questions intended to rate five attitude dimensions (strongly agree to strongly disagree) of people towards their environment (adapted from Tarrant, Kruger & Du Preez 2016). Three different scales were developed, assessing a person's liking, knowledge and cultural beliefs and these were incorporated into the questionnaire (Tarrant, Kruger & Du Preez 2016). Depending on the response, the answer was assigned a score of -1 (strongly disagree), -0.5 (disagree), 0 (unsure), 0.5 (agree) or +1 (strongly agree). The values attributed to the responses to the 42 questions were added together and an attitude score was calculated. The average attitude scores of all the respondents were calculated for each site.

Structured environmental education

A school-based environmental education programme was developed to align with the Department of Education curriculum. The education programme, Frogs in the Classroom, specifically targets learners from Grade 3–7. 'Frogs in the Classroom' consists of three lessons, with formal and summative assessments used to evaluate knowledge gained through the modules.

Outreach and events

Structured social media campaigns and community events based on environmental calendar days, including the 'Leap Day for Frogs' campaign and frog tourism events, were designed to promote appreciation for frogs and their habitats through the direct involvement of the public, with an emphasis on experiential learning for youth. In addition, unstructured social media campaigns on key *H. pickersgilli* management highlights were intermittently shared through EWT and other partner platforms to broaden public knowledge around amphibian conservation efforts.

Conservation conversations

Conversations were held with community members living in the vicinity of project sites, including Isipingo and Adam's Rural, to build knowledge and understanding of the importance of wetlands and related biodiversity. Conversations were recorded and digitally analysed according to sentiment and strength of sentiment to determine if the emotional tone of the message is positive, negative or neutral.

Signage

A BMP-specific signboard was developed in collaboration with key project partners including DFFE, EWT, Ezemvelo KZN Wildlife, Johannesburg Zoo and SANBI, and placed at various locations, as well as location-specific signboards at Umhlanga Lagoon Nature Reserve and Umlalazi Nature Reserve (Figure 6B). Pickersgill's Reed Frog Custodian agreements were signed with Simbithi and Zimbali eco-estates and included the display of custodian signboards.

Skills and capacity development

Site-specific community members were upskilled through tailored learning programmes accredited with the South African Qualification Authority. The learning programmes provided essential skills in environmental monitoring, compliance and invasive alien plant control to support rehabilitation activities.

Employment

Community members were employed by the Endangered Wildlife Trust as biodiversity protection, environmental compliance and invasive alien plant control officers at priority sites to perform specific ecological rehabilitation functions.

Results

The scores for each variable and the final ranking for each of the 38 wetlands known to have *H. pickersgilli* as of 25 April 2019 are provided in Table S3. Those wetlands in protected areas proclaimed in accordance with the National Environmental Management Protected Areas Act ranked at the top, whereas those in sugar estates ranked at the bottom. This ranking allows for informed decision-making in terms of where resources should be allocated to ensure the long-term survival of *H. pickersgilli*. This ranking does not mean that wetlands known to have *H. pickersgilli* and that are low ranked are unimportant. The provincial ecosystem status of much of the Indian Ocean Coastal Belt where *H. pickersgilli* occurs is Critically Endangered (Jewitt 2018). All habitat for this species should be protected in perpetuity to achieve the goal of having the species downlisted to Least Concern in accordance with the IUCN Red List process.

The scores for the annual wetland health (AWH) and Ecological Goods & Services (EGS) Quality Assessments are presented in Table S4. The Adams Rural Wetland had consistently high AWH and EGS scores, while the continued degradation of the Isipingo Wetland was indicated by its declining scores.

The results of the monitoring of released captive-bred *H. pickersgilli* at River Horse Valley in Durban are presented in Table S5. Of the fifty adult frogs that were released towards the end of summer on 5 March 2019, none were recorded in the subsequent summer when monitoring commenced. After the release of 50 adults and 20 tadpoles on 18 February 2020, all the tadpoles were found drowned on 19 February 2020 owing to the large amount of rain that had fallen overnight, resulting in a rise in the water level that covered the perforated lid of the plastic tadpole enclosure. Only two of the marked adult frogs were seen on that same day, after the flood, although one was being eaten by a spider. None were recorded on subsequent monitoring occasions. A further release of 396 adults was effected at the same site on 10 November 2020. Few were recorded on subsequent monitoring occasions and after a month none were recorded again.

Table S3. Ranking of sites with Pickersgill's reed frog, *Hyperolius pickersgilli*, according to the ranking criteria (Table S1). PS = protection status, Man. = type of management, Size (ha) = habitat size (ha), Land use = land use context, Owner = ownership, Conn. = connectivity, PES = vegetation integrity, Other fauna = other fauna of conservation importance, Will = stakeholder willingness to implement

Wetland	PS	Man.	Size (ha)	Land use	Owner	Threats	Conn.	PES	Other fauna	Will	Overall score	Rank
St Lucia Estuary	4	3	4	4	4	3	4	4	4	4	3.82	1
Mapelane Forest Reserve, Mapelane camp, next to road near reception	4	3	3	4	4	3	4	4	4	4	3.73	2
Mtunzini, Raffia palm forest	4	3	3	4	4	3	2	3	4	4	3.38	3
Umlalazi Nature Reserve	4	4	3	4	4	3	2	3	3	4	3.38	3
Mt Moreland, Froggy Swamp	2	2	2	3	3	2	4	3	4	4	2.93	5
Simbithi Eco-Estate, Shaka's Rock	1	4	2	3	3	2	2	4	4	4	2.90	6
Port Durnford area	1	2	3	1	3	3	4	3	3	4	2.68	7
Adam's Rural Wetlands	1	2	3	3	2	2	2	3	4	4	2.62	8
Zulti South – Forestry Station (eSikhawini) Wetlands (W11)	0	2	3	0	3	2	4	3	4	4	2.50	9
Mt Moreland, Lake Victoria	2	2	3	1	3	2	2	2	4	4	2.47	10
Lake Nsezi (James Harvey)	0	1	4	1	3	2	4	4	3	2	2.37	11
Mtunzini, Forest Lodge	1	1	3	3	3	3	2	3	3	2	2.35	12
Golokodo East, towards Eston	0	2	2	3	2	2	2	3	3	4	2.32	13
Golokodo West, towards Eston	0	2	2	3	2	2	2	3	3	4	2.32	13
Mtunzini, Zini Estate	1	1	2	3	3	2	2	3	3	2	2.23	15
Mahunu, near eSikhawini	0	0	3	2	2	3	4	3	3	2	2.20	16
Zimbali Estate, North Coast	1	1	1	3	3	2	2	3	4	2	2.18	17
Empisini Nature Reserve	4	1	2	1	2	2	0	2	3	4	2.10	18
Widenham Wetland, Umkomaas	1	2	2	3	2	2	2	2	1	4	2.08	19
Zulti South – Kraal Hill (Wetland 4)	0	0	3	2	2	2	4	3	3	1	2.03	20
Nkomba Conservation Area, Pennington, South Coast	1	1	2	3	2	2	2	2	1	4	1.97	21
Zulti South Mine Lease Area, Wetland 8	0	0	1	2	2	2	4	3	3	2	1.93	22
District DC28, uMhlathuze Local Municipality (KZN282), Nyembe, Kraal Hill	0	0	3	2	2	3	2	3	3	1	1.88	23

Table S3. Ranking of sites with Pickersgill's reed frog, *Hyperolius pickersgilli*, according to the ranking criteria (Table S1). PS = protection status, Man. = type of management, Size (ha) = habitat size (ha), Land use = land use context, Owner = ownership, Conn. = connectivity, PES = vegetation integrity, Other fauna = other fauna of conservation importance, Will = stakeholder willingness to implement (continued)

Wetland	PS	Man.	Size (ha)	Land use	Owner	Threats	Conn.	PES	Other fauna	Will	Overall score	Rank
Richard's Bay	0	1	2	3	2	2	2	2	3	2	1.87	24
Richards Bay, John Ross Bridge, Nseleni River	0	0	4	1	2	2	4	1	3	2	1.87	24
Fibres Road North, Durban South, DDOP site	0	0	3	1	3	1	2	1	4	2	1.72	26
Isipingo Tributary Wetland	0	2	2	1	2	1	2	1	4	2	1.72	26
District DC28, uMlalazi Local Municipality (KZN284), Fairbreeze (Tronox)	0	3	2	0	1	2	2	1	3	2	1.57	28
SAPREF, Durban South basin (DDOP site)	0	0	1	2	3	2	0	2	4	2	1.55	29
Prospecton Wetland, Durban South basin (DDOP site)	0	0	3	1	3	2	0	1	4	2	1.55	29
Stanger	0	0	3	1	4	2	2	1	1	2	1.55	29
Fibres Road South, Durban South, DDOP site	0	0	2	2	3	1	0	1	4	2	1.52	32
Groutville	0	0	4	1	2	2	2	1	1	2	1.45	33
Amatikulu, Proposed prawn farm, N of Amatikulu mouth	0	0	3	1	3	2	2	1	1	1	1.38	34
Senla Sugar Estates, N bank of Zinkwazi River Mouth, in vlei surrounded by cane	0	0	2	1	3	1	2	1	1	1	1.22	35
Tugela River Mouth (3.5 km W of the mouth)	0	0	2	1	3	1	2	1	1	1	1.22	35
Nonoti, Nonoti Sugar Estate	0	0	1	1	3	1	2	1	1	1	1.12	37
Sezela	0	0	1	1	3	1	2	1	1	1	1.12	37

Table S4. Results of the annual wetland health (AWH %) and Ecological Goods & Services Quality Assessments (Score: 1 = poor to 5 = excellent)

Site	District	2018		2019		2020		2021		2022	
		AWH	EGS	AWH	EGS	AWH	EGS	AWH	EGS	AWH	EGS
Adams Rural Wetland	eThekwini	81.6	-	82.1	3.92	-	3.99	-	4.04	79.2	3.77
Widenham Wetland	eThekwini	42.0	-	46.2	-	-	-	-	-	47.6	3.68
Isipingo Wetland	eThekwini	23.2	-	21.6	-	-	-	-	3.76	20.3	3.28
Froggy Swamp Wetland (Mt Moreland Wetland)	eThekwini	67.6	-	-	-	-	-	-	-	-	-
Nyoni	iLembe	-	3.2	-	3.25	-	2.94	-	-	-	-
Groutville	iLembe	-	2.7	-	3.25	-	3.25	-	-	-	-
KwaDukuza	iLembe	-	2.2	-	-	-	-	-	-	-	-

Table S5. Results of the monitoring for released captive Pickersgill's reed frogs, *Hyperolius pickersgilli*, at the River Horse Valley release site

Date of release (number released)	Monitoring date	Type of monitoring	Number of *Hyperolius pickersgilli* detected
5 March 2019 (50)	25 September 2019	Manual acoustic	0
	26–28 September 2019	Automated acoustic	0
	13–15 December 2019	Automated acoustic	0
	3 February 2020	eDNA (2 water samples)	0
18 February 2020 (70, including 20 tadpoles)	19 February 2020	Visual	2
	24 February 2020	Manual acoustic	0
	9 March 2020	Manual acoustic	0
10 November 2020 (396)	12 November 2020	Manual acoustic	1
	24 November 2020	Manual acoustic	6
	9 December 2020	Manual acoustic	3
	29 December 2020	Manual acoustic	0

Table S5. Results of the monitoring for released captive Pickersgill's reed frogs, *Hyperolius pickersgilli*, at the River Horse Valley release site (continued)

Date of release (number released)	Monitoring date	Type of monitoring	Number of *Hyperolius pickersgilli* detected
10 November 2020 (396) (continued)	22 January 2021	Manual acoustic	0
	22 February 2021	Manual acoustic	0
	12 October 2021	Manual acoustic	0
	26–29 October 2021	Automated acoustic	0
	27 January 2022	Manual acoustic	0

Table S6. Additional details from the SWOT analysis described in the main text

Strengths	
Collaboration between stakeholders	Partners were afforded freedom to work on projects and were given support from the provincial biodiversity authority (Ezemvelo KZN Wildlife) in terms of the permits granted and stakeholder engagements undertaken. Collaborative efforts also led to tangible action on the ground and the resulting actions brought about positive processes with participating stakeholders, e.g., the rehabilitation of the Widenham wetland site by a varied group of stakeholders and agriculturalists working together to proclaim wetland habitat on their farms in Gingindlovu as a Protected Environment. The groundwork and engagement with communities by the EWT in areas where the habitat of *H. pickersgilli* was located provided the platform to work from and build on. Community buy-in for the conservation of *H. pickersgilli* and its habitat is vital and the development of meaningful relationships with traditional authorities and communities and the engagement of the community assisted in the conservation management of *H. pickersgilli*. There was local support from eThekwini Municipality, which led to the proclamation of a wetland owned by the municipality as a nature reserve.
Knowledge sharing and awareness gains	The participation of local schools at Adams Mission in an education and awareness programme developed by the EWT and inclusion of *H. pickersgilli* project updates in the EWT's annual integrated reports was effective in spreading knowledge of the species amongst people who did not know about the frog and its plight. Since the process to develop the BMP was initiated in 2013, there has been extensive media coverage related to the species. At least nine television and online documentary visual media outputs were produced (Earth Touch Insider, Euro News, TRT News, CNN Inside Africa, SABC The Agenda, SABC 50/50) and hundreds of popular articles (Euro News, TRT News, CNN Inside Africa, SABC The Agenda, SABC 50/50). The EWT's Wild Chat series on frogs featured three episodes with a total of 751 views. Numerous social media posts were used to make the public aware of the Johannesburg Zoo's Amphibian Research Project (ARP). On an international level, some articles were published through the Amphibian Ark platform relating to *H. pickersgilli* in the ARP. An updated signboard with BMP partner logos displayed with details about *H. pickersgilli* was produced in 2021 and has been erected at two wetland sites where the species occurs, namely Umlalazi Nature Reserve and Umhlanga Lagoon Nature Reserve.

Table S6. Additional details from the SWOT analysis described in the main text (continued)

Strengths (continued)	
Knowledge sharing and awareness gains (continued)	Students visiting the zoo for World Environmental Day, Wetland Week and Water Week programmes were introduced to the Johannesburg Zoo ARP's biosecure breeding facility. People's Weather channel featured the documentary '400 Frogs' on the ARP's captive breeding and release programme during March 2021. Interviews were conducted by some media outlets at various times of the year. The programme '400 Frogs' continued to be screened on national television with good feedback from numerous members of the public that have seen the programme on national television. Telephonic interviews with radio stations highlighted the conservation project and its success. Numerous information and awareness talks were conducted within the zoo to staff, as well as to members of the public.
Habitat gains	Three sites where *H. pickersgilli* occur (Sobonakhona, 503 ha; Widenham Wetland, 3 ha; Umgavusa, 127 ha) qualified for Protected Environment category through the Biodiversity Stewardship process, potentially significantly increasing the area under formal protection should all these sites be gazetted in the protected area category. A Protected Area Management Plan (PAMP) was drafted for the Umgavusa Protected Environment (Acker-Cooper, Tarrant & Mbuyisa 2022) and approved by the landowners in 2022, as were the land use map and provisional management actions. After the public participation process was completed, the site was proclaimed as a Protected Environment in May 2023. The Widenham Wetland has been rezoned to 'Conservation Reserve' status by the eThekwini Municipality and a PAMP, with the site being declared in April 2024 as Protected Environment, developed. In addition, the eThekwini Municipality has agreed to the rehabilitation of the Widenham Wetland, for which a conceptual rehabilitation plan was commissioned (Edwards et al. 2023). Previously unknown *H. pickersgilli* subpopulations were discovered at various protected or secure sites including Amatikulu Nature Reserve, Umgavusa Protected Environment, Empisini Nature Reserve, Meycol Nature Reserve, Ongoye Forest Reserve, Simbithi Eco-Estate, TC Robinson Nature Reserve (Scottburgh) and Umhlanga Lagoon Nature Reserve. Habitat loss caused by development was mitigated through commenting on development applications at five sites with *H. pickersgilli* and through the application of the environmental impact assessment mitigation hierarchy at one site.
Improved wetland health	Restoration projects targeting the removal of invasive alien plants (IAP) were implemented at three sites, Adam's Rural, where 20 local community members were employed, Groutville and Nyoni (iLembe District Municipality), where 10 local community members were employed at each. Wetland habitat and ecological goods and services (EGS) assessments were implemented at each site to determine the effectiveness of clearing activities. Invasive alien plant clearing was disrupted in 2020 due to the Covid-19 pandemic. The habitat assessments showed improved conditions where IAP control was implemented. The eThekwini Municipality has agreed to the rehabilitation of the Widenham Wetland, for which a conceptual and detailed rehabilitation plan was commissioned. Approximately 951 ha were cleared of invasive alien plants (IAPs) at four priority coastal wetlands in the eThekwini Metropolitan Area (± 636 ha) and the iLembe District (± 315 ha) over the 5-year period. An IAP management plan was developed for four wetlands in the iLembe District Municipality. Annual wetland health and Ecological Goods & Services (EGS) assessments were conducted at four sites with *H. pickersgilli*, along 4 597 transects with 17 495 quadrants (Table S4). The EGS Quality Assessment toolkit and application (Acker-Cooper et al. 2019) was used by local community members employed as Biodiversity Protection Officers to capture data on the state of the natural resources based on a score ranging from 1 (bad condition) to 5 (excellent condition). Results showed that there was a gradual increase in the quality of ecological resources at the Adam's Rural study site since 2018 where IAP clearing was implemented and where social surveys were conducted: environmental attitude surveys (n = 377); community engagement surveys (n = 528); sentiment assessments (n = 879). Based on the continuous social and wetland assessments, the interrelationship between people and their environment was demonstrated, supporting the importance of maintaining or rehabilitating wetlands within areas inhabited by people (Acker 2022). Long-term data comparing amphibian diversity in relation to wetland health indicated that generally amphibian diversity decreased as habitat condition decreased supporting the importance of restoration or rehabilitation of degraded habitat (Acker-Cooper, Tarrant & Mbuyisa 2022). Assessments of habitat integrity were made at project sites following severe flooding in 2022 in KwaZulu-Natal, which showed that wetlands with poor present ecological state (PES) had a lower ecological resilience to extreme climatic events when compared to wetlands with good PES.

Table S6. Additional details from the SWOT analysis described in the main text (continued)

Improved wetland health	A situational analysis was conducted through the One Health Forum to investigate the use of disposable diapers in communities. A comparative report to inform management and policy actions required to address disposable diaper waste was produced (Acker-Cooper et al. 2023). *Juncus kraussii* is weaved to produce traditional sleeping mats, baskets, beer strainers and other craftwork items by the Zulu people. This sedge species is in great demand because of its cultural and economic value and has been extensively and unsustainably harvested in the wild. In recent years, the wetland vegetation composition at the Umlalazi Nature Reserve has changed, including because of increased eutrophication through inflow of sewerage. A wetland rehabilitation programme was started in 2022, to ensure that *J. kraussii* debris mats that remain post-harvest are thinned out to promote vegetation regrowth. The effective management of natural resource stocks has the advantage of providing sustainable benefits to local communities while simultaneously protecting biodiversity. Engaging with the harvesters during the harvesting event is critical to them understanding the reasons for the management of the harvest. This knowledge-sharing is to ensure the sustainable supply of natural resources while conserving biodiversity, highlighting the importance of protected areas in this regard. Both Simbithi Eco-Estate and Zimbali Coastal Resort have signed agreements with the EWT as Pickersgill's Reed Frog Custodians. At Zimbali Coastal Resort, Ballito, removal of woody species and invasive alien plants from wetlands, the supplementary planting of vegetation and storm water control into wetlands, the minimizing of the area of maintained space within and adjoining wetlands and expanding the natural wetland habitat space for *H. pickersgilli* and other frog species was conducted (Brendan Smith, pers. comm., 26 May 2022).
Research, monitoring and improved security for the wild *H. pickersgilli* population	Passive acoustic monitoring (PAM) was conducted at Adam's Rural, Mt Moreland, Nyoni, Simbithi Eco-Estate (Acker-Cooper & Tarrant 2022), Gingindlovu, the Widenham wetland, and the River Horse Valley and the Buffelsdraai Landfill Site buffer zone release sites (for monitoring the success of the release of *H. pickersgilli*), as well as manually on an *ad hoc* basis at several sites. More than 8 000 hours of call data have been collected using PAM and subsets of these data were analysed for three honours projects through UKZN in 2020. Passive acoustic monitoring was found to be a useful tool in analysing the species richness of frogs at different sites (Du Toit 2020). Automatic classification was possible for *H. pickersgilli*. No geographic variation in *H. pickersgilli* call variation was documented, indicating that the set of unique acoustic identifiers, namely call duration, number of pulses, peak frequency, call period and inter-pulse interval are suitable unique acoustic identifiers, which can be pooled across geographic localities to detect the species. PAM is therefore feasible for this species and automated detection/classification algorithms, such as machine learning approaches, will be applicable in the future (Padayachee 2020). Acoustic resource partitioning was clear in four of the five studied assemblages, in which no overlap occurred, and species were well separated in acoustic space. The main call components associated with the discrimination of the species were the dominant, fundamental, start- and end-frequencies (Silver 2020). Regarding the Johannesburg Zoo's captive breeding and insurance population project, 140 mature adults were collected from the wild and transported to the zoo. From these, 786 offspring were bred, with a mortality of 2% (15 individuals died) and a productivity of 98 %. A total of 550 skin swab samples were taken from the captive *H. pickersgilli* to determine the presence or absence of the chytrid fungus *Batrachochytrium dendrobatidis*. All samples were negative and this ensured that the breeding population was free from this fatal disease.

Table S6. Additional details from the SWOT analysis described in the main text (continued)

Strengths (continued)	
Research and implementation planning	More than 1 000 individuals should be released at a site for the chances of the release to be successful, and movement of the released frogs away from the release site should be impeded if possible (Germano & Bishop 2009; Berger-Tal, Blumstein & Swaisgood 2020). An assessment of predation pressure should be conducted prior to release to ensure that the site is suitable and the effects of stress in the frogs after release needs to be considered (Germano & Bishop 2009; Berger-Tal et al. 2020). Plentiful spiders that include amphibians in their diets (although usually present at sites with *H. pickersgilli*), and predatory fish and birds were present at River Horse Valley, as determined through metabarcoding analysis of water samples and by observation. Translocations have variable success rates, and several key factors need to be considered to maximise chances of success. They also need to be supported by additional conservation interventions to tackle the initial threat of habitat loss. Natal habitat preference induction is known in a few amphibian species and captive-bred released amphibians may search for habitat with similar cues to their natal habitat (Davis & Stamps 2004; Stamps & Swaisgood 2007). Enrichment of the captive breeding environment should therefore mimic conspicuous cues to be found at the release site, such as vegetation structure and auditory cues (e.g., recordings from the release site could be played during the evening in the biosecure facility). Appropriate predator-avoidance response may need to be developed in the captive frogs before release.
Funding and employment	For example, finance was provided to the Johannesburg Zoo for the breeding of *H. pickersgilli* while funding was received by EWT from the DFFE's Natural Resource Management (NRM) programme between 2015 and 2020 for alien clearing at wetlands where *H. pickersgilli* occurs. This funding enabled the employment and upskilling of more than 140 local people for the removal of invasive alien plants. The KZN Frog Route was initiated based on wetland sites in the distribution of *H. pickersgilli*, including a strong foundation for the Adam's Rural Tour Guides eco-tourism initiative. Four people from the Adam's Rural site have been accredited site guides. The EWT's Pickersgill's Reed Frog Recovery Project employed nine full-time local community members at sites where *H. pickersgilli* occurs in the eThekwini Municipality and supported four sustainable livelihood enterprises, including a bursary for early childcare development. Three young women from the Zamani Camp community in Isipingo were selected for SMME development in 2018. The Zamani Community Skills Development Centre was launched in 2020 to replace the SMME development programme. To date, three workshops have been held with 128 participants, but this initiative was discontinued in 2020 due to the Covid-19 pandemic. EWT also hosted three water placement graduates and one research assistant during the reporting period and trained 98 traditional leaders from 18 authorities in KwaZulu-Natal on environmental compliance legislation to strengthen civic responsibility actions in support of the BMP for *H. pickersgilli*. Several organisations contributed funding in kind.
Weaknesses	
Stakeholder participation	Some members of the PRFF were uncertain of their roles during the implementation of the BMP and did not understand that they were part of a team, both within an organisation and between organisations. Project implementation depended on the willingness of members to assist; some members needed to be more aware of and own their responsibilities.
Opportunities	
Partnership development	Estates could expand residential support by meeting with residents to understand and improve buy-in from the estates. Linking residents and visitors with the natural environment through educational walks (as has been the case at Simbithi Eco-Estate) will help build emotional attachment to the wetlands that might otherwise be drained and may spearhead inclusions of environmental management considerations and actions within estate grounds management systems. Brainstorming sessions, including estate boards and environmental managers, would assist in this regard.

Table S6. Additional details from the SWOT analysis described in the main text (continued)

Opportunities (continued)	
Government support	Formalisation of systems that have been developed already by BMP partners, e.g., technical tools useful for compliance (Acker-Cooper, Little & Roxburgh 2021) and EGS monitoring and BDS management, and learning programmes, could occur through adoption by local government and eventually by provincial and national departments.
Research and monitoring	We need to know how events caused by climate change could impact the *H. pickersgilli* population, including by assessing the outcomes from climate change modeling for amphibian species. The opportunity to expand the predictive distribution model for *H. pickersgilli* in relation to climate models is now ripe. Understanding catchments better will enable the exploration of opportunities that will reduce the risk of climate change to *H. pickersgilli* and its habitat, e.g., the dispersal routes maps that have been included in municipal Spatial Development Frameworks, which could be shared with all BMP stakeholders. Postgraduate students need to be motivated and inspired to conduct research on *H. pickersgilli* and its habitat and on the threats of climate change to the species, building on the six post-graduate studies already completed on various aspects of *H. pickersgilli* and its ecology since 2012.

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Introduction of *Sesamum radiatum* in green spaces: preliminary genetic study using HAT-RAPD

Authors

[1]Julie Dumortier
[1]Samson Medza-Mve
[2]Oumar Doungous
[3]Klaus Eimert

Affiliations

[1]Masuku University of Science and Technology, BP 941 Franceville, Gabon.
[2]Institute of Agricultural Research for Development, Ekona Regional Research Centre, PMB 25 Buea, Cameroon.
[3]Institute of Molecular Plant Sciences, Hochschule Geisenheim University, Von-Lade-Strasse 1, D-65366 Geisenheim, Germany.

Corresponding Author

Klaus Eimert; e-mail: klaus.eimert@hs-gm.de

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Background and aim: The promotion of indigenous floral diversity would have a positive impact on ecosystem services and provide a source of additional income for local residents. *Sesamum radiatum* (Pedaliaceae) has great potential because it can provide a wide range of ornamental, ethnobotanical and nutritional services. Genetic studies are advocated before the increased introduction of a species into green spaces. Therefore, we aimed to study genetic diversity and differentiation among both disjunct and geographically close populations of *S. radiatum* in Gabon and Cameroon, to better manage indigenous genetic resources.

Methods: Thirteen autochthonous populations of *S. radiatum* from two disjunct savanna areas of southeastern Gabon and northern Cameroon, separated by rain forest, were analysed using a highly reproducible high annealing temperature-random amplified polymorphic (HAT-RAPD) protocol. Genetic differentiation was assessed using distance-based and Bayesian approaches.

Results and conclusion: The observed values of genetic differentiation between populations varied considerably (F_{ST} 0.041 to 0.706), with the majority found in the very high genetic differentiation range. Only two major genetic clusters were identified, mostly coinciding with geographic sampling areas. One of the populations from Cameroon showed signs of admixture possibly due to more intense agricultural activities in the area. The genetic differentiation among geographically close populations in Gabon is weak and most likely due to indigenous anthropogenic activities in connection with the traditional use of *S. radiatum*. Thus, the production and dissemination of planting material used, for instance, for green space development should take place within the main clusters in order not to distort the existing genetic structure, while benefiting from sufficient genetic diversity within the regions themselves.

Keywords: green spaces, indigenous species, genetic diversity, *Sesamum radiatum*

Introduction

In a situation of ever increasing urbanisation, confronted with the challenges of sustainable development, vegetation is the best means of structuring habitats in developing countries (Ali Khodja 2011). In this context, the development of public green spaces is a key element (Wolch et al. 2014). The urbanisation process in Africa remains marked by the lack of planning that has prevailed since the 1950s (Vermeiren et al. 2012), which contributes to the deterioration of the urban environment quality through the removal of the original vegetation cover (Kabanyegeye et al. 2022). However, the development and management of green spaces in sub-Saharan Africa cannot keep up with the spatial expansion of cities. This growth is rapid and poorly controlled, which causes a series of adverse socio-economic and environmental impacts, including a loss of biodiversity and the degradation of ecosystem services (Kaleghana

& Mweru 2018). Moreover, green spaces development plans in Central Africa are implemented with the massive use of exotic, non-native plants to the detriment of local plants. This approach prevents the utilisation of indigenous species and deprives autochthonous plant populations of their potential ecosystem services (Kabanyegeye et al. 2022). The promotion of indigenous floral diversity would have a significant positive impact on the functional quality of the landscape, allowing for the enhancement of their ecosystem services and providing a source of additional income for local residents. Gabon alone has a very rich botanical diversity, with a total flora estimated between 6 100 and 7 000 species of plants (Sosef et al. 2006). In this reservoir with undeniable potential, which remains entirely underexploited from an ornamental point of view, we highlight *Sesamum radiatum* Thonn. ex Hornem., a plant of the family Pedaliaceae.

Sesamum radiatum (Figure 1) or black benniseed is native to West and Central Africa. The leaves of *S. radiatum* are consumed as a vegetable in the countries of this region, particularly in Nigeria, Ghana, Benin and north Cameroon (Adebisi & Oni 2023), where it can amount to 50–100% of the incomes of rural households (Mbaye & Moustier 2000). The plant is used in traditional pharmacopoeia, an avenue for enriching research for new chemical entities that could lead to production of medicines for use in different therapeutic areas (Lavaee et al. 2019). It is found on nutrient-poor sites, growing in sandy, rocky or gravelly places, and it tolerates heat and drought well and continues to grow and bloom during the dry season (Bedigian 2003). As such, it is capable of occupying open places where few other herbaceous plants grow. *Sesamum radiatum* is also a hermaphroditic plant, optionally allogamous with a pollen/egg ratio equivalent to 66.1 and a development cycle that spans about 75 days (Zhang et al. 2019).

Additionally, *S. radiatum* has a high potential to contribute to ecosystem services. Ecosystem services can be defined as the services rendered to human populations by the natural functioning of ecosystems (Maréchal et al. 2016). *Sesamum radiatum* in urban green spaces generates a wide range of ecosystem services, including provisioning services such as food and medicine, regulating services like environmental stewardship and erosion control, supporting services by being melliferous, serving as green manure, providing habitat and conserving genetic diversity, and finally cultural services, which encompass aesthetic appreciation, recreation and spirituality. All of these characteristics, including its aesthetic value, illustrate the species' great potential as an autochthonous plant utilised in green spaces. Beyond green spaces, *S. radiatum* also has relevance in agriculture. Several characteristics of *S. radiatum* make it easy to multiply and use as a rapidly growing crop. *Sesamum radiatum* is among the wild relatives of sesame (*Sesamum indicum*) that are proposed as a potential source of pest and microbe resistance alleles (Kawase 2000). Thus, inclusion of *S. radiatum* into sesame breeding programmes will be an effective strategy to improve biotic stress tolerance characters and broaden the breeding potential of sesame.

Despite all its varied potentials, *S. radiatum* remains a genetically understudied species. A comprehensive understanding of the genetics of *S. radiatum* may provide a scientific foundation for its sustainable use, conservation and improvement, whether in agriculture, green spaces or traditional practices. This knowledge facilitates informed decision-making for the cultivation, utilisation and conservation of this versatile plant species. To the best of our knowledge, there is no germplasm collection for *S. radiatum*, and little is known about its genetics. Research to define the genetic diversity of *S. radiatum*, for example in Benin, has depended mainly on the use of quantitative morphological traits (Adéoti et al. 2012). However, the use of morphological and agronomic characteristics is associated with a strong influence from environmental factors. First efforts made using amplified fragment length polymorphism (AFLP) markers revealed low diversity or differentiation within the accessions analysed (Adéoti et al. 2011). The absence of detailed molecular data across multiple sesame accessions and related species also hampers further investigations into the origin and domestication of sesame. Uncu et al. (2015) emphasised the need for more characterisation of wild germplasm including African

Figure 1. *Sesamum radiatum*, habit of the flowering plant in the savanna.

species, interspecific crosses and molecular studies to efficiently harness potentialities of wild sesame species. In this context, *S. radiatum* may contribute genes that could be beneficial to *S. indicum*.

HAT-RAPD may represent a simpler and more efficient marker system for extensive *S. radiatum* biodiversity conservation and utilisation strategies. The advantage of HAT-RAPD is its simplicity and cost-effectiveness. It is not necessary to have prior information about the DNA sequence as is required for microsatellites or single nucleotide polymorphisms (SNPs), and this technique avoids the specialised electrophoretic equipment needed for AFLPs. A good knowledge of the genetic diversity and differentiation of *S. radiatum* will also make it possible to appreciate its ability to respond to environmental changes and adaptability in new environments (Miller & Cramer 2005) and will facilitate the knowledge-based preservation of natural genetic structures of the autochthonous *S. radiatum* populations. We started our study from the postulate that the distribution of *S. radiatum* is partitioned by deep equatorial tropical forest. Indeed, *S. radiatum* occurs in savannas and is not known from the tropical rainforest spanning Equatorial Guinea and eastward, and appears to represent a natural barrier (Figure 2). The objective of this work is to analyse the genetic diversity and potential differentiation of *S. radiatum* accessions on both side of this natural barrier, from the southeastern border of Gabon to the north of Cameroon. It is interesting to evaluate plants with ornamental, nutritional and cultural values from natural formations to ultimately establish a global strategy for their introduction and integration into local markets, ensuring that the process is systematic, quality controlled and adapted to needs and on-site conditions. The objective is to make them gradually available and accessible to the local populations. In the end, our goal is to promote the use of native plants for more sustainable green spaces development. Knowledge of the biology and genetic situation of autochthonous species with nutritional and decorative potential constitutes a prerequisite for valorisation through domestication. This study could be a first step to identify genes or genetic variants associated with these local adaptations. It would facilitate the identification of genetically distinct populations in different regions with implications for the conservation of genetic diversity to promote the preservation of unique populations for the species' maintenance.

Materials and methods

Sampling area

The native distribution area of *Sesamum radiatum* includes West and Central African countries (Figure 2A). Our sampling areas were located in two savannas separated by the tropical equatorial rainforest, where the species has not been observed, thus, creating a natural barrier in-between. This natural barrier is close to the species' centre of distribution. The two sampling areas were located respectively about seven hundred kilometres southeast and northeast of *S. radiatum* distribution area centre (which correspond approximately to Malabo city). By choosing sampling areas on both sides of this natural barrier, we increased the probability of capturing a greater part of the species genetic diversity, subject to different selective pressures, which could induce distinct genetic characteristics. Its populations could have developed local adaptations to cope with the specific environmental conditions in the two geographically distant regions. While both sampling areas were ecologically classified as savanna, they were not meteorologically identical. The average maximum temperatures are 34°C for the northern Cameroon region and 28°C for southeastern Gabon. In terms of annual rainfall, the northern Cameroon region receives only 700 mm of precipitation compared to a maximum of 1 900 mm in southeastern Gabon (for detailed information see Supplementary Table S1).

Plant material

Whole young leaves were collected from the apical part of 123 *S. radiatum* plants in 13 populations – i.e., those populations occupying savanna habitats of southeastern Gabon and northern Cameroon (Figure 2B). Leaves were harvested from six to ten plants per population, with individual plants in a given population separated by 100–150 m, and populations separated by 10–786 km (Figure 2, Table 1, Supplementary Table S1).

DNA extraction and HAT-RAPD analysis

DNA extraction was performed following the protocol of Eimert et al. (2016) with slight modifications. Specifically, the amount of plant material to be extracted had to be limited to 10 mg of dry leaves per 900 μl buffer because of the very high viscosity of the crude extracts, due to the richness in polysaccharides within the leaves. Polysaccharides were largely removed using polyvinylpolypyrrolidone (PVPP, 10 mg per sample) in UEB (urea extraction buffer composed of 7 M urea, 0.3125 M NaCl, 50 mM Tris-Cl pH 8, 20 mM EDTA pH 8 and 1% Sarkosine in a volume of water). For additional purification we used RNase treatment. DNA purification also included the use of phenol-chloroform-isoamyl alcohol (25:24:1). Finally, TE buffer was used to dissolve the plant DNA that is relatively free of major contaminants. The quantity and quality of DNA were estimated using a Nanodrop spectrophotometer (Thermo Scientific NanoDrop TM8000). Mean DNA concentration was 101.3 ng/μl (range 30.1–433.7 ng/μl). DNA purity

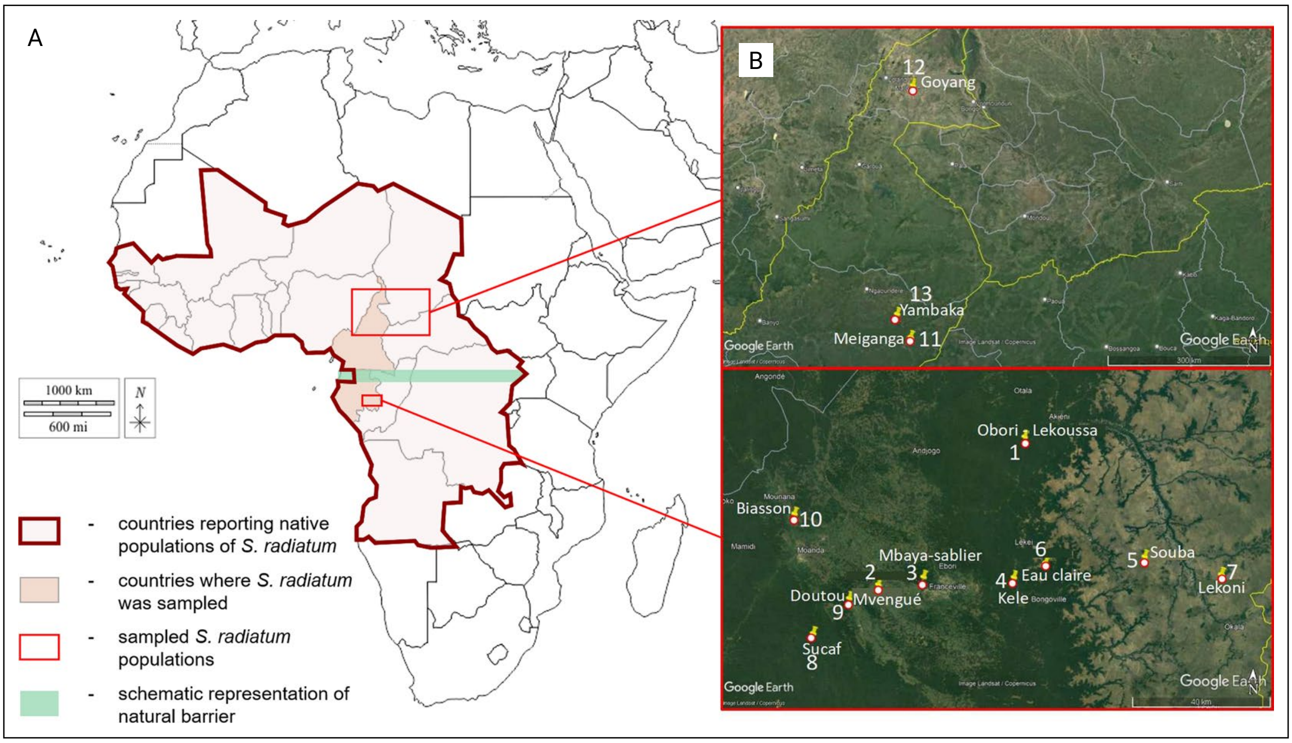

Figure 2. A, Overview of *Sesamum radiatum* distribution area, the two countries of origin are filled with light red delimited by the borders of the federal countries (thin grey lines), insets show sampling locations with B, Google Earth satellite views of the thirteen sampling sites (1–13).

was for 260/280 ratios 2.08 (range 1.64–2.61) and for 260/230 ratios 1.20 (range 0.43–1.98). DNA samples are available from the authors upon request. Prior to use, all DNA solutions were diluted with sterile deionised water to 5 ng/µl to ensure that all targets are amplified uniformly, reducing amplification biases and improving the reliability and comparability of the results. Amplifications were achieved using DNA extracts with a minimum OD260/280 ratio of 1.40.

The primers selected for the study (UBC 305, UBC 308 and UBC 312, Table S2) were part of the RAPD set of the University of British Columbia (UBC, Vancouver, Canada), chosen for their high GC content to facilitate the HAT-RAPD specific approach. The high GC content allows for the higher annealing temperatures of HAT-RAPD polymerase chain reactions (PCRs) avoiding the unspecific priming inherent to low-temperature RAPD PCRs (Chundet et al. 2007, Ruangsuttapha et al. 2007). HAT-RAPD reactions were performed in reaction volumes of 20 µl containing 5 ng/µl DNA, 1.5 µM primer, 5 mM four deoxynucleotide triphosphates (dATP, dCTP, dGTP, dTTP), 0.1 U/µl DreamTaq DNA polymerase (Fermentas, Thermo Scientific) and 1× PCR Green Buffer, using a Primus Advanced thermocycler (PeqLab, VWR International GmbH). The amplification was initiated by a denaturation step at 95°C for 5 minutes, followed by 38 cycles of 1 minute at 95°C, 1 minute at 45°C and 2 minutes at 72°C. Ramp speeds were set to 2°C/sec for heating and 1°C for cooling. The resulting DNA fragments were separated by horizontal gel electrophoresis (1.3% agarose in Tris-borate-EDTA Buffer). Gels were stained with 7.5 µl ROTI®GelStain (Carl Roth GmbH, Karlsruhe, Germany) and scanned using a MF-ChemiBIS 3.2 gel documentation system (DNR Bio-Imaging Systems, Neve Yamin, Israel).

Data analysis

Amplified polymorphic HAT-RAPD markers were scored as present (1) or absent (0) for each sample. Ambiguous bands that could not be easily distinguished were not scored (Williams et al. 1990). Thus, for the three primers and the 123 samples from 13 populations, 56 polymorphic loci were analysed. Allelic frequencies of loci were calculated using fingerprint analysis with missing data (FAMD, Schlueter & Harris 2006) using Lynch and Milligan's (1994) estimation recommended for RAPD markers. Pairwise F_{ST} values (Fixation index; Wright 1969; Holsinger & Weir 2009) were also calculated using FAMD based on the Jaccard similarity coefficient (Jaccard 1912), average coefficient calculated from 100 draws (d = 1-s). Here, also the unbiased expected heterozygosity was calculated as (2N / [2N-1])*He, where N is the number of different alleles in a population, and He equals 1-Σpi 2, where pi is the frequency of the i^{th} allele in the population. STRUCTURE 2.3 software (Pritchard et al. 2000; Falush et al. 2007; Hubisz et al. 2009) was used to detect genetic structures within the sample populations. Here, the first 100 000 steps in the Marcov chain were used as burn-in to reach equilibrium distribution, minimising the effect of the starting configuration. This was followed by 50 000 additional Markov chain steps for each K-value and the calculation was iterated 20 times to ensure consistency and reliability of the results. Settings were assuming an admixture model and correlated allele frequencies without locpriors in order to minimise skewed clusterings due to prior assumptions. The most likely number of clusters (K, tested for 1 through 13) was calculated according to Evanno et al. (2005) using the Structure Harvester program (Earl & VonHoldt 2012), where the best K was calculated based on the second order rate of change of the likelihood (ΔK, with higher numerical values indicating higher likelihoods). Based on the F_{ST} data found, distance-based cluster analysis (NJ – neighbourhood joining; Saitou & Nei 1987) for populations was calculated in FAMD and a dendrogram was constructed from 1 000 repetitions. A Principal Coordinate Analysis (PCoA; Gower 1966) for populations was conducted in GenAlEx plug-in version 6.5 (Peakall & Smouse 2006, 2012), which was also used for analysis of molecular variance (AMOVA analysis) (set to 999 permutations; Excoffier et al. 1992) to assess the hierarchical compartmentalisation of genetic variations within and among populations and between the two previously detected regions (K=2). The correlation of genetic, geographic and environmental patterns was analysed using Mantel tests (Mantel 1967; Sokal 1979) through the zt-win software (Bonnet & Van de Peer 2002) with 10 000 simulations per parameter. This analysis can reveal correlating patterns such as isolation by distance, where geographically distant populations are more genetically distinct, or adaptation to altitude, where populations at similar altitudes might be more genetically similar regardless of geographic distance. The altitude and geographic (linear) distances between the centroids of the sampled populations were determined with Google Earth™ using the 'ruler' tool. Climate data on precipitation and temperature (Supplementary Table S1) were collected based on data from the IRD (The Research Institute for Development) ground stations observation using inverse distance weighted with monthly time step and half a square degree for spatial scale. Data correspond to the average monthly values cumulated over 20 years (1991–2021).

Results

The genetic fingerprint profiles of *S. radiatum* samples show a varying degree of heterogeneity within and among populations. Pairwise F_{ST} values vary from 0.041 (between population 5 and 7) to 0.706 (between population 1 and 12) (Table 1). The overall average of interpopulation F_{ST} of all samples is 0.284. The genetic diversity within the populations is described by the heterozygosity. The unbiased expected heterozygosity over all populations is 0.256.

We used structure analysis to determine the most likely number of genetic groups (K) potentially situated in the observed populations, ranging from a minimum of 1 to a maximum of 13. In these calculations a higher ΔK indicates a greater probability of the hypothesis of the corresponding K value. Here, the most likely K value was observed for K = 2 (ΔK = 73, Supplementary Figure S1) for all models tested from the STRUCTURE analysis using all loci. Thus, we observed two main clusters with populations 1 through 10 belonging to the first cluster and populations 11 through 13 to the second cluster (Figure 3). These clusters largely correspond to the two geographical extremes, southeastern Gabon and northern Cameroon, with population 13 appearing to be an admixed population of the two main clusters. A lower likelihood (ΔK = 58) was calculated for a potential K = 3 (Supplementary Figure S1) with two possible subclusters within the Gabonese region, differentiating populations 1, 2, 3, 4, 6, and 9 (subcluster A, Figure 3, lower panel, dark blue) from populations 5, 7, 8, and 10 (subcluster B, Figure 3, lower panel, light blue). Almost all Gabonese populations show a certain amount of admixture between the subclusters, with population 3 exhibiting an almost equal allocation of both subclusters, with subcluster A (Figure 3, dark blue) slightly prevailing. No significant probability was observed for higher K values (see Supplementary Figures S1 and S2).

The PCoA (Figure 4), carried out on all the samples, supports the relative genetic distance of the populations from each other, with 46.48% and 20.48% of the genetic differentiation explained by the first two axes, respectively. Here, one group consists of populations

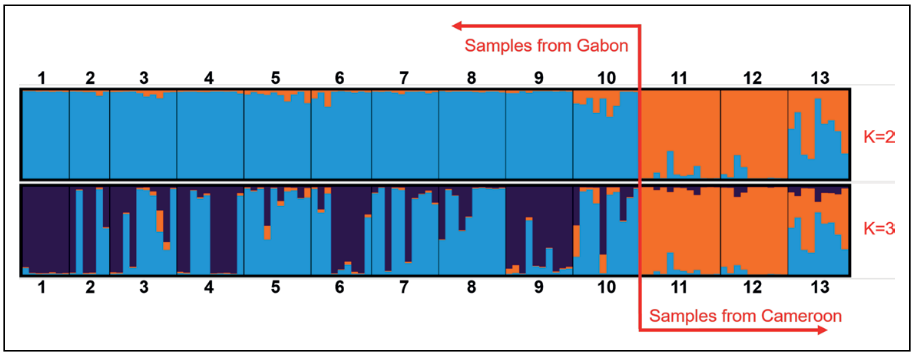

Figure 3. Bayesian estimate of genetic structure for the thirteen populations (designation 1–13) with no priors, assuming admixture and correlated allele frequencies for K = 2 and K = 3.

Table 1. Geographic and genetic distances between all sampled populations. Below the diagonal: pairwise F_{ST} values using all loci (Coefficient: Standard Jaccard, distance transformation: d = 1-s, with probability P for all F_{ST} values < 0.001, based on 999 permutations). Above the diagonal: pairwise geographical distances (linear distance between the centroids of the populations, in km)

Populations	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	60	50	40	49	37	69	83	69	70	858	1301	897
2	0.062*	0	13	40	77	49	99	23	10	32	905	1347	943
3	0.277	0.082	0	26	64	35	86	36	22	42	902	1344	940
4	0.141	0.077	0.142	0	38	10	60	60	48	66	899	1342	938
5	0.367	0.170	0.131	0.218	0	29	23	99	86	102	890	1334	930
6	0.154	0.053	0.112	0.087	0.122	0	51	70	58	74	893	1337	933
7	0.300	0.109	0.102	0.144	0.041	0.057	0	119	108	125	894	1338	935
8	0.382	0.130	0.157	0.230	0.076	0.177	0.068	0	15	35	922	1363	959
9	0.238	0.139	0.247	0.119	0.289	0.132	0.234	0.252	0	29	910	1352	948
10	0.412	0.203	0.220	0.277	0.094	0.166	0.080	0.159	0.310	0	889	1330	926
11	0.671	0.522	0.467	0.568	0.434	0.490	0.493	0.556	0.631	0.451	0	445	48
12	0.706	0.557	0.509	0.602	0.459	0.515	0.524	0.583	0.668	0.483	0.096	0	405
13	0.424	0.245	0.217	0.326	0.171	0.238	0.222	0.287	0.398	0.270	0.324	0.339	0

*Colours below the diagonal visualise the levels of differentiation according to Hartl & Clark (1997) and Frankham et al. (2002): < 0.05 low (yellow), 0.05 < 0.15 moderate (bronze), 0.15 < 0.25 high (orange), > 0.25 very high (red). Colours above the diagonal indicate the minimum and maximum distances between sampled populations.

1 through 10 and the second group of populations 11 through 13, with the population 13 occupying an intermediate position, suggesting admixture between the two main clusters. A cluster analysis revealed a similar configuration, but with the mentioned population 13 being placed nearer to populations 11 and 12 from Cameroon, than to the populations from Gabon (Supplementary Figure S3).

The AMOVA analysis of all the data applied to all samples shows that 32% of the total genetic differentiation can be detected among the populations and 68% variability within populations. Mantel tests, applied to all populations, show that there is a strong and highly significant correlation between genetic and geographical distances with R (correlation coefficient) = 0.784 (P = 0.003). Significant correlations with genetic distances were also observed for temperature (R = 0.664, P = 0.004) and precipitation (R = 0.691, P = 0.001).

Discussion

Sesamum radiatum, a traditional leafy vegetable, has strong potential to contribute to the ecosystem services provided by green spaces essential to human well-being. The genetic analysis of *S. radiatum* populations aims to give a basis for the valorisation of local nutritional plants with decorative potential and its popularisation through domestication. *Sesamum radiatum* has many advantages because it is easy to cultivate and can adapt to a wide

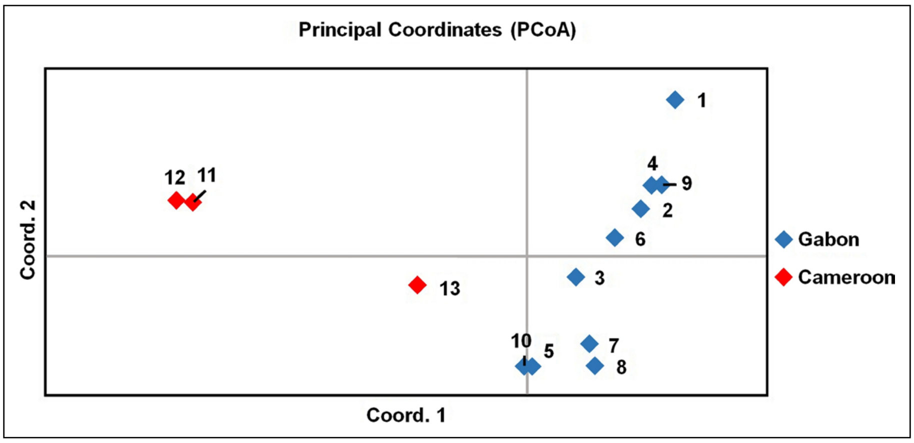

Figure 4. Principle coordinate analysis (PCoA) based on genetic distances among *Sesamum radiatum* populations (1 000 000 iterations) using all loci. The first two axes explain 46.48% and 20.48% of the variation, respectively. Colours denote the countries of origin of the populations [Coord. = coordinate].

variety of conditions. It provides ecosystem processes, such as nutrient cycling, erosion control and pest regulation, thereby helping to maintain the balance of ecosystems. By assessing the genetic diversity and potential differentiation of *S. radiatum* populations from different regions, the study lays the foundation for searching for genes or genetic variants associated with local adaptations. This information is valuable for the conservation of genetic diversity and the development of green spaces using native plants with ornamental and functional potential. The study results could facilitate the identification of genetically distinct populations, with implications for the preservation of unique populations and maintenance of the species.

HAT-RAPD markers were used in this study to assess the genetic diversity of *S. radiatum* accessions from two regions of Central Africa. This DNA profiling technique was utilised because of the lack of knowledge about genetic sequence information from *S. radiatum* and the cost efficiency of HAT-RAPD. A similar RAPD technique was earlier used to genetically characterise accessions of another member of the Pedaliaceae family, *Sesamum indicum* (Salazar et al. 2006).

Genetic diversity within *S. radiatum* populations remains very high with an overall mean equivalent to 0.284, which is above the unbiased expected heterozygosity for the overall populations (0.256). This high genetic diversity is likely due to the reproductive biology of *S. radiatum* as a hermaphrodite plant with preferential allogamy and anemophilous pollination (Ahohuendo et al. 2012). It is possible that *S. radiatum* has an estimated cross-pollination rate of up to 60% (Awoleye & Illoh 2017). As observed by Yermamos (1980), *S. indicum*, a plant of the same family and with agromorphological similarities, has approximately 10 to 20% of its diversity genetics of its populations linked to this cross-pollination. This could also explain the high level of genetic diversity observed in our study. According to Bhat et al. (1999), a high local diversity of *S. indicum* is also associated with cross-pollination, depending on the presence of pollinating insects at the time of flowering.

Distance-based analysis of the electrophoretic profiles identified two main clusters, mostly consistent with their geographic origin: southeastern Gabon and northern Cameroon, except for population 13 where we see evidence for admixture. Such general pattern is typical for large populations in the absence of disruptive selection (Hartl & Clark 1997) with genetic drift as the main driver of population genetic differentiation.

In this study, Mantel tests support the role of geographical distance and climatic factors to have jointly affected the genetic differentiation of *S. radiatum*. The correlation between the spatial structure of clusters and the genetic structure might be related to genetic drift through founding effects. The distance between the two savannas has very likely contributed to an inhibited gene flow. The significant correlation between genetic distance and climatic factors suggest that differences of temperature and precipitation between the two savannas may have driven local adaptation or divergent selection in the areas. The climatic conditions of the two clusters are not at all identical. Therefore, one might speculate that the populations of each cluster may have acquired morphological or physiological characteristics adapted in response to specific ecological conditions (Sauvion & Darnis 2022). Thus, populations in the two areas may represent different ecotypes. Concerning population 13 in Cameroon, there were many agricultural activities in the locality compared to other sites. This could be one of the reasons why we observed significant admixture of the two main genetic clusters only in this Cameroonian population. However, our current dataset may not be sufficient to achieve this level of discrimination. This can be done with additional sampling from West African and other Central African countries.

Further Bayesian analysis of the Gabonese cluster allows for the possible existence of two subgroups within the cluster. However, cluster analysis cannot find any evidence for further isolation by distance or for selective adaptation within this cluster. Also, AMOVA shows no strong differentiation between the populations of this cluster. Hence, we argue that this weak differentiation is most likely due to anthropogenic activities (seed exchange etc.). Indeed, the first subcluster (populations 1, 2, 3, 4, 6, 9) is characterised by semi-urban environments with a proximity to main roads suggesting high anthropogenic pressures. The second subcluster (populations 5, 7, 8, 10) is characterised by more isolated areas with less anthropogenic pressure. The populations 5 and 7, which are the genetically closest populations, belong exactly to the same type of habitat, the Guineo-Congolia savanna formation, which stretches to the Congo. The area from which population 8 was sampled is located in a large private area belonging to the SUCAF Gabon Company (Sucrerie Africaine du Gabon), a sugar cane producer. In the 4 400 ha area, access to the public to this population is limited. Finally, population 10 is also geographically isolated, but less so than other populations. Population 10 was far from inhabited areas and without agricultural activities in the vicinity. All these elements suggest that the subclusters diversity could strongly depend on human factors and that the anthropogenic activities, affecting the plants directly, as well as their environs, can be considered a strong driver of genetic differentiation.

Conclusions

The HAT-RAPD method allowed for the genetic delimitation based on the actual biological situation. The two detected clusters may be shaped by geographic isolation (isolation by distance and genetic drift) or by adaptive differentiation (adaptation to different environmental factors) or anthropogenic factors (agricultural expansion or seed distribution by humans). However, we cannot, at this point, definitely differentiate between the driving factors of the differentiation of the observed populations. On the other hand, for the populations in Gabon that are geographically proximate, diversity tends to be explained by indigenous anthropogenic activities and the traditional use of *S. radiatum*. Indeed, *S. radiatum* is used in the culinary habits and customs of the inhabitants. An archaeological dig in the Lastoursville region, located 200 km from the sampling sites, has uncovered seeds of *S. radiatum* or a related species in clay pots thousands of years old. The populations of the Stone Age harvested and therefore already consumed sesame seeds (White & Abernetty 1997). Thus, if we want to promote a more rational and intensive use of this plant in green space development programs, the source of seeds is a key element. The production and dissemination of planting material should take place within the clusters in order not to modify the existing genetic structure, while benefiting from sufficient genetic diversity within the regions themselves. Such an approach of detailed genetic studies of *S. radiatum* populations, allows the precise determination of regions specific to the origin and the establishment of appropriate management.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors’ contributions

Conceptualisation by S.M., O.D. and K.E.; methodology, investigation and analysis by J.D. and K.E.; writing of original draft by J.D.; review and editing by J.D., S.M., O.D. and K.E.. All authors have read and agreed to the published version of the manuscript.

Ethical considerations

Gabon and Cameroon are both members of the CEMAC (Economic and Monetary Community of Central Africa). Within this network, no permission was necessary for the collection of the leaf samples. There should be no negative impact on the sampled *S. radiatum* populations as no plants were removed from their environment. Only a few leaves per plant were collected. The necessary phytosanitary and export permits to the EU were obtained from the Gabonese Agency for Food Safety (AGASA).

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Data availability statement

DNA samples and the complete character table (RAPD, raw data) are available upon request.

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Supplementary Material

Table S1. Population data

Population number (name)[a]	Latitude[b]	Longitude[b]	Average annual precipitation	Average annual night temp.	Average annual day temp.	Altitude[c]
1 (Obori-Lekoussa)	-1.238944	13.785194	1700 mm	22°C	28°C	450
2 (Mvengue)	-1.633853	13.418206	1800 mm	22°C	28°C	380
3 (Mbaya-Sablier)	-1.610456	13.534858	1800 mm	22°C	28°C	320
4 (Kele)	-1.603692	13.769108	1800 mm	22°C	28°C	430
5 (Souba)	-1.538844	14.106994	1800 mm	22°C	28°C	650
6 (L'eau Claire)	-1.563700	13.849944	1800 mm	22°C	28°C	550
7 (Lekoni)	-1.580514	14.307678	1800 mm	22°C	28°C	580
8 (Sucaf)	-1.766047	13.252611	1900 mm	22°C	28°C	407
9 (Doutou)	-1.672053	13.343592	1900 mm	22°C	28°C	460
10 (Biasson)	-1.457733	13.194086	1700 mm	22°C	28°C	570
11 (Meiganga)	6.502781	14.303231	1500 mm	16°C	25°C	990
12 (Goyang)	10.522042	14.237358	700 mm	22°C	34°C	430
13 (Yambaka)	6.869014	14.077717	1500 mm	16°C	25°C	1110

[a]Near settlement in parenthesis. [b]In decimal degrees. [c]In metres above main sea level.

Table S2. Primer data

Primer name	Primer sequence[a]	GC content[b]
UBC305	GCT GGT ACC C	70
UBC308	AGC GGC TAG G	70
UBC312	ACG GCG TCA C	70

[a]In 5′–3′ direction. [b]In percent (%).

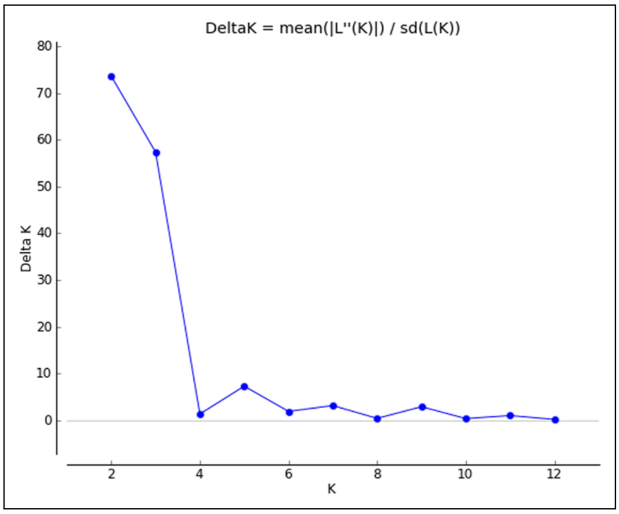

Figure S1. Delta K (ΔK) values (y-axis) for the most likely number of clusters (K; x-axis).

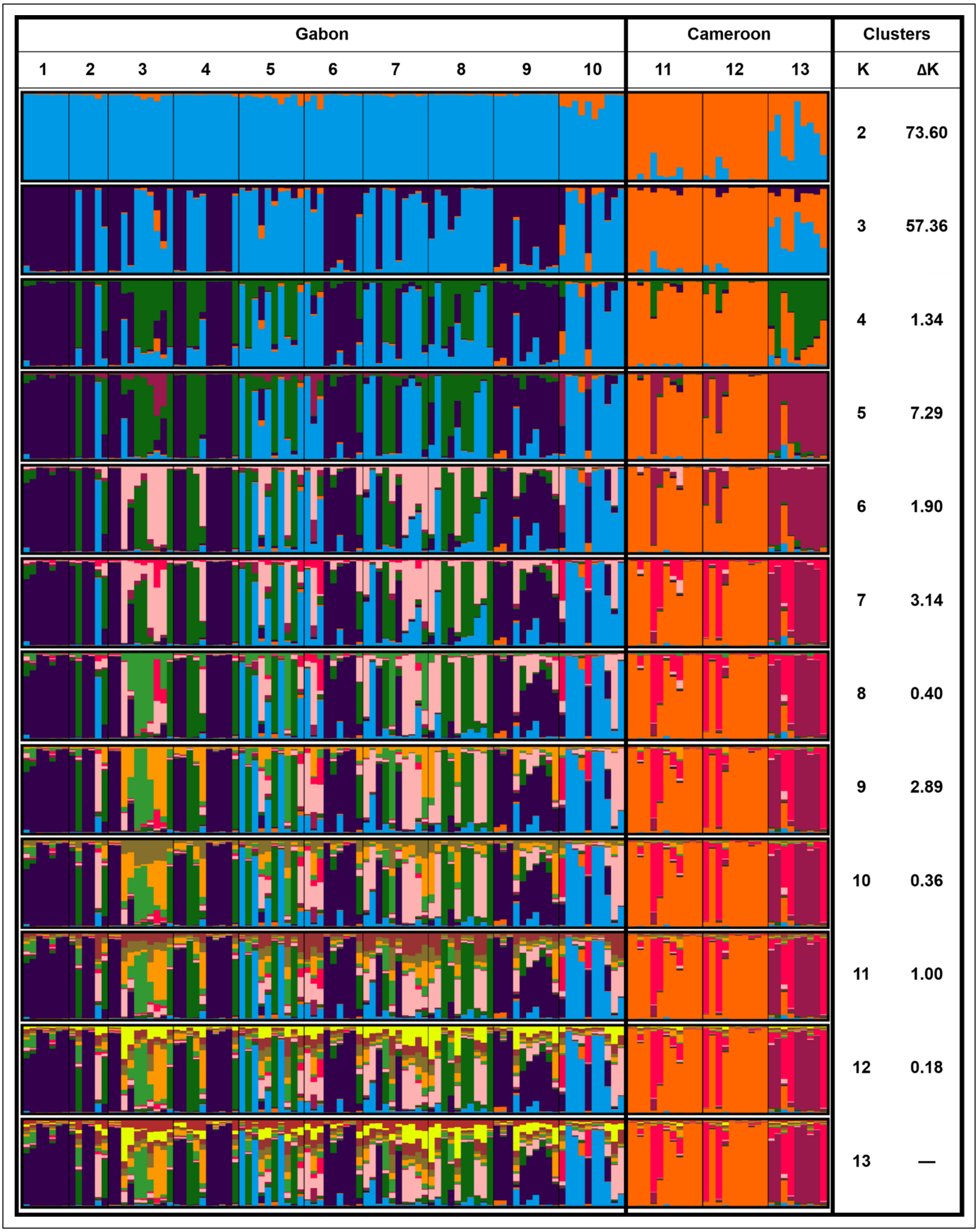

Figure S2. Bayesian estimate of genetic structure for the thirteen populations (designation 1–13) with no locpriors, assuming admixture and correlated allele frequencies for K = 2 to K = 13, and with the corresponding likelihoods (ΔK values).

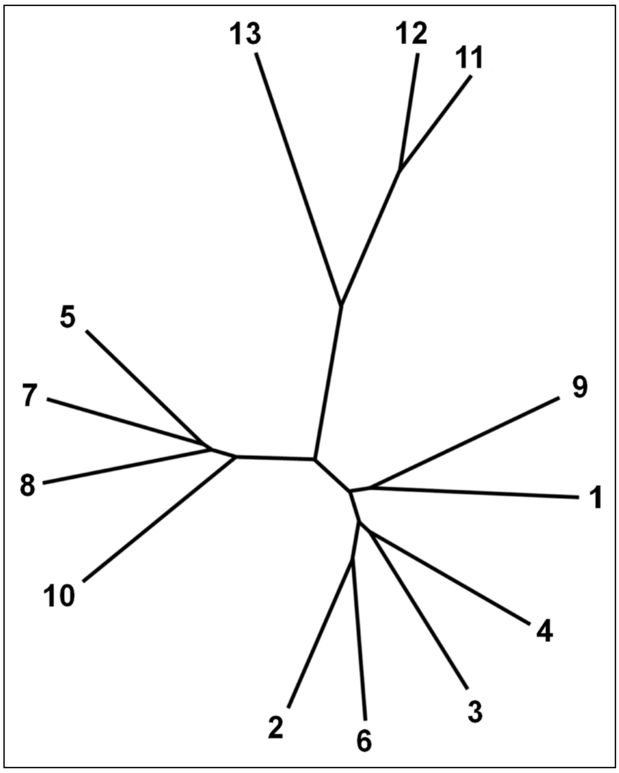

Figure S3. Dendrogram of cluster analysis of *Sesamum radiatum* using all loci (UPGMA, Jaccard, distance d = 1-s, 1 000 repetitions).

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New records of Lamiaceae (subfamily Nepetoideae) from Central Africa with the description of five new species

Authors

[1,2,3]Pierre J. Meerts
[4]Alan J. Paton

Affiliations

[1]Meise Botanic Garden, Nieuwelaan 38, 1860 Meise, Belgium.
[2]Fédération Wallonie-Bruxelles, Service Général de l'Enseignement supérieur et de la Recherche scientifique, Rue A. Lavallée 1, 1080 Brussels, Belgium.
[3]Université Libre de Bruxelles, Av. F.D. Roosevelt 50 CP 244, 1050 Brussels, Belgium.
[4]Science Directorate, Royal Botanic Gardens, Kew, Richmond TW9 3AE, UK.

Corresponding Author

Pierre J. Meerts; e-mail: pierre.meerts@plantentuinmeise.be

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Background: Subfamily Nepetoideae is the last subfamily of Lamiaceae not yet dealt with by the Flore d'Afrique centrale, and many specimens are still unidentified in the collections.

Objectives: To prepare the treatment of subfamily Nepetoideae (*Coleus* excluded) by analysing herbarium specimens.

Methods: Herbarium material from BR, BRLU, K and POZG was studied.

Results: Five species and one variety new to science are described (*Equilabium mabwense, Fuerstia upembensis, Ocimum gnidioides, O. hirsutissimum* var. *paradoxum, Orthosiphon collinus, Plectranthus villosicaulis*). Four new synonyms are proposed. A lectotype is designated for *Ocimum fimbriatum*. Fifteen taxa are reported as new to the Democratic Republic of Congo, two to Rwanda and one to Burundi. New records of rare taxa are also included.

Conclusion: Of the 26 taxa discussed in this note, 20 are found in Haut-Katanga, highlighting the region's significant contribution to the diversity of Lamiaceae subfamily Nepetoideae in Central Africa.

Keywords: Democratic Republic of Congo, distribution, endemism, flora, Haut-Katanga, Labiatae

Introduction

The completion of Lamiaceae for the *Flore d'Afrique centrale* (the Democratic Republic of Congo (D.R. Congo), Rwanda, Burundi) is on its way, with five subfamilies published so far, namely Premnoideae and Viticoideae (Paton & Meerts 2020), Scutellarioideae and Lamioideae (Meerts 2022) and Ajugoideae (Meerts 2023). Regional treatments of the Lamiaceae have been published for limited parts of that territory i.e., Rwanda (Troupin & Ayobangira 1985), and the Virunga National Park (Robyns 1947), but these are badly outdated. The whole family is now covered by standard floras in neighbouring regions, notably *Flora of Tropical East Africa* (Paton et al. 2009), *Flora Zambesiaca* (Paton et al. 2013) and the *Flore du Gabon* (Paton et al. 2022). The preparation of the treatment of the subfamily Nepetoideae is in progress. *Coleus*, by far the largest genus of the subfamily (89 species in Central Africa), has been recently revised, including 15 species new to science (Meerts & Paton 2024). In this paper, we deal with the remaining genera. During the revision of the herbarium specimens, a number of taxa new to science have come to our attention, which we publish here. New country records are also reported here, as well as new records for poorly known taxa with restricted distributions.

Materials and methods

The study was conducted in BR, BRLU, K and POZG and is based upon the examination of specimens either collected after the most recent revision of the relevant genus, or more ancient specimens that had remained unidentified so far. Herbarium acronyms are according to Thiers (2021). Other specimens have been retrieved from GBIF (https://www.gbif.org/fr/occurrence/). The nomenclature of accepted species names follows the World Flora Online (https://www.worldfloraonline.org/). The specimens cited are grouped according to the phytogeographic regions following Robyns (1948).

Results

New records for D.R. Congo, Rwanda and Burundi are documented below. These comprise five species and one variety new to science. Fifteen, two and one species are added to the flora of D.R. Congo, Rwanda and Burundi, respectively. Four new synonyms are proposed and one lectotype is designated. Genera are dealt with in alphabetic order.

Endostemon *N.E.Br.*

Endostemon obtusifolius *(E.Mey.) N.E.Br.* in Fl. Cap. [Harvey] 5(1): 296 (1910).

TYPES: SOUTH AFRICA, Transkei, *Drège s.n.* (BM, lecto.!, designated here; K, iso.!).

Plectranthus intrusus Briq. in Bulletin de l'Herbier Boissier, sér. 2, 1: 834 (1901), *syn. nov*.

Equilabium intrusum (Briq.) Mwany. & A.J.Paton in Phytokeys 129: 117 (2019), *syn. nov.*

Distribution

Angola, D.R. Congo (new country record), Malawi, Mozambique, Tanzania, South Africa, Zambia, Zimbabwe.

Habitat

Fallow fields, degraded savanna.

Specimens examined

D.R. CONGO, **Bas-Congo**: Kititi, 1909, *Allard 14*; Yié, zone Maluku, recru postcultural, 6 Apr. 1976, *Breyne 2949* (BR); Yié, zone Maluku, rudérale, 30 Dec. 1976, *Breyne 3173* (BR); M'Vuazi, dans un champ, 23 Sept. 1957, *Delhaye 247* (BR); Environs de Ndembo, 1898, *Gillet s.n*. (2 sheets) (BR); Kisantu, 1899, *Gillet 194* (BR); Kisantu, 1900, *Gillet 662* (BR); Mboso, près de Ngeba (Territ. Madimba), savane, 15 Dec. 1980, *Nkunga* in *Pauwels 6429* (BR); Kimpako, Feb. 1909, *Vanderyst s.n*.; Makanga, 15 May 1908, *Vanderyst s.n.* (BR); Mayidi, 11 Jan. 1907, Yokolo, Apr. 1933, *Vanderyst 39847* (MO, WAG, BR).

Discussion

Plectranthus intrusus Briq. has long been an enigmatic species, supposedly endemic to SW D.R. Congo. It was interpreted by Paton et al. (2019) as belonging in *Equilabium*. Re-examination of the type material and other collections in BR shows that it is identical to *Endostemon obtusifolius*. The latter is new to D.R. Congo, but the Congolese localities in Bas-Congo are a short distance from previously known localities in N Angola. All previous records of *E. membranaceus* (Benth.) Ayob. ex A.J.Paton & Harley in D.R. Congo (except *Bequaert 7746*) were also incorrect identifications of *E. obtusifolius*.

Bibliography

Paton et al. (1994, 2013).

Equilabium *Mwany. & A.J.Paton*

Equilabium candelabriforme *(Launert) Mwany. & A.J.Paton*

Distribution

D.R. Congo, Namibia, Tanzania, Zambia, Zimbabwe.

Habitat

Savanna.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Env. de Sakabinda, savane à *Acacia*, près de la source de la Lufunfu, 9 Apr. 1971, *Lisowski 23542* & *23542a* (POZG).

Discussion

New country record for D.R. Congo. The new locality is situated a short distance from the nearest localities in Zambia.

Bibliography

Paton et al. (2009, 2013).

Equilabium janthinothryx *(Lebrun & L.Touss.) Mwany. & A.J.Paton*

Distribution

D.R. Congo, Rwanda (new country record), Uganda.

Habitat

Savanna, scrub, often on shallow rocky soil, termite mounds, fallow fields, at 1 000–2 100 m a.s.l.

Specimens examined (new identifications only)

RWANDA, **Lacs Edouard et Kivu**: Kisenyi, Mont Kama, 1 580 m a.s.l., fissure de rocher, 10 Aug. 1948, *Mullenders 2685* (BR). D.R. CONGO, **Lacs Edouard et Kivu**: Parc National Albert [Virunga], Chana (?) termitière en savane, 11 May 1959, *Keremera 396* (BR); Lulinga après de Mabenga (PNA) [Virunga], 1 000 m a.s.l., savane boisée, 12 Mar. 1957, *De Witte 14284* (BR); Parc National Albert [Virunga], vallée de la Rwindi (affl. Lac Edouard), rive gauche en aval du pont, 1 020 m a.s.l., galerie à *Euphorbia nyakae*, 3 Sept. 1956, *De Witte 13380* (BR).

Discussion

New country record for Rwanda. *E. janthinothryx* is very closely related to the east African *E. longipes*, from which it differs in the slightly longer calyx and pedicel and indumentum of rachis consisting only of very short glandular hairs (< 0.2 mm). *E. janthinothryx* has a narrow distribution range in eastern D.R. Congo, western Rwanda and southern Uganda, i.e. at the western limit of *E. longipes'* distribution range.

Bibliography

Robyns (1947), Paton et al. (2009), as *Plectranthus janthinothryx*.

Equilabium mabwense *Meerts & A.J.Paton, sp. nov.*

TYPES: D.R. CONGO, **Haut-Katanga/Bas-Katanga**: Upemba National Park, près de Mabwe, sous-bois de forêt katangaise, 18 Nov. 1948, *Van Meel* sub *De Witte 4629* (BR0000017708074, holo!; K, iso.). urn:lsid:ipni.org:names:77351580-1

Relationships

Close to *E. viphyense* (Brummitt & Seyani) Mwany., Culham & A.J.Paton on account of the vertical tuberous rootstock with annual shoots, the red sessile glands on calyx and corolla, differing in the indumentum of the stem lacking long hairs, the longer petiole, the asymmetric, ovate-elliptic obtusely cuneate (not cordiform) leaf blade, the longer pedicels, the longer corolla; *E. stenophyllum* (Baker) Mwany. & A.J.Paton has similar vertical, carrot-like tubers but leaves are very different in shape.

Description

Perennial herb ± 80 cm high, with a thickened, vertical, more or less fleshy rootstock; stem erect, fleshy, ± 6 mm in diam. in lower part (in dry material), shortly pubescent, with retrorse eglandular somewhat curly hairs and orange sessile glands, in the inflorescence only with papilliform (0.1–0.2 mm) glandular hairs, branching in the upper part. *Leaves* opposite, often with smaller leaves in the axils, the lowermost ones often broader than long, petiole 1.5–7.0 cm, striate, with curly eglandular hairs; lamina ovate-elliptic, elliptic to broadly ovate, very variable in shape on the same shoot, 5.5–14.0 × 3.0–7.0 cm, remarkably asymmetric, with the two halves of the same blade of different shapes, base obtusely cuneate, to almost rounded or almost auriculate, apex acute to subobtuse, with 5–6 pairs of secondary veins and many subsidiaries, margin irregularly crenate-serrate, upper surface shortly pubescent and with many red sessile glands (± 15/mm^2), lower surface shortly pubescent on venation (retrorse hairs), and with dense red sessile glands (± 30/mm^2). *Inflorescence* broadly paniculate, very lax, of opposite thyrses in the 2–5 upper nodes of the stem, in the axils of foliaceous bracts upwardly decreasing in size, the others in the axils of foliaceous bracts; each thyrse ± 25–35 cm long, very lax, of ± 15 verticils spaced 10–15 mm apart at anthesis, up to 25 mm in fruit; bracts broadly ovate to obovate, ± 1–3 mm long, ciliate, those subtending thyrses up to 7 × 5 mm; rachis with short papilliform mostly glandular hairs (0.1–0.2 mm), and sessile orange glands; cymes subsessile, 2- or 3-flowered; pedicel patent, 6–8 mm at anthesis, up to 9 mm in fruit, papillate and with tiny glandular hairs. *Calyx* campanulate, ± 3–4 mm long at anthesis, with red sessile glands and papillae, up to 8.5 mm long in fruit, tube slightly curving, upper lobe recurved, decurrent, ovate-elliptic, 3–4 mm long, acute at apex, lateral lobes of lower lip narrowly triangular, subulate, ± 2 mm long, middle lobes of lower lip subulate, ± 3 mm long. *Corolla* ± 15–20 mm long, colour not observed (collecting note in *De Witte 4629*: 'violacée très pâle' [very pale purplish]), in herbarium flushed mauve on lower lip, with red sessile glands, tube sigmoid ± 10 mm long, narrowest in the middle, expanding to throat, very shortly papillate-puberulent, upper lip erect, 2-lobed, ± 6–7 mm long, lower lip carinate, ± 6–12 mm long, 2.5 mm deep, hairy within. *Fruit* not observed. Figure 1, Figure S1.

Etymology

The specific epithet refers to Mabwe, a locality near Lake Upemba, where the species was collected.

Diagnostic characters

A geophyte with a fleshy, carrot-like vertical rhizome, annual shoots, more or less fleshy, asymmetric leaves generally not cordate at base, red sessile glands on calyx and corolla.

Distribution and habitat

E. mabwense is endemic to the northern part of Haut-Katanga near the limit with lower Katanga. It grows in dry

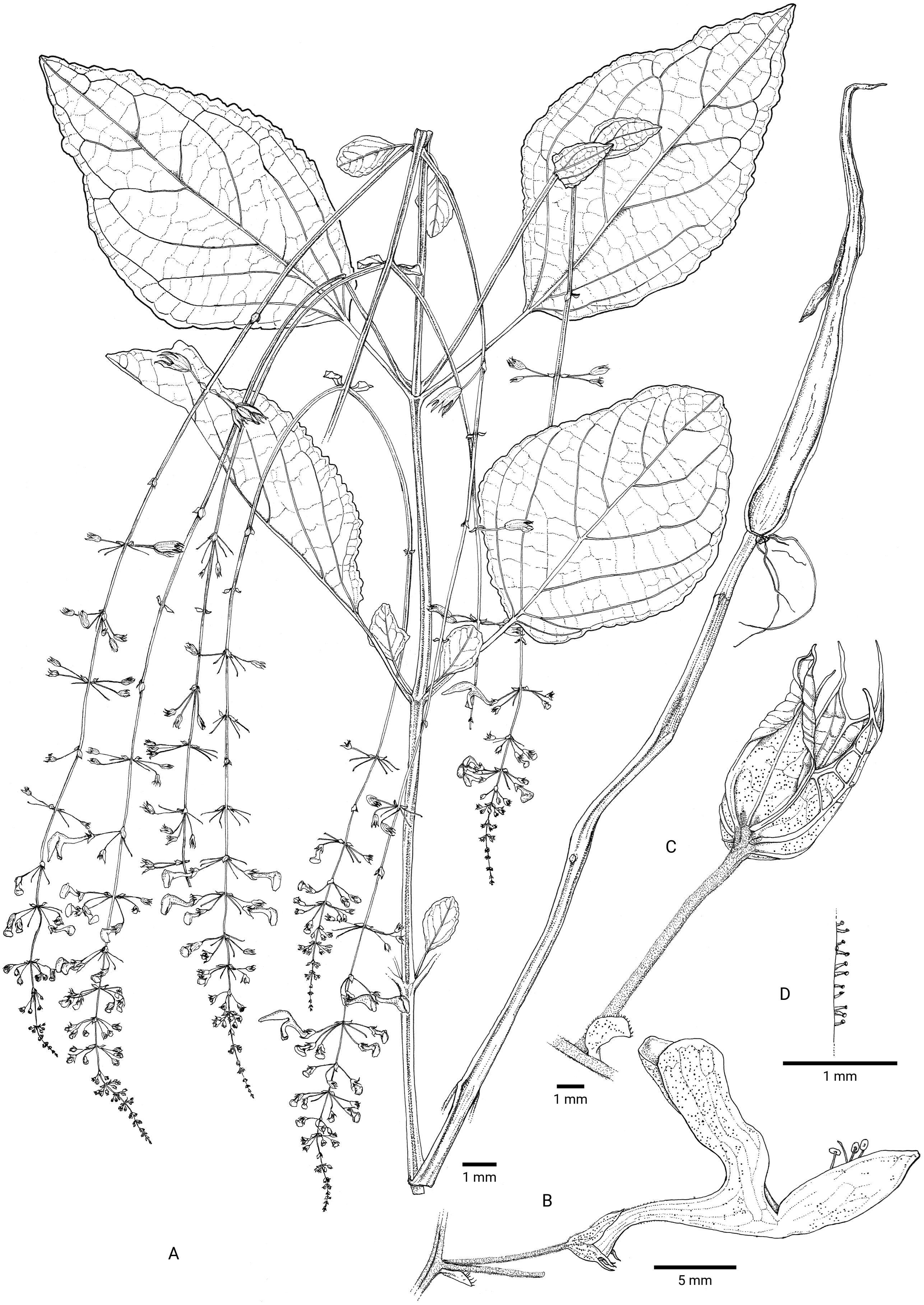

Figure 1. *Equilabium mabwense*. A, whole plant; B, flower at anthesis; C, fruiting calyx; D, detail of pubescence of corolla tube. From *Van Meel* sub *De Witte 4629* (BR). Artist: Hilde Orye.

tropical woodland (miombo). It has been collected in flower in the rainy season, from November to March.

Conservation status

Conservation status is Data Deficient (DD). It is unclear if the species was collected within the core area of Upemba National Park, which is protected, or in the 'zone annexe' in which human activities are allowed.

Additional specimens examined

D.R. CONGO, **Haut-Katanga**: Parc national de l'Upemba, près de Mabwe, forêt katangaise, 29 Feb. 1948, *Van Meel* sub *De Witte 4738* (BR); Mabwe, sous-bois de forêt katangaise, terrain sablonneux, 8 Mar. 1949, *Van Meel* sub *De Witte 5824* (BR).

Equilabium masukense *(Baker) Mwany. & A.J.Paton var.* **masukense**

Distribution

Burundi, D.R. Congo (new country record), Kenya, Malawi, Tanzania, Zambia.

Habitat

Rocky outcrops or open areas in dry woodlands (miombo) and grasslands, disturbed ground; at 1 300–1 800 m a.s.l.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Kundelungu, lieu-dit 'La Dalle', 1 450 m a.s.l., lisière de forêt galerie, 18 Feb. 1969, *Lisowski, Malaisse & Symoens 2558* (BR). BURUNDI, **Kiharo**: Mosso, dans une forêt claire à dominance de *Berlinia* sp., 28 Mar. 1952, *Michel & Reed 1504* (BR); Kioffi, Mosso, Forêt de *Brachystegia* sp., 27 Mar. 1952, *Michel & Reed 1581* (BR); Kininya, Mosso, Forêt de *Brachystegia*, 8 May 1952, *Michel & Reed 1872* (BR); Rusengo, Buyogom, 1 700 m a.s.l., rudérale, 17 Apr. 1952, *Michel 4002* (BR).

Discussion

New country record for D.R. Congo. Paton et al. (2013) recorded this species in D.R. Congo but the source of this information could not be traced. In Burundi the species was known hitherto from a single collection.

Bibliography

Paton et al. (2009, 2013).

Equilabium parvum *(Oliv.) Mwany. & A.J.Paton*

Distribution

Burundi, D.R. Congo, Kenya, Malawi, Rwanda (new country record), Tanzania, Uganda, Zambia.

Habitat

Swamp savannas, fallow fields, tree plantations, degraded woodland and forest; at 1 200–2 900 m a.s.l.

Specimen examined (Rwanda only)

RWANDA, **Lacs Edouard et Kivu**: Route Cyangugu-Butare, à 6 km de Cyangugu, 1 700 m a.s.l., bord de route dans une zone habitée, 19 Jan. 1971, *Bouxin 9* (BR).

Discussion

New country record for Rwanda. The new record in Rwanda represents one of the westernmost localities of *E. parvum,* an east African species.

Bibliography

Paton et al. (2009).

Equilabium pulcherrimum *(A.J.Paton) Mwany. & A.J.Paton*

Distribution

S D.R. Congo (new country record), N Zambia.

Habitat

Savanna.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Env. Kolwezi, près du village Muilu, pente rocheuse, 8 Apr. 1971, *Lisowski 23313* (POZG); Plateau de la Manika, poste sud Musokatanda, 40 km SW de Kolwezi, 10°53'S, 25°05'E, forêt claire pâturée, 1 400 m a.s.l., 17 Feb. 1982, *Malaisse & Robbrecht 2356* (BR); 47 km WSW de Kolwezi, 1 340 m a.s.l., rudéral, bord de piste en zone de forêt claire, 14 Mar. 1983, *Schaijes 1889* (BR).

Discussion

New country record for D.R. Congo. The last two specimens were hitherto misidentified as *Coleus schizophyllus* (Meerts & Paton 2024). All Congolese collections are situated in the region of Kolwezi, ± 100–150 km NE of the type locality (Kalene hill, Zambia). The region is subject to rapidly increasing human settlement and disturbance of natural vegetation.

Bibliography

Paton et al. (2013).

Equilabium stolzii *(Gilli) Mwany. & A.J.Paton*

Distribution

D.R. Congo (new country record), Malawi, Tanzania.

Habitat

Wet savanna, marshland, springs.

Specimens examined

D.R. CONGO, **Haut-Katanga:** Marungu, Kasiki, 20–27 Jun. 1931, *De Witte 493bis* [BR0000016835351] (BR)*;* Marungu, Kipiri, bosquet bordant une rivière dans un vallon encaissé, Jun. 1957, *Duvigneaud 3714C1* (BRLU); Marungu, Kasiki, tête de source de la Bwasoa, formation marécageuse à Kotschya, 27 Jun. 1957, *Duvigneaud 3733C* (BRLU); Marungu, rivière Mobolozi, 27 Jun. 1957, *Duvigneaud 3734* (BRLU); Marungu, tête de source de la Kapangala, cirque boisé à *Lobelia*, 27 Jun. 1957, *Duvigneaud 3740C* (BRLU); Marungu, 1940, *Jurion 267* (BR).

Discussion

New country record for D.R. Congo. All collections are situated in the Marungu massif, a region with Afromontane vegetation and with phytogeographic affinity with eastern Africa. The species distribution range is relatively restricted stretching from Lake Malawi to Marungu. The gathering *De Witte 493* consists of two sheets i.e., [BR0000016835344] which is *Coleus marunguensis* Meerts & A.J.Paton (Meerts & Paton 2024), and [BR0000016835351] which is *Equilabium stolzii*; the latter was renumbered by us as '*De Witte 493bis*'.

Bibliography

Paton et al. (2009, 2013).

Fuerstia *T.C.E.Fr.*

Fuerstia angustifolia *G.Taylor*

Distribution

Angola, D.R. Congo (new country record), Malawi, Tanzania, Zambia.

Habitat

Steppic savanna, dry woodlands, dambos, often on sandy soil; at 1 000–1 400 m a.s.l.

Specimens examined

D.R. CONGO, **Haut-Katanga**: 2 km S of Mofya, Ferme Servranckx, *Duvigneaud 3470* (BRLU); Biano-hôtel, savane arborée de pente sur sable profond, 8 Dec. 1959, *Duvigneaud 4455* (BRLU); Biano-hôtel, *Duvigneaud 4459* (BRLU); 33 km S of Kolwezi, forêt claire de pente, 16 Dec. 1959, *Duvigneaud 4605* (BRLU); Entre Pande et Kakonge, forêt sur macigno, à *Brachystegia bussei*, *Duvigneaud 4775* (BRLU); Forêt claire riche en *Monotes*, 27 Dec. 1959, *Duvigneaud 4788* (BRLU); Fungurume, savane steppique cuprifère, *Malaisse, Kisimba & Saad 1013* (BRLU); Fungurume, colline XII, sur la route vers Kwatebala, 16 Dec. 2007, *Senterre, Handjila & Semereab 4879* (BR).

Discussion

New country record for D.R. Congo.

Bibliography

Paton et al. (2013).

Fuerstia upembensis *Meerts & A.J.Paton, sp. nov.*

TYPES: D.R. CONGO, **Haut-Katanga**, Upemba National Park, Kaswabilenga, rive droite de la Lufira, [08°81'S, 26°43'E], 700 m a.s.l., forêt claire, 23 Oct. 1947, *De Witte 3003* (BR0000017708005, holo!; K iso.). urn:lsid:ipni.org:names:77351581-1

Relationships

Similar to three Angolan species with opposite leaves and 2-flowered verticils i.e., *F. adpressa* A.J.Paton, *F. rara* G.Taylor and *F. rigida* (Benth.) A.J.Paton*,* the last two also having thickened rhizomes, differing from all of these in having greenish white corolla (vs purplish), from *F. adpressa* in having ascending-patent leaves (vs erect, appressed on stem), from *F. rigida* in having fewer leaves without glandular hairs, and from *F. rara* in having conspicuous glands on leaves.

Description

Geophytic perennial herb, with tufted shoots, often with remains of burnt stems at base, ± 30–60 cm high; rootstock of 1 to several woody ± horizontal rhizomes ± 5–10 mm thick. *Stem* erect, unbranched, with 3–5 nodes under the inflorescence, quadrangular, striate, shortly pubescent, with patent to slightly recurved mostly eglandular hairs of different lengths, and pale sessile glands, in the inflorescence glandular hairs abruptly more abundant. *Leaves* opposite, more rarely ternate, ascending to patent, often outwardly falcate, often with young shoots in the axils, 3–6 pairs to a stem, the lowermost pair much reduced; petiole 0–1 mm; blade flat to folded along midrib, narrowly elliptic to narrowly ovate- to obovate-elliptic, 15–75 × 4–22 mm, base cuneate to attenuate, apex acute, margin entire to somewhat crenate-serrulate distally, very narrowly recurved, shortly ciliate, dull and with sparse erect ± 0.3 mm long eglandular hairs on upper surface, very shortly hispidulous with antrorse hairs on lower surface of veins, glabrescent, glandular punctate on both surfaces, with 4 or 5 secondary veins on either side, diverging at an acute angle, reticulum becoming more or less prominent on ageing. *Inflorescence* unbranched or, more often, with a pair of ascending basal branches, 6–12 cm long, lax, with 10 to 15 verticils spaced 1–13 mm apart; bracts subtending pedicels narrowly ovate-elliptic, acute, 1.0–2.5 mm long, up to 10 mm long under the lowermost branched node; cymes 1-flowered, pedicel ascending, 2–3 mm at anthesis, elongating to 5 mm, with dense glandular and eglandular hairs and sessile glands. *Calyx* pale green, patent at anthesis, then downwardly pointing, tubular, ± 5–6 mm long at anthesis, with dense eglandular and glandular hairs and pale sessile glands, upper lobe ovate-triangular, ± 1 mm long, recurving, lateral lobes triangular, acuminate, ± 0.8 mm long, lower lobes filiform, ± 0.8 mm long; fruiting calyx ± 12 mm long. *Corolla* greenish white, 8–11 mm long, tube 4–5 mm long, upper lip 3–6 mm long, recurving, lower lip ± 3–6 mm long, horizontal. Two fertile stamens, 2 staminodes. *Fruit* not observed. Figure 2, Figure S2.

Etymology

The specific epithet refers to Upemba National Park, where the species was collected.

Diagnostic characters

A perennial herb with annual shoots, thick woody rhizomes, 3–5 pairs of opposite leaves, leaf blade ascending to patent, with sessile glands and without glandular hairs, 2-flowered verticils, and greenish white corolla.

Distribution and habitat

Endemic of D.R. Congo, Haut-Katanga; dry woodlands (miombo) and savanna, often in frequently burnt places.

Conservation status

Probably Least Concern (LC); even though the species is known from only five localities, two of these are situated within a protected area.

Additional specimens examined

D.R. CONGO, **Haut-Katanga:** Domaine de Muhila (Kansimba), forêt claire, près de la grand route, après la traversée de la rivière Konko, 28 Sept. 1970, *Bulaimu 173* (POZG-V-0072867); Plateau de Muhila, près du village Baton, savane, 1 350 m a.s.l., 6 Nov. 1970, *Lisowski 23700* (POZG-V-0072107); Parc national de l'Upemba, entre Kabenga et Kasiba, 1 250 m a.s.l., lambeau de forêt katangaise récemment incendié, 18 May 1949, *Van Meel* sub *De Witte 6379* (BR); Tembwe (baie) [near Moba], colline rocheuse, 19 Dec. 1946, *Van Meel 297* (BR).

Note

The specimen *Lukuesa 538* (BR, BRLU) (Mitwaba, Plateau des Kibara, Steppe, à l'W. de la route Jadotville-Manono, près de la source de la Musundu, 19 Oct. 1958) most likely belongs here, differing in the shorter leaves, with yellow sessile glands on both sides.

Bibliography

Taylor (1932), Paton (1994).

Isodon *(Benth.) Schrad. ex Spach*

Isodon schimperi *(Vatke) J.K.Morton*

Distribution

Burundi, D.R. Congo (new country record), Ethiopia, Rwanda, South Sudan, Uganda.

Habitat

Montane forest edges, bushland, grassland, by rivers and swamps; at 1 050–2 850 m a.s.l.

Specimens examined (new identifications only)

D.R. CONGO, **Lac Albert**: Mont Dra, Blukwa, sous bois, 13 Oct. 1937, *Gilbert 553* (BR). **Lacs Edouard et Kivu**: Entre Butembo et Lubero par Katwa, 23 km, jachère, 11 Oct. 1974, *Baudet 630* (BR); Bwito, Kihondo, 1 650 m a.s.l., 25 Mar. 1954, *Deru 116* (BR); Kirorirwe [Kirorerwa], forêt à *Acanthus*, 9 Mar. 1934, *De Witte 1447* (BR); Bisoke, riv. Susa, 2 400–2 600 m a.s.l., forêt de amboo, 2 Feb. 1935, *De Witte 2211* (BR); Env. De Kiandolili, le long de la piste Mutwanga-Kalonge, 1 800 m a.s.l., forêt ombrophile, 11 Oct. 1952, *Frédéricq* sub *de Witte 8257* (BR, WAG); Parc national Albert [Virunga], Rumangabo, 1958, *Donis 3970, 4084* (BR); Territ. Masisi, Bukombo, entre cultures et savanes à *Pennisetum*, 1 420 m a.s.l., 29 Apr. 1957, *Gutzwiller 826* (BR); Territ. Walikale, Ibusha, Mutongo, 1 050 m a.s.l., 12 May 1958, *Gutzwiller 2886* (BR); Bukombo (zone Masisi), 1 300 m a.s.l., savane à *Pennisetum*, 8 Mar. 1958, *Gutzwiller 3522* (WAG); Ouest du lac Kivu, 2 000 m a.s.l., 1929, *Humbert 7803* (BR); Volcan Ninagongo [Nyiragongo], 2 000–2 200 m a.s.l., 1929, *Humbert 7940* (BR); Mushumangabo, 2 075 m a.s.l., forêt, Aug. 1937, *Lebrun 7136* (BR, K); Versant sud du Mikeno, 2 400–2 600 m a.s.l., étage des bambous et de la forêt mixte, Aug. 1937, *Lebrun 7297* (BR, K); Parc national des Virunga, Ruwenzori, entre Mutwanga et le gîte de Kalonge, 1 400–1 700 m a.s.l., jachère à *Pennisetum purpureum*, 28 Dec. 1977, *Lejoly 2272* (BR); Parc national Albert [Virunga], flanc NW du volcan Karisimbi, 2 400–2 800 m a.s.l., étage des bambous et forêt mixte, 17 Aug. 1937, *Louis 5255* (BR, K); Territ. Rutshuru, Parc National des Virunga, Kibumba, forêt secondaire, Jun. 2009, *Mangambu 2068* (BR); West Ridge of Lamia, 2 300 ft [700 m a.s.l.], 5 Aug. 1952, *Osmaston 1951* (BR); Territ. Kabare, Kahuzi, forêt de montagne, 20 Jul. 1976, *Pauwels 5642* (BR); Ruamoli valley, 8 600 ft [2 620 m a.s.l.], gulley, bamboo

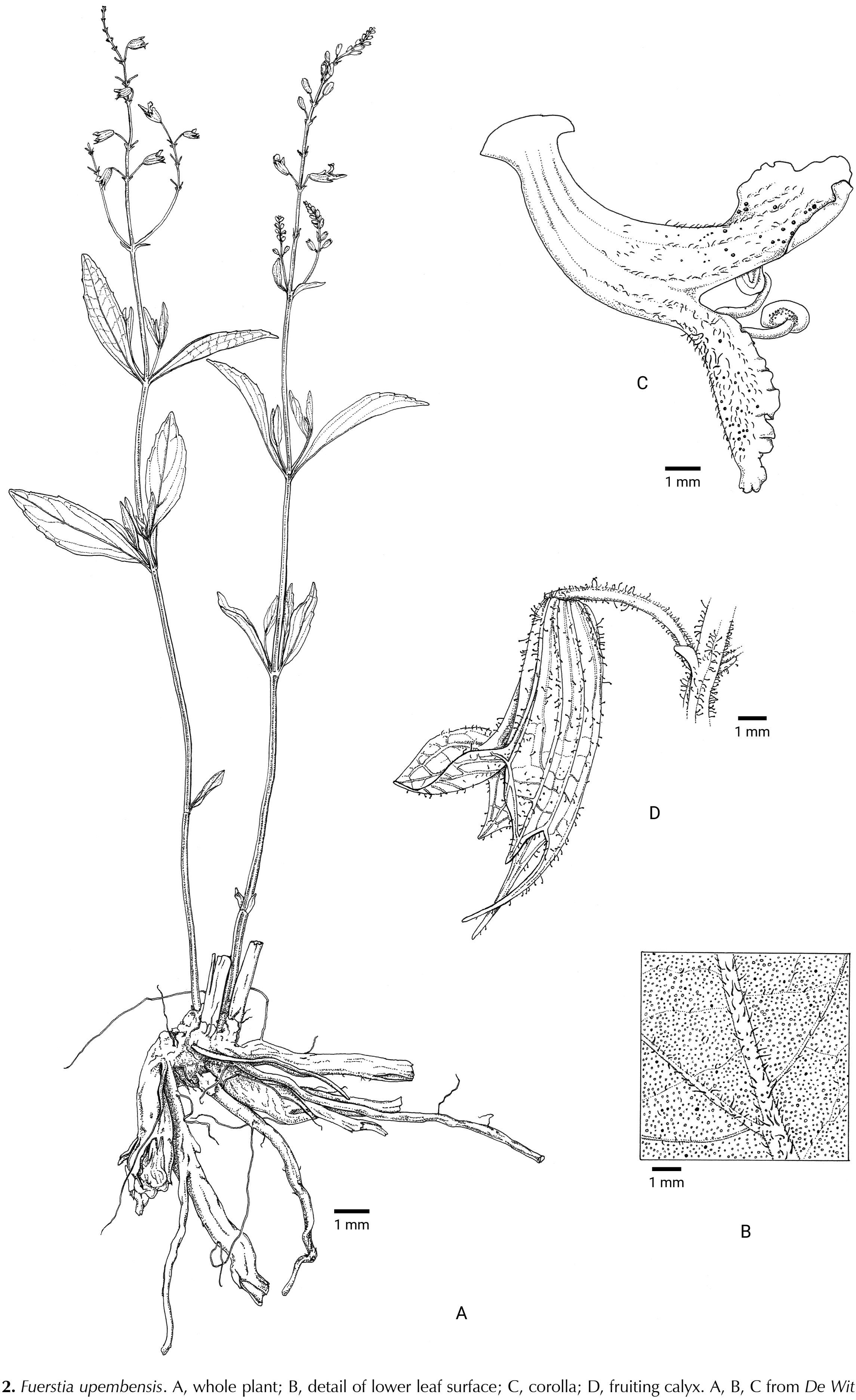

Figure 2. *Fuerstia upembensis*. A, whole plant; B, detail of lower leaf surface; C, corolla; D, fruiting calyx. A, B, C from *De Witte 3003* (BR), D from *Van Meel 297* (BR). Artist: Hilde Orye.

forest, 5 Aug. 1952, *Ross 843* (BR); Tshibinda, Kivu, 1929, *Scaetta 1228* (BR); Tshifunzi, 1928, *Scaetta 695* (BR); Entre Karoba et Mofumo, 1 900–2 100 m a.s.l., 1928, *Scaetta 848* (BR); Nord Kivu, Virunga, Kibati, 1 900 m a.s.l., südliches Lavavorland der Westgruppe, im Busch, 30 Sept. 1954, *Stauffer 547* (BR, K); Katana, 1932, *Vanden Hout 425* (BR).

Discussion

New country record for D.R. Congo. *I. schimperi* occurs in the mountains of NE Africa from Ethiopia southwards to Burundi. It had not been formally reported from D.R. Congo so far. It is closely related to the widespread *I. ramosissimus* (Hook.f.) Codd with which it has often been confused, e.g. by Troupin and Ayobangira (1985) in the *Flore du Rwanda* [see Polhill (2009) for a discussion of the distinction of the two species]. The examination of material of *Isodon* from D.R. Congo has shown that *I. schimperi* is widespread in the mountains of N Kivu.

Bibliography

Robyns (1947), Troupin & Ayobangira (1985), Polhill (2009).

Ocimum *L.*

Ocimum amicorum *A.J.Paton*

Distribution

D.R. Congo (new country record), Tanzania.

Habitat

Clearings in miombo woodland and savanna, often on moist soil.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Dikulushi, 1 000 m a.s.l., clairière de forêt claire, 25 Oct. 1980, *Malaisse 11145* (BR); Upemba, près de la tête de source de la Ziveba (?), 1 680 m a.s.l., terrain marécageux en pente de 30°, 24 Aug. 1949, *Van Meel* sub *De Witte 7510* (BR).

Discussion

New country record for D.R. Congo. *O. amicorum* was known hitherto from a relatively narrow range in SW Tanzania (Ufipa District). Newly identified materials from D.R. Congo extend the species' range ± 750 km to the west.

Bibliography

Paton et al. (2009).

Ocimum angustifolium *Benth.*

Distribution

Angola, Botswana, D.R. Congo (new country record), Kenya, Malawi, Mozambique, South Africa, Tanzania, Zambia, Zimbabwe.

Habitat

Steppic savanna, sometimes on moist soil, at 1 200–1 700 m a.s.l.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Marungu, section de Mulongoshi, 1 700 m a.s.l., Nov. 1945, *Quarré 7213* (BR); Territ. Jadotville [Likasi], Busumba, 90 km NE de E'ville [Lubumbashi], 1 278 m a.s.l., 28 Sept. 1957, *De Caters 131* (BR); Haut-Shaba [Haut-Katanga], Domaine de Muhia [Muhila], Mont Kiseye, 1 700 m a.s.l., 7 Nov. 1970, *Lisowski 23323* (POZG, 7 sheets).

Discussion

New country record for D.R. Congo. *Ocimum angustifolium* is an east African species, broadly distributed from Kenya southwards to South Africa (northern provinces). Three specimens from D.R. Congo (Haut-Katanga) have been recently identified. Other specimens filed as *O. angustifolium* in POZG are errors for narrow-leaved forms of *O. obovatum* E.Mey. ex Benth. [e.g. *Lisowski 23267* (POZG)].

Bibliography

Sebald (1989), Paton (1995), Paton et al. (2009).

Ocimum dambicola *A.J.Paton*

Distribution

Burundi (new country record), D.R. Congo (new country record), Malawi, Tanzania, Zambia.

Habitat

Savanna.

Specimens examined

D.R. CONGO, **Ubangi-Uele:** Tukpwo, savane, 22 Oct. 1954, *Gérard 1602* (BR). BURUNDI, Kininya Mosso, savane à *Loudetia arundinacea*, 12 Jun. 1952, *Michel 2786* (BR): Mosso, Ruyigi, savane légèrement boisée, 11 Oct. 1951, *Michel & Reed 534* (BR).

Discussion

New country record for Burundi and D.R. Congo. The new localities in Burundi are situated at short distance from the previously known localities in N Tanzania; the new locality in NE D.R. Congo is disjunct.

Bibliography

Paton (1995, as *Becium obovatum* subsp. *punctatum*), Paton et al. (2009, 2013).

Ocimum fimbriatum *Briq.* var. **fimbriatum**

TYPES: ANGOLA, *Mechow 165* (B, holo., destroyed; BR0000006249465, lectotype designated here).

Clerodendrum sessilifolium Moldenke in Phytologia 4: 289 (1953), *syn. nov.*

Ocimum glabrifolium var. *sapinii* De Wild. in Annales de la Société scientifique de Bruxelles 41: 20 (1921), *syn. nov.*

Distribution

Angola, Burundi, D.R. Congo, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe.

Habitat

Dry deciduous woodland, savanna, at 900–2 100 m a.s.l.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Nikondama [Bikondama?], Oct. 1911, *Hock s.n.* (BR [BR0000008978585]); Bukama, 5 Jun. 1911, *Bequaert 111* (BR); Sankisia, 24 Sept. 1911, *Bequaert 212* (BR); Nasondoye, forêt mulu [muhulu] sur Kalahari, 11 Dec. 1959, *Duvigneaud 4514Be* (BRLU); Dilolo, Jun. 1908, *Sapin s.n.* (BR [BR0000005570942] & [BR0000005570959]); Parc national de l'Upemba, entre Kabenga et Kaziba, lambeau de forêt katangaise récemment incendiée, 1 250 m a.s.l., 18 May 1949, *Van Meel* sub *De Witte 6382* (BR); Environs de Lubudi, 1937, *Cabu 112* (BR); Fungurume, colline 5, petite zone d'affleurement cuprifère entourée d'une savane arborée basse, 6 Dec. 2007, *Senterre, Handjila & Semereab 4779* (BR).

Discussion

Clerodendrum sessilifolium has long been an enigmatic species, known only from the type specimen. During our revision of *Clerodendrum* for Central Africa (Meerts 2022), we have re-examined that material. The specimen has very few flowers, but bowl-shaped sessile glands are conspicuous in the inflorescence, thus pointing to *Ocimum*. Calyx shape, with fimbriate lateral teeth, separated from lower teeth by a sinus, points to *O. fimbriatum*. This is a most polymorphic species for leaf shape and size, and several varieties have been described. *Hock s.n*. (type specimen of *C. sessilifolium*) and *Sapin s.n.* (type specimen of *O. glabrifolium* var. *sapinii*) are remarkable in having larger leaves, with blade more ovate than usual for *O. fimbriatum* subsp. *fimbriatum*; however, variation is continuous and we consider these names as synonyms of *O. fimbriatum* var. *fimbriatum*. *O. fimbriatum* var. *bequaertii* (De Wild.) A.J.Paton also has broad leaves, but they are distinctly petiolate. Such broad-leaved morphs appear to be more frequent in W Katanga compared to the rest of the distribution range.

Bibliography

Sebald (1988), Paton (1995), Paton et al. (2009, 2013).

Ocimum gnidioides *Meerts & A.J.Paton, sp. nov.*

TYPE: D.R. CONGO, **Haut-Katanga**, entre les 2ème et 3ème rivières sur la piste du détournement de la piste Kolwezi-Musokantanda, 10°48′12″S, 25°19′28″E, 1 454 m a.s.l., 21 Oct. 1989, forêt claire à petits arbres, *Schaijes 4481* (BR0000017713641, holo!). urn:lsid:ipni.org:names:77351582-1

Relationships

Superficially similar to *O. ericoides* (P.A.Duvign. & Plancke) A.J.Paton on account of the small leaves, differing in lack of fascicles of leaves in the axils, the leaves tightly appressed onto the stem (*O. ericoides*: becoming patent to reflexed), the leaf blade pubescent on both surfaces (*O. ericoides*: subglabrous), the margin often with a tooth on either side (*O. ericoides*: margin entire), the reticulum slightly prominent on both surfaces, thickened leaf margin, and the pale mauve corolla with darker stripes (*O. ericoides*: cream-coloured without stripes).

Description

Perennial geophyte, up to 50 cm high, with tufted annual shoots on a thickened, vertical woody rhizome. *Stem* erect, more or less virgate, quadrangular, ± 1.5 mm thick in lower part, pubescent, with patent eglandular hairs 0.25–0.50 mm, and sessile glands, unbranched or sparingly branched, internodes ± 10 mm. *Leaves* up to 35 pairs to a stem, opposite, sessile, erect, without fascicles of young leaves in the axils; lamina more or less coriaceous, narrowly elliptic, obovate-elliptic or ovate-elliptic, 8–15 × 2–4 mm, base cuneate to almost rounded, apex acute to obtuse, flat or more often gutter-shaped, margin thickened by a submarginal vein, entire or often distally with 1 or 2 teeth on either side, 3–5 secondary veins on either side, diverging at a narrow angle, venation slightly prominent on both surfaces (in herbarium), pubescent on both surfaces like the stem, gland-dotted. *Inflorescence* terminal, 1 cm long at anthesis, elongating to 9 cm, with ± 10 verticils spaced 2 mm apart at anthesis, up to 20 mm in fruit, bracts narrowly ovate, 3–4 mm long, early caducous or more or less persistent and forming a coma; pedicel 1 mm, ascending to patent. *Calyx* ± 5 mm long at anthesis, accrescent to at least 8 mm (fully mature calyx not seen), tube shortly pubescent and with pale sessile glands, upper lip obovate, ± 2 mm long, margin of lateral lobes denticulate to slightly fimbriate, with a fringe of white hairs, middle lobes of lower lip subulate, purplish, 3 mm. *Corolla* pale mauvish with darker stripes, ± 10 mm long, tube ± 6 mm long, lobes conspicuously fimbriate, stamens exserted 10–15 mm. *Fruit* not seen. Figure 3, Figure S3.

Etymology

The specific epithet *gnidioides* refers to the resemblance of the plant to some species of *Gnidia*, which also have many small erect leaves.

Diagnostic characters

A suffrutex with short internodes, small, erect leaves with lamina pubescent on both surfaces and slightly prominent reticulum.

Distribution and habitat

Endemic of D.R. Congo (Haut-Katanga, region of Kolwezi); steppic savanna, at ± 1 500 m a.s.l.

Conservation status

Probably Endangered (EN); known only from the type specimen, and one picture of a living plant in nature, both in the region of Kolwezi, subject to rapid increase in human settlement and disturbance of the natural flora.

Additional specimens examined

D.R. CONGO, **Haut-Katanga**: Plateau sablonneux de la Manika, au sud de Kolwezi, Aug. 1950, *Schmitz 4122* (BR); Mutshatsha, 16 Oct. 2016, W.McCleland (photo iNaturalist).

Note

Another specimen possibly belongs here (*Schmitz 5588* (BR)); it departs from the type in having less numerous, broader, obovate leaves, but it has the diagnostic traits of lamina pubescent on both surfaces, prominent veins and a thickened leaf margin.

Ocimum gratissimum subsp. **iringense** *Ayob. ex A.J.Paton*

Distribution

D.R. Congo (new country record), Tanzania.

Habitat

Shrub savanna, cultivated land, pastures, rocky scree, at 800 m a.s.l. in D.R. Congo, 700–1 200 m a.s.l. elsewhere.

Specimen examined

D.R. CONGO, **Haut-Katanga**: Kasanga [near Kalemie], éboulis rocheux, 30 Mar. 1947, *Van Meel 1420* (BR).

Discussion

New country record for D.R. Congo. The new locality represents the western limit of the distribution range.

Bibliography

Ayobangira (1990), Paton et al. (2009).

Ocimum hirsutissimum *(P.A.Duvign.) A.J.Paton* var. **hirsutissimum**

Distribution

Endemic of D.R. Congo (Haut-Katanga, Kibara massif).

Habitat

Steppic savanna, at ± 1 600 m a.s.l.

Specimens examined (new identifications only)

D.R. CONGO, **Haut-Katanga**: Mitwaba, savane herbeuse, 1 600 m a.s.l., Feb. 1953, *Desenfans 2363* (BRLU); au sud du Makomo, relevé 143, savane herbeuse, 16 Aug. 1953, *Desenfans 3904* (BRLU); au sud de Makomo, relevé 179, 1 650 m a.s.l., savane herbeuse, 19 Mar. 1954, *Desenfans 5353* (BRLU); au sud du point Kisonsa, relevé 182, 24 Mar. 1954, *Desenfans 5440* (BRLU); Mitwaba, plateau des Kibara, steppe de pente rocheuse ou latéritique, 9 Sept. 1956, *Duvigneaud & Timperman 2698B* (BRLU); 14 km au nord de Mitwaba, steppe sur plateau latéritique, 16 Jan. 1960, *Duvigneaud 5070L1* (BRLU); N de Mitwaba, pâturage brûlé, 30 Jun. 1988, *Pauwels 7132* (BR); Mitwaba, Oct. 1956, *Vanden Brande M252* (BRLU).

Discussion

O. hirsutissimum is related to *O. centraliafricanum* in having more or less patent leaves folded along the midrib, with secondary veins parallel to the margin. It is most distinct in having the upper lip of the calyx ovate-elliptic, acute, upright, particularly large, much exceeding calyx throat, and the lateral lobes of the calyx lacking the characteristic white floccose indumentum of *O. centraliafricanum*; it usually has ternate leaves (rarely opposite); the bracts are foliaceous, forming a conspicuous persistent coma. The type specimen is remarkable by the hispid to villose indumentum on all vegetative parts consisting of patent hairs 1–2 mm long. It is an endemic of the Kibara massif, in the region of Mitwaba.

Bibliography

Plancke (1959), Ayobangira (1987, 1990), Paton (1993).

Figure 3. *Ocimum gnidioides*. A, whole plant; B, leaf lower surface; C, flower at anthesis; D, young fruiting calyx. From *Schaijes 4481* (BR). Artist: Hilde Orye.

Ocimum hirsutissimum *(P.A.Duvign.) A.J.Paton* var. **paradoxum** *Meerts & A.J.Paton, var. nov.*

TYPES: D.R. CONGO, **Haut-Katanga**, Parc National de l'Upemba, Mukana, savane brûlée, 1 810 m a.s.l., 26 Aug. 1947, *De Witte 2788* (BR [BR0000016581036], holo!; UPS, iso.). urn:lsid:ipni.org:names:77351583-1

Diagnostic features

Differing from the typical variety in the much less developed indumentum, with the stem pubescent to tomentose, with antrorse hairs, not hispid-villose with patent hairs, and leaves subglabrous or pubescent only on veins, not wholly villose. Figure 4, Figure S4.

Etymology

The varietal epithet *paradoxum* refers to the paradoxical occurrence of specimens with much reduced pubescence in a species that is otherwise wholly hispid.

Distribution and habitat

Endemic of D.R. Congo (Haut-Katanga, Kibara massif); steppic savanna at high altitude (1 700–1 850 m), on rocky soil.

Conservation status

Probably Least Concern (LC); even though the variety is known from only four locations, they are all situated within the Upemba National Park.

Additional specimens studied

D.R. CONGO, **Haut-Katanga:** Mitwaba, 26 km au sud du poste, steppe de plateau sur micaschiste à *Tristachya tholonii* et *Parinari pumila*, 11 Sept. 1956, *Duvigneaud & Timperman 2733Be* (BRLU); Parc national de l'Upemba, entre Kabwe-Kanono et Mukana, savane herbeuse d'altitude, 30 Sept. 1948, *Van Meel* sub *De Witte 4357* (BR, P, WAG); Parc national de l'Upemba, entre Lusinga et Mukana, savane herbeuse d'altitude, 1 815 m a.s.l., 28 Mar. 1949, *Van Meel* sub *De Witte 5919* (BR)*;* Parc national de l'Upemba, pente rocheuse de 45° près de la tête de source de la rivière Kadidiki, 1 775 m a.s.l., 25 Aug. 1949, *Vvan Meel* sub *De Witte 7576* Mitwaba, 26 km au sud du poste, steppe de plateau sur micaschistes à *Tristachya thollonii* et *Parinari pumila*, 11 Sept. 1956, *Duvigneaud & Timperman 2733Be* (BRLU).

Discussion

Newly identified materials of *O. hirsutissimum*, collected in the same region as the type, show that the indumentum is not always villose. We propose to recognise at varietal rank a group of specimens with much shorter indumentum on stem and with leaves almost glabrous. *O. hirsutissimum* var. *paradoxum* is superficially similar to *O. pyramidatum,* on account of the ternate, spreading leaves, differing by the calyx traits (*O. hirsutissimum*: upper calyx lip elliptic, exceeding calyx throat by > 3 mm; *O. pyramidatum*: upper calyx lip obovate, exceeding calyx throat by ± 1 mm). The specimen *Duvigneaud & Timperman 2733Be* (BRLU) belongs here except for the villose indumentum on the lower surface of midvein and opposite (not ternate) leaves.

Bibliography

Plancke (1959), Ayobangira (1987, 1990), Paton (1993).

Ocimum mearnsii *(Ayob. ex Sebald) A.J.Paton*

Distribution

D.R. Congo (new country record), Kenya, Tanzania, Uganda.

Habitat

Steppic savanna (in D.R. Congo), seasonally flooded and/or overgrazed placed elsewhere, at ± 1 500 m a.s.l. in D.R. Congo, 1 500–2 100 m a.s.l. elsewhere.

Specimen examined

D.R. CONGO, **Haut-Katanga**: Parc national de l'Upemba, savane d'altitude entre Mukana et Kabwe Kanono, 18 Oct. 1948, *Van Meel* sub *De Witte 4533* (BR).

Discussion

New country record for D.R. Congo. The new locality in Upemba National Park is remarkably disjunct, > 1 000 km from the nearest localities in N Tanzania.

Bibliography

Sebald (1989), Paton (1995), Paton et al. (2009).

Ocimum mitwabense *(Ayob.) A.J.Paton*

Distribution

Endemic of D.R. Congo (Haut-Katanga, Kibara massif).

Habitat

Steppic savanna, at ± 1 500 m a.s.l.

Specimens examined (new identifications only)

D.R. CONGO, **Haut-Katanga**: Mitwaba, champ d'aviation, relevé 180, savane herbeuse; 20 Mar. 1954, *Desenfans 5393* (BRLU); Mitwaba, en face de l'hôtel, grande steppe de plateau passant au verger à *Monotes*,

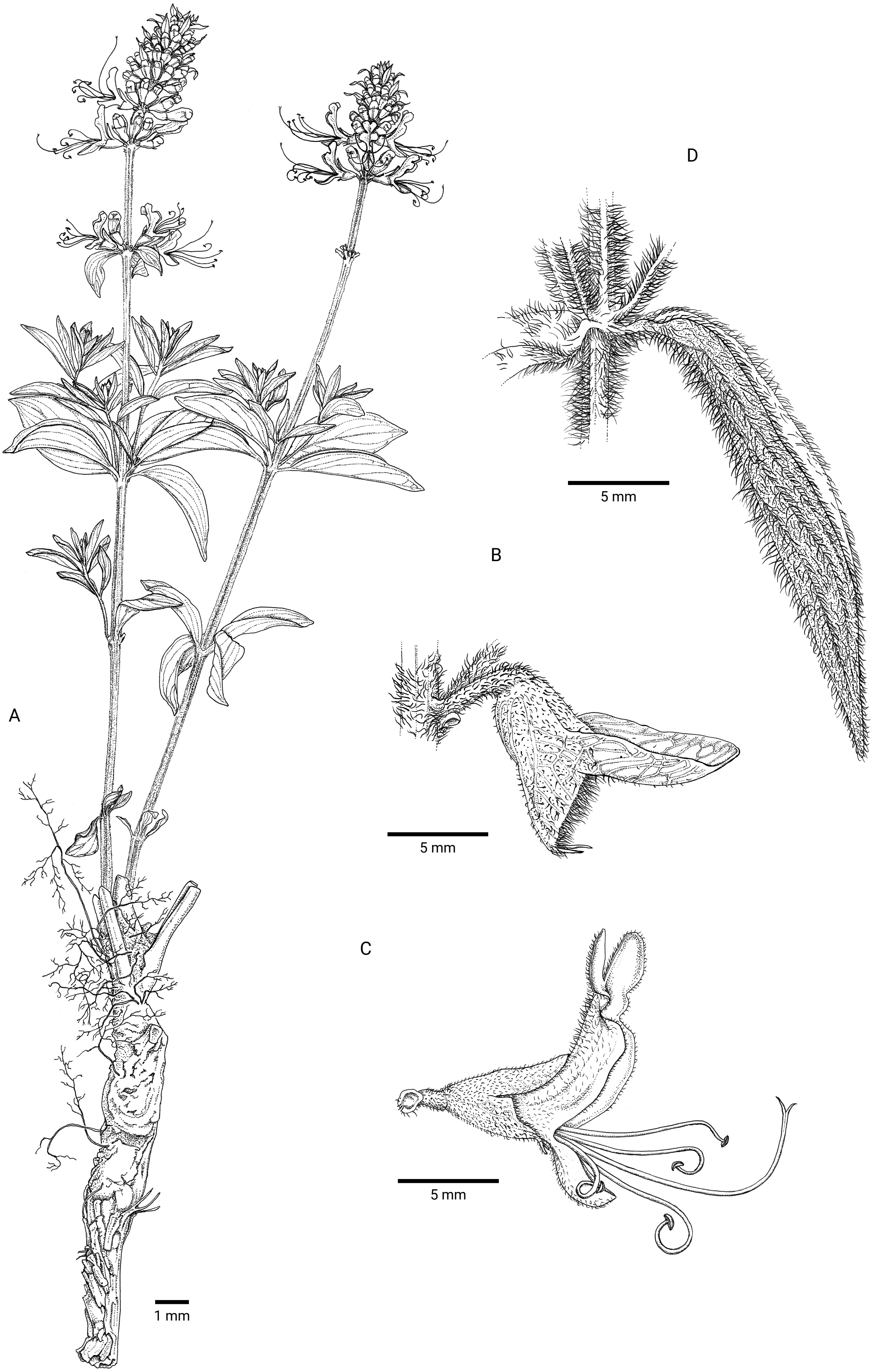

Figure 4. *Ocimum hirsutissimum* var. *paradoxum*. A, whole plant; B, fruiting calyx; C, flower; var. *hirsutissimum* D, indumentum of stem and leaf. A, B, C from *De Witte 2788*, D from *Pauwels 7132*. Artist: Hilde Orye.

9 Sept. 1956, *Duvigneaud & Timperman 2692Be* (BRLU); massif des Kibara, hôtel Mitwaba, Sept. 1945, *Mortelmans 57* (BR).

Discussion

O. mitwabense is a somewhat enigmatic taxon known from only a few collections. It is related to *O. centraliafricanum* R.E.Fr. on account of the arching veins parallel to lamina margin, differing in coriaceous leaves, and the calyx lacking the white floccose indumentum on lateral lobes.

Bibliography

Ayobangira (1987, 1990), Paton (1993).

Ocimum pyramidatum *(A.J.Paton) A.J.Paton*

Distribution

D.R. Congo (new country record), Tanzania.

Habitat

Open dry woodland and grassland, at ± 1 100 m a.s.l. in D.R. Congo, 1 050–1 600 m a.s.l. elsewhere.

Specimen examined

D.R. CONGO, **Bas-Katanga**: Kamina, 1 100 m a.s.l., prairie marécageuse, 19 Sept. 1947, *Mullenders 1400* (BR).

Discussion

New country record for D.R. Congo. *O. pyramidatum* was hitherto reported only from a narrow range in SW Tanzania. The new collection extends the range ± 800 km to the west. This specimen had been wrongly identified as *O. obovatum* by Sebald (1989). It differs from Tanzanian material [*Richards 7127, 7277, 11595* (K)] in having a shorter calyx at anthesis (4 mm vs 5–7 mm long).

Bibliography

Paton et al. (2009).

Orthosiphon *Benth.*

Orthosiphon collinus *Ayob. ex Meerts & A.J.Paton sp. nov.*

TYPES: D.R. Congo, **Haut-Katanga**, 67 km E de Mitwaba, dembo dans un vallon en auge, steppe humide, après incendie, 10 Sept. 1956 [‘1957’ on label in error], *Duvigneaud & Timperman 2722La* (BRLU0043430, holo!; K, iso). urn:lsid:ipni.org:names:77351584-1

Relationships

Related to *O. rufinervis* G.Taylor, differing in the subsessile, erect (vs petiolate, patent) leaves with narrower leaf blade (5–10 mm vs 10–25 mm wide), with yellow glands (vs red), smaller bracts (1.5–3.5 mm vs 4–5 mm long), much shorter corolla (± 7 mm vs 11–14 mm long).

Description

Perennial herb or suffrutex 15–20 cm high; rootstock a woody rhizome, tubers not observed; stem erect, unbranched, quadrangular, sulcate in upper half, papillate to puberulous in lower half (retrorse hairs), subglabrous upwards, becoming abruptly pubescent in the inflorescence with short patent to retrorse eglandular hairs. *Leaves* opposite-decussate, ± 8 pairs to a stem, lowermost 2 pairs much reduced, ascending to erect, subsessile, blade coriaceous, pale green, narrowly ovate elliptic to narrowly elliptic, 20–42 × 5–10 mm, much longer than the internodes, base cuneate, apex acute, margin recurved or thickened, subentire to slightly serrate distally with ± 5 teeth on either side, 3–5 pairs of veins diverging at a narrow angle, reticulum prominent on both surfaces, subglabrous, yellow gland-dotted on both surfaces, lower surface paler. *Inflorescence* terminal, a thyrse 4–5 cm long, with ± 6 verticils, spaced 5–12 mm apart, cymes 3-flowered, bract ovate ± 1.5–3.0 × 1.0–1.5 mm, acuminate, reflexed, ciliate; pedicel patent to ascending, curving at tip, ± 2 mm, puberulent. *Calyx* ± 4 mm long at anthesis, accrescent to 6 mm in fruit, more or less flushed purple, patent to reflexed, tube campanulate, shortly pubescent (eglandular hairs), with sessile glands, upper lobe ovate to obovate, ± 2 mm long, subacute at tip, upwardly recurving, decurrent, lateral lobes ovate-triangular, subulate, ± 2 mm, median lobes of lower lip subulate, attenuate into a filiform point 3–4 mm, ciliolate. *Corolla* ± 7 mm long, pale-coloured in herbarium, puberulent (curly hairs), lower lip ± 2 mm long. *Fertile stamens* 4, anther ± 0.8 mm long, thecae divergent. *Fruit* not observed. Figure 5, Figure S5.

Etymology

The specific epithet ‘*collinus*’ was proposed by Ayobangira (1990) referring to the hilly landscape in which the species was collected.

Diagnostic characters

A suffrutex with ascending to erect, subentire, coriaceous leaves, and 3-flowered cymes.

Distribution and habitat

Endemic of D.R. Congo (Haut-Katanga); steppic savanna in dambo, on seasonally flooded soil.

Conservation status

Data Deficient (DD); the species is known only from the type collection.

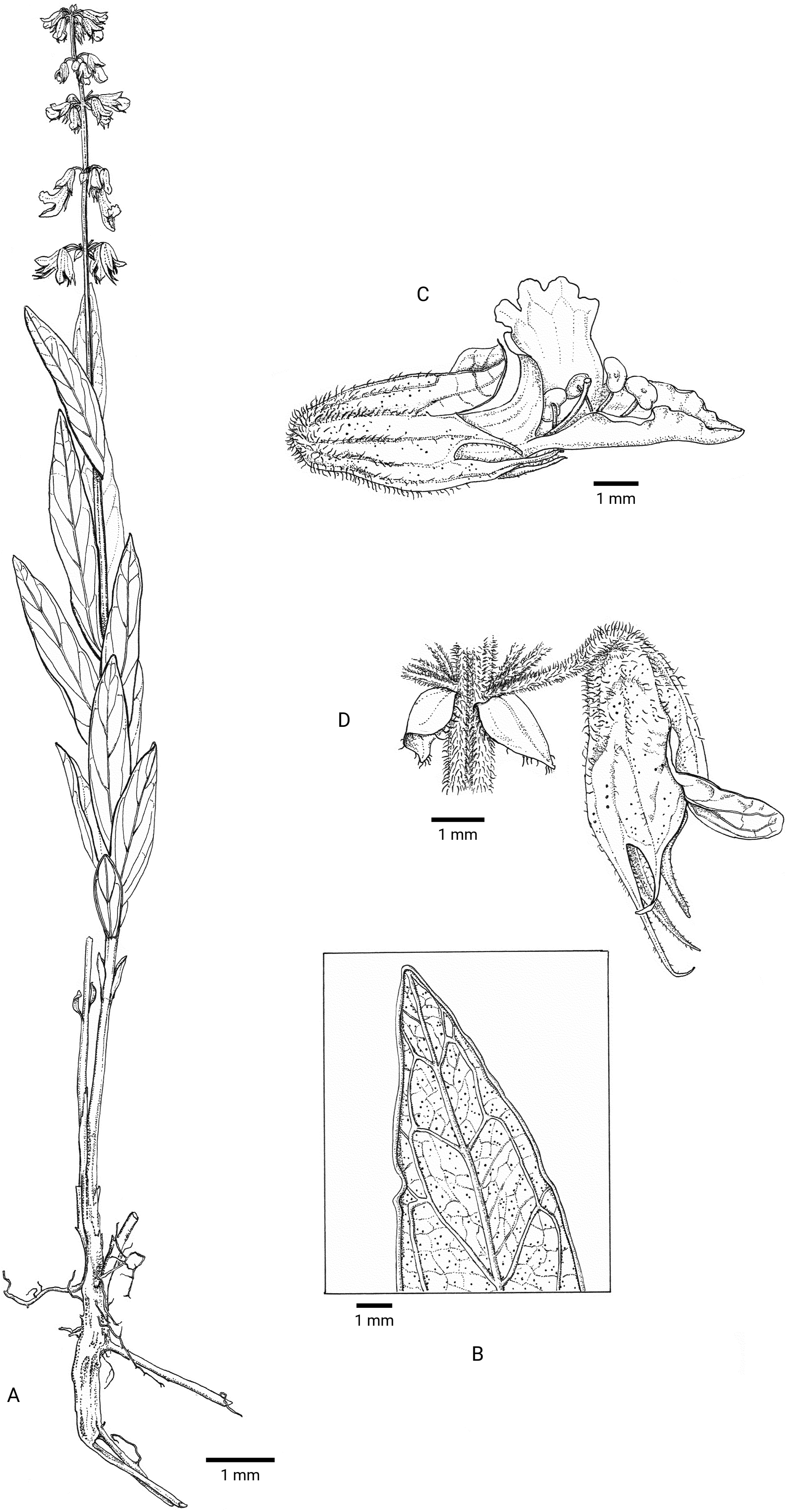

Figure 5. *Orthosiphon collinus*. A, whole plant; B, detail of lower surface of leaf; C, flower at anthesis; D, verticil and one fruiting calyx. From *Duvigneaud & Timperman 2722La* (BRLU). Artist: Hilde Orye.

Additional specimens examined

None.

Discussion

This species was proposed by Ayobangira (1990) but was never effectively published. It is superficially similar to *Fuerstia rigida* (Benth.) A.J.Paton on account of habit, small coriaceous erect leaves with prominent veins, differing in the eglandular indumentum, the 3-flowered cymes (*Fuerstia rigida*: 1-flowered), and the androecium with 4 stamens.

Bibliography

Ayobangira (1990).

Orthosiphon rufinervis *G.Taylor*

Distribution

Angola, Central African Republic, D.R. Congo (new country record), Zambia.

Habitat

Steppic savanna, often on seasonally waterlogged soil.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Dilolo, dilungu de la Mangoa, steppe frais à *Eragrostis capensis*, 20 Aug. 1956, *Duvigneaud & Timperman 2404* (BRLU); Région de Kisenge, tête de source de la rivière Kamalengu, dilungu, 25 Sept. 1958, *Plancke 155/2087 & 2088* (BRLU); env. de Kabiasha, près du village Kimangu, dembo, 18 May 1970, *Lisowski 23533* (POZG, 3 sheets).

Discussion

New country record for D.R. Congo. *O. rufinervis* is a relatively rare species throughout its range.

Bibliography

Paton et al. (2013).

Plectranthus *L'Hér.*

Plectranthus asymmetricus *A.J.Paton*

Distribution

S D.R. Congo (Haut-Katanga) (new country record), N Zambia.

Habitat

Evergreen forest, boulders, especially near watercourses; at 1 200–1 350 m a.s.l.

Specimens examined

D.R. CONGO, **Haut-Katanga**: Route Mitwaba–Manono, 45 km, riv. Kalumengongo (zone Mitwaba), 08°19′S, 27°16′E, 1 140 m a.s.l., rochers humides en bordure de rivière, 3 Feb. 1986, *Bamps & Malaisse 8620* (BR); Route Lubumbashi–Likasi, 50 km, riv. Kamianga (zone Kambove), 11°18′S, 27°17′E, 1 335 m a.s.l., thalweg de ravin boisé, 15 Jan. 1986, *Bamps & Malaisse 8027* (BR); Route Lubumbashi–Likasi, 70 km, ravin de la Luafi (zone Kambove), 11°12′S, 27°08′E, 1 200 m a.s.l., talus humifère de fond de ravin boisé, 14 Jan. 1986, *Bamps & Malaisse 8017* (BR); 5 km NW de Shilatembo, ruisseau temporaire de la Kamianga, 1 340 m a.s.l., forêt dense (ravin encaissé) très humide (aspect guinéen), 5 Feb. 1982, *Malaisse & Robbrecht 1733* (BR); 5 km N de Shilatembo, forêt dense de ravin du ruisseau temporaire Kamianga, 13 Jan. 1984, *Malaisse 12947* (BR).

Discussion

New country record for D.R. Congo. The species was previously known from the type specimen only, in N Zambia. The four new localities extend the range ± 400 km to the north.

Bibliography

Paton et al. (2013).

Plectranthus villosicaulis *Meerts & A.J.Paton, sp. nov.*

TYPES: D.R. CONGO, **Kivu**, Ndolere, territ. Kabare, at 1 800 m a.s.l., forêt de montagne, 6 Apr. 1959, *A.Léonard 3703* (BR0000017710756, holo!; K, iso.). urn:lsid:ipni.org:names:77351585-1

Differing from all previously known species in the genus by the dark brown villose indumentum on stem angles; superficially similar to *Coleus decurrens* Gürke on account of the leaf lamina long attenuated at base, differing in the shorter corolla (6–9 mm vs 15–20 mm long), purplish to pinkish (vs yellow), and the villose indumentum on stem angles.

Description

Perennial herb or shrub up to 2 m high. Stem erect, quadrangular, with dense brown villous indumentum on angles, sparingly branched. *Leaves* opposite, ascending, petiole 0.2–1.0 cm, not clearly distinct from lamina; lamina elliptic, 6–19 × 1.5–6.6 cm, base very progressively attenuate into the petiole, apex acuminate, margin serrate, upper surface sparsely rusty pubescent, lower surface appressed pubescent on veins and densely gland dotted (± 20 glands/mm^2), with 5–11 pairs of secondary veins. *Inflorescence* lax, simple or with 1 or 2 short basal branches, ± 6–10 cm long at anthesis, elongating to 16–22 cm in fruit, with 8–15 (–22) verticils, spaced 7–15 mm apart in fruit, cymes subsessile, 3-flowered, bracts ovate ± 4 × 2.5 mm, reflexed, ciliate, persistent; pedicel 1–3 mm at anthesis, 5–6 mm at fruiting, patent, rusty pubescent, inserted slightly eccentrically on calyx. *Calyx* 3–5 mm long at anthesis, 7.5–10.0 mm long at fruiting, with red sessile glands and shortly stipitate pale minute glands, patent or downwardly pointing, tubulose to campanulate, with short stipitate pale glands, throat oblique, upper lobe ovate-elliptic, ± 5 mm long, subacute to subobtuse, curving upwards, slightly decurrent, lateral lobes of lower lip narrowly triangular, ± 2.5 mm, middle lobes of lower lip 3–4 mm long, long attenuate, somewhat curving upwards. *Corolla* pinkish, with red sessile glands, ± 6–9 mm long, tube almost straight, saccate at base, ± 4 mm long, upper lip ± 1.5 mm long, erect, 4-lobed, lower lip cucullate ± 4 mm. *Stamens* free, adnate to corolla tube, not exserted from corolla throat. *Fruit*: nutlets ovoid, slightly angled, ± 1.2 mm, dull brown, smooth. Figure 6, Figure S6.

Etymology

The specific epithet '*villosicaulis*' refers to the villose indumentum on the angles of the stem.

Diagnostic characters

A shrub with sessile leaves long attenuate at base, and villose brown indumentum on stem angles.

Distribution and habitat

Endemic to D.R. Congo (Kivu and Kwango). Forests, at 800–1 800 m a.s.l.

Conservation status

This species is known from two localities (one in Kwango and one in Kivu), none of which is protected. It has not been collected after 1959. It is possibly endangered (EN).

Additional specimens examined

D.R. CONGO, **Kasaï**: Panzi, forêt, 10 Feb. 1950, *Callens 2300* (BR); Panzi, 1925, *Vanderyst 15801* (BR); Panzi, 1925, *Vanderyst 15852* (BR); Panzi, Manzengele, 1925, *Vanderyst 17308* (BR).

Discussion

Plectranthus villosicaulis is superficially similar to *Coleus decurrens* on account of leaf traits (lamina long attenuate at base into a pseudopetiole), and the 3-flowered cymes, differing in the remarkable stem indumentum, the much smaller, rose corolla with saccate tube, and calyx structure. The geographic distribution is intriguing, with two disjunct groups of populations more than 1 000 km apart, one in Kwango, and the other one in Kivu, suggesting that the species might be present elsewhere in the Congo Basin. Targeted field work is needed to collect more material of this interesting taxon.

Conclusion

Five species and one variety new to science are described in this note. In addition, fifteen, two and one species are new country records for D.R. Congo, Rwanda and Burundi, respectively. Of the 26 taxa discussed in this note, 20 are present in Haut-Katanga, in the Zambezian region of the Democratic Republic of Congo. Five of the six new taxa are located there. This highlights the importance of this region for the diversity and conservation of Lamiaceae subfamily Nepetoideae in Central Africa.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

P.M. contributed to the conceptualisation, methodology, investigation, data curation, writing – original draft, writing – review and editing.

A.J.P. contributed to validation, investigation, writing – review and editing, supervision.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

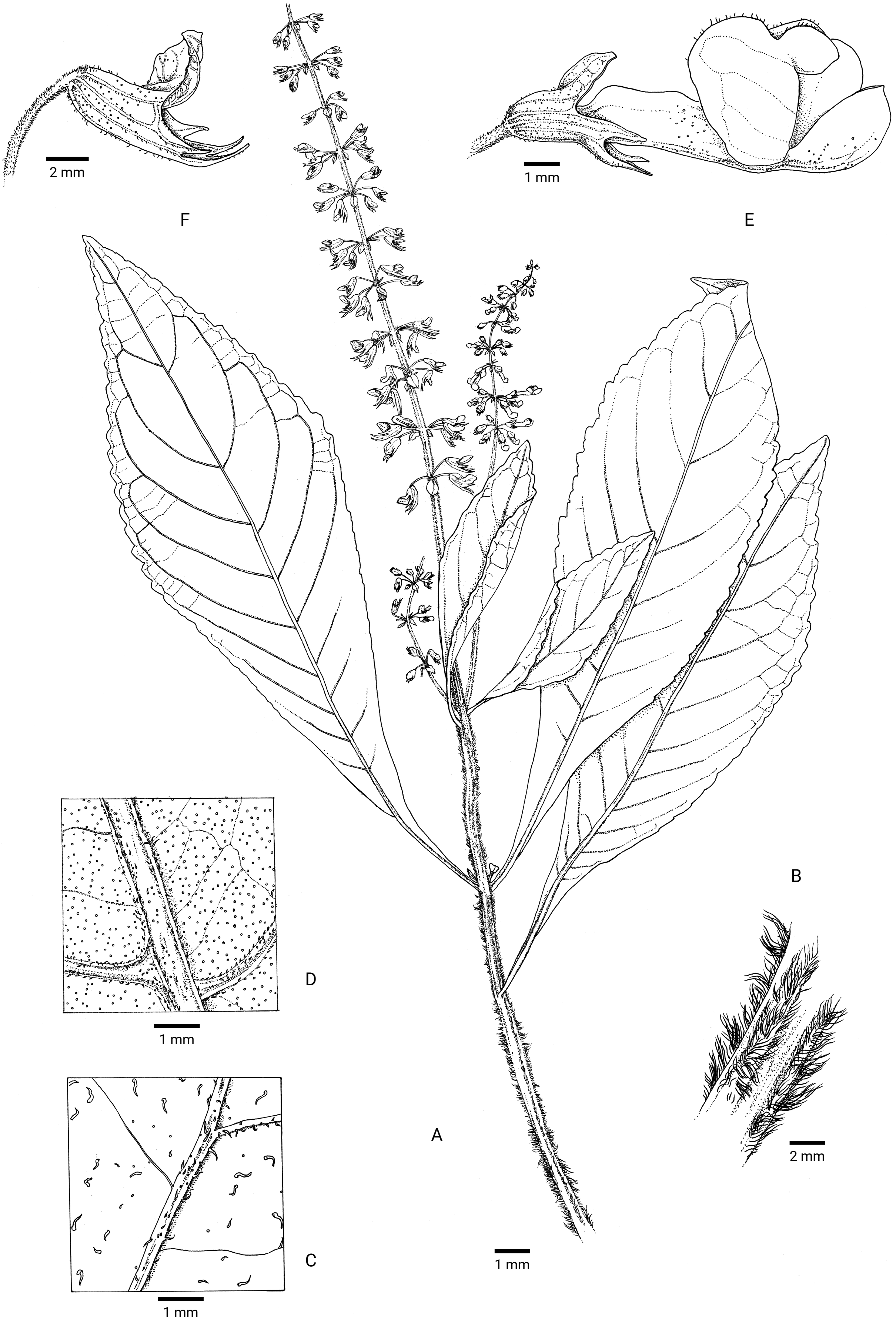

Figure 6. *Plectranthus villosicaulis*. A, branch in fruit; B, detail of stem pubescence; C, detail of upper surface of leaf; D, detail of lower surface of leaf; E, flower at anthesis; F, fruiting calyx. A, B, E from *Vanderyst 5852,* C, D from *Callens 1300,* F from *A.Léonard 3703*. Artist: Hilde Orye.

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The Madrid Nomenclature Section: outcomes and important changes to the *Code* following the XXth International Botanical Congress

Authors

[1,2]Ronell R. Klopper
[3]A. Muthama Muasya
[4]Gideon F. Smith

Affiliations

[1]Foundational Research & Services Directorate, South African National Biodiversity Institute, Private Bag X101, Pretoria 0001, South Africa.
[2]H.G.W.J. Schweickerdt Herbarium, Department of Plant & Soil Sciences, University of Pretoria, Pretoria, South Africa.
[3]Bolus Herbarium, Department of Biological Sciences, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa.
[4]Ria Olivier Herbarium, Department of Botany, Nelson Mandela University, P.O. Box 77000, Gqeberha 6031, South Africa.

Corresponding Author

Ronell Klopper; e-mail: R.Klopper@sanbi.org.za

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Background: The International Botanical Congress takes place more or less every six years. In the week preceding this conference, a meeting of the Nomenclature Section is held to consider proposals, both published and from the floor, to amend the *International Code of Nomenclature for algae, fungi, and plants*.

Objectives: To report on the most significant outcomes of the deliberations that took place during, and decisions taken at, the Nomenclature Section and the final plenary session of the XXth International Botanical Congress that was held in Madrid, Spain, in July 2024.

Methods: Decisions relevant to workers on South African algae, fungi and plants are summarised from the published reports of the relevant Permanent Nomenclature Committees and the General Committee, as well as from the published report of congress action.

Results: This contribution is a summary of the most important decisions taken at the Nomenclature Section meeting and International Botanical Congress in Madrid, specifically highlighting those outcomes that are important for South African phycologists, mycologists and botanists.

Keywords: *Madrid Code*, nomenclature, offensive epithets, registration, typification.

Background

The International Botanical Congress (IBC) is normally held every six years at different venues across the world. Bids from possible host countries are invited, after which the venue for the next conference is chosen by a selection committee. As a result of the impact of the global COVID-19 pandemic, the XXth IBC took place seven years after the 2017 IBC (Shenzhen, China), during the week of 21–27 July 2024, at the conference and events centre of IFEMA MADRID in the Barajas section of Spain's capital. The 2024 IBC was attended by over 3 000 participants from more than 90 countries.

Associated with each IBC is a meeting of the Nomenclature Section (NS), which is the only event where the chapters of the *International Code of Nomenclature for algae, fungi, and plants* (ICN or the *Code*) can be amended, based on published and floor proposals. The ICN contains the rules (articles) and recommendations that govern how algae, fungi and plants are named. Chapter F of the ICN contains articles that only relate to fungi and is the only chapter not amended at the IBC NS. The current San Juan Chapter F (May et al. 2019) was amended at the International Mycological Congress (IMC) held in Maastricht, the Netherlands, in August 2024.

Proposals to amend the current version of the ICN, the *Shenzhen Code* (Turland et al. 2018), mostly have been published in the journal *Taxon* (mouthpiece of the International Association for Plant Taxonomy, IAPT) from June 2020 to October 2023. Unless automatically rejected in the preliminary mail vote (i.e., receiving more than 75% 'no' votes) and not reintroduced with the requisite support, the proposals were discussed and final votes were cast on them at the NS in Madrid. For any proposal to amend the *Code* to succeed, a supermajority, i.e., at least 60% of votes cast, must be achieved (see Division III Prov. 5.1*(a)* of the ICN; Turland et al. 2018).

The NS also has the power to ratify recommendations from the General Committee regarding the conservation or rejection of plant names, suppression of works, and binding decisions on spelling and valid publication of names, among others. Proposals relating to the abovementioned matters are also published in *Taxon*, after which they are evaluated by the relevant Permanent Nomenclature Committee, with a final recommendation on the proposals made by the General Committee. During the final session of the NS, the reports of the General Committee are presented for ratification, and the Permanent Nomenclature Committees for the next intersessional period are elected.

Preparatory work

In the lead up to the meeting in Madrid, several discussion sessions were held regarding some of the more controversial proposals to amend the *Code*. The main purpose of these were to solicit opinions from users of plant names regarding the impact of these proposals, should they be accepted. Two of these sessions are worth highlighting, as they included several taxonomists from various herbaria and university departments in South Africa and Namibia, and were facilitated by at least one or two of the authors of this paper.

The first session (facilitated by A.M.M and also attended by R.R.K) was held during the IAPT Navigating Nomenclature Workshop held in Tulbagh, South Africa, 19–22 October 2023. This workshop was attended by 34 delegates from seven South African institutions (representing 11 herbaria; Sadler 2024). Discussions were mostly centred around the proposals dealing with offensive names.

The second was an online session (facilitated by R.R.K, with assistance from A.M.M) held on 28 May 2024. This meeting was attended by 54 people from 15 institutions (18 herbaria) from across South Africa and Namibia. Information was provided and discussions held on some of the more controversial proposals and those that would have far-reaching effects for herbaria and taxonomists. These included proposals dealing with ethics in nomenclature, offensive names, institutional votes, typification, valid publication, DNA sequences as types, registration of names, automatic correction of spelling errors, gender of names and virtual participation in the Nomenclature Section meetings. The main aim of this session was to inform taxonomists and herbarium curators of the proposed changes to the *Code*, and to openly discuss these matters to facilitate the guiding of proxy votes from the region.

In addition, G.F.S. conducted more than 50 one-on-one interviews with users of plant names in general on proposals to amend the *Code* that could be construed as contentious. Interviewees included junior and senior students, university lecturers, collection managers, database managers and members of a range of botanical (broadly defined) societies.

Madrid Nomenclature Section

As is tradition, the Nomenclature Section (NS) convened in the week preceding the IBC (15–19 July 2024). The Madrid NS was held in the conference hall of the impressive central campus main building of the Consejo Superior de Investigaciones Científicas (CSIC) (Figure 1). A total of 173 participants, representing 36 countries, attended the 2024 NS meeting in person (Turland et al. 2024b; Figure 2). Among them they carried institutional votes of a total of 192 institutions from 48 countries. The authors of this paper represented South Africa at the NS in Madrid. Between them, the first two authors carried a total of 16 proxy votes from nine southern African herbaria (eight from South Africa, one from Namibia). Other African delegates attending the NS in person were from Liberia (two individual votes) and Nigeria (non-voting), while proxy institutional votes were presented from Cameroon (one vote), Ivory Coast (one vote) and Kenya (four votes) (Turland et al. 2024b).

The Madrid NS was significant in that it was broadcast live on the internet for the first time (Knapp et al. 2024). Participants from across the globe could observe the discussions at the meeting in real time at no cost. This provided a valuable opportunity for people who could not physically attend the meeting to still follow the discussions. However, online observers could not participate in the discussions nor cast votes. A total of 219 unique users accessed the livestream during the course of the week.

The NS had the massive task of discussing and voting on a total of 433 published proposals (plus an additional 14 proposals submitted from the floor) during the five days of the meeting. This is the largest number of proposals submitted to amend the *Code* at an NS since the Stockholm meeting in 1950 where 550 proposals

Figure 1. The central campus main building of the Consejo Superior de Investigaciones Científicas (CSIC) where the Madrid Nomenclature Section was held. Photograph: Ronell R. Klopper.

Figure 2. Attendees of the Madrid Nomenclature Section. Photograph: David García Herráez.

were tabled. A synopsis of all published proposals with comments from the Rapporteurs was published in February 2024 in *Taxon* (Turland & Wiersema 2024). Following ICN Division III Provisions 2.5 and 2.6 (Turland et al. 2018), a preliminary guiding vote ('mail vote') was held from February to May 2024, to assess the level of support for all the proposals. Individual members of the IAPT, members of the Permanent Nomenclature Committees, and authors of proposals to amend the *Code* were entitled to vote in this guiding vote. Results from the preliminary guiding vote were published in July 2024 (Turland et al. 2024a). During the guiding vote (preliminary mail vote), a total of 106 (24.5%) proposals received more than 75% 'no' votes, meaning that they were automatically rejected, and could only be discussed at the NS through a proposal to discuss them being moved at the NS and supported by five people attending the NS (see Division III Provision 5.5 of the ICN; Turland et al. 2018). This left 301 published proposals for discussion at the NS in Madrid.

The final decision of the Madrid NS on the 447 proposals under consideration (433 published, 14 submitted from the floor) are as follows: 142 were accepted, 278 rejected, 22 referred to the Editorial Committee, one referred to a Special-purpose Committee, and five withdrawn. Further detailed information on the outcomes of all proposals are available in the report of IBC action on nomenclature proposals (Turland et al. 2024b; see also Turland 2025). The resolution from the NS was accepted by the final plenary session during the closing ceremony of the IBC on Saturday afternoon 27 July 2024, whereafter the NS decisions came into effect (Turland et al. 2024b).

The most significant changes made to the ICN in Madrid include the following:

- Facilitating voluntary registration of names and types of algae and plants after valid publication to improve the rapid indexing of names and nomenclatural acts, and efficient data exchange (Brinda & Watson 2023).
- Amendments that clarify aspects concerning the nomenclature of fossil plants and remove impediments to their typification (Gravendyck et al. 2020, 2022).
- Creating a mechanism by which offensive names published after 1 January 2026 can be rejected (following substantial amendments to proposals 120 and 121, Hammer & Thiele 2021; see also Thiele & Smith 2024).
- Addition of a new Article 61.6 to permanently and retroactively eradicate epithets with the offensive root '*caf[f][e]r*-' by treating them as having been published as '*af[e]r*-', meaning from Africa (Smith & Figueiredo 2021; see also Smith & Figueiredo 2024).
- Changing the allocation of institutional votes to one vote per institution, regardless of the size of the collection and taxonomic activity, in order to reduce the geographic imbalance (following amendments to proposal 286, Ulloa Ulloa et al. 2024).
- Changing Provision 5 of Division III to allow for the acceptance of recommendations of the General Committee by a simple majority of votes (50%) (Smith et al. 2022).
- Extending the responsibility to appoint committees to address controversial and other naming issues to the General Committee. Up to now such committees could only be appointed by an NS of an IBC, i.e., at more or less six-yearly intervals. This development has the potential to fast-track the way in which nomenclature issues are dealt with in the future (Smith 2022).

At the 2024 NS, four Special-purpose Committees were established, as follows: on Types and Typification; Typeless Names and DNA Sequences as Types; Naming Ambiregnal Organisms; and Ethics in Nomenclature. During the next intersessional period, these committees should investigate the specific issues allocated to them, and report on these by proposing possible solutions or action at the XXIst IBC, which will be held in Cape Town, South Africa, in 2029.

Seven reports containing 500 recommendations from the General Committee (reports 22–31; Wilson 2021, 2022a, 2022b, 2023a, 2023b, 2023c, 2023d, 2024a, 2024b, 2024c) were accepted at the final session of the NS. These reports included recommendations pertaining to Art. 14 (to conserve 253 names; not to conserve 84 names), Art. 14.13 (to treat six lists of fungal names as conserved), Art. 56 (to reject 79 names; not to reject 15 names), Art. 34 (to suppress 13 publications), Art. 38.4 (to treat eight names as validly published; 11 as not validly published) and Art. 53.5 (to treat seven similar names as homonyms and 24 similar names as not homonymic) (Turland et al. 2024b).

Officials and members of the General and Permanent Nomenclature Committees for the intersessional period leading up to the next IBC were elected during the final session of the Madrid NS. Despite being under-represented at the meeting itself, South Africa is well represented with members on most of these committees, namely on the Nomenclature Committee for Algae (Jonathan Taylor, North-West University), the Nomenclature Committee for Bryophytes [Jacques van Rooy, South African National Biodiversity Institute (SANBI), retired], the Nomenclature Committee for Vascular Plants (Ronell Klopper, SANBI & University of Pretoria and Madeleen Struwig, North-West University), the Committee on Institutional Votes (Muthama Muasya, University of Cape Town), as well as on the Editorial Committee who will produce the new *Madrid Code* (Ronell Klopper, SANBI & University of Pretoria and Gideon Smith, Nelson Mandela University) (Turland et al. 2024b).

The Madrid IBC was significant for Africa in several ways: an elegant way to permanently and retroactively eradicate offensive racial epithets, i.e., those with the root '*caf[e]r-*' or '*caff[e]r-*', was accepted by a vote of 63% in favour, despite efforts to retain these epithets. In addition, the next IBC and NS will be hosted on the African continent for the first time, in Cape Town, South Africa, during July 2029 (see https://ibccapetown2029.co.za/).

The new *Madrid Code* (Turland et al. 2025) is expected to be available from the University of Chicago Press by July 2025.

Summary of decisions relevant to South African Bryophyta and vascular plant names, and all algae and fungi names

A summary of decisions from the General Committee, which was ratified at the Madrid NS, on names that are relevant to South African vascular plants (indigenous and naturalised) and bryophytes, and all algae and fungi names are given below. For information on other decisions from the General Committee, the relevant reports (reports 22–31; Wilson 2021, 2022a, 2022b, 2023a, 2023b, 2023c, 2023d, 2024a, 2024b, 2024c) and the report of congress action from the NS (Turland et al. 2024b) should be consulted. The original proposals, as published in *Taxon*, or the reports from the relevant Permanent Nomenclature Committee provide further information on these proposals and the impact of the respective committee decisions.

In the following list of names, the number in brackets preceding the decision and names is the number under which the proposal was published and reported on. Abbreviations (publication titles excluded) used are: cons. = conserved; nom. cons. = conserved name; orth. cons. = conserved with a specific spelling (orthography); typ. cons. = conserved with a conserved type; rej. = rejected.

Conserved names

Algae

(2273) cons. *Gelidium bipectinatum* against *Fucus serra* (*Gelidium serra*); (2365) cons. *Cyanospira* G.Florenz. & al. (Cyanophyceae) against *Cyanospira* Chodat (Euglenophyceae); (2608) cons. *Peridinium splendor-maris* (=*Blepharocysta splendor-maris*) (Dinophyceae) (typ. cons.); (2711) cons. *Gracilariopsis* against *Gracilariophila* (Rhodophyta: Gracilariaceae); (2742) cons. *Stenokalyx* against *Stenocalyx*; (2832) cons. *Pseudokephyrion* Pascher against *Dinobryopsis* Lemmerm. and *Kephyriopsis* Pascher (Chrysophyceae: Dinobryaceae); (2833) cons. *Phalacroma* (Dinophysales: Dinophyceae); (2916) cons. *Discosphaera* Haeckel (Rhabdosphaeraceae, Prymnesiophyta, Algae) against *Discosphaera* Dumort. (Hypoxylaceae, Xylariales, Ascomycota, Fungi).

Bryophyta

(2468) cons. *Haplocladium* (Müll.Hal.) Müll.Hal. against *Haplocladium* Nägeli.

Vascular plants

(2483) cons. *Scilla* (Hyacinthaceae) (typ. cons.); (2495) cons. *Avena sterilis* (Gramineae) (typ. cons.); (2508) cons. *Microlepia* against *Scyphofilix* (Dennstaedtiaceae); (2555) cons. *Tetraria* (Cyperaceae) (typ. cons.); (2580) cons. *Astroloba* against *Poellnitzia* (Asphodelaceae); (2594) cons. *Selaginella*, nom. cons., against additional name *Didiclis* (Selaginellaceae); (2618) cons. *Bulbostylis*, nom. cons., against additional name *Nemum* (Cyperaceae); (2627) cons. *Senega* against *Senegaria*, *Anthallogea*, *Corymbula*, *Leptrochia*, *Pylostachya* and *Sexilia* (Polygalaceae); (2628) cons. *Hedyotis pentandra* Schumach. (=*Pentodon pentandrus*) (Rubiaceae) against *H. pentandra* (Retz.) Forsyth f. (Vahliaceae); (2631) cons. *Commelina erecta* (Commelinaceae) (typ. cons.); (2633) cons. *Arctotis calendula* (=*Arctotheca calendula*) against *A. tristis* (=*Arctotheca tristis*) (Asteraceae: Arctotideae); (2654) cons. *Aloe glauca* (Asphodelaceae: Alooideae) (typ. cons.); (2655) cons. *Aloe melanacantha* against *A. muricata* (Asphodelaceae: Alooideae); (2657) cons. *Telosma* against *Stephanotella* (Apocynaceae); (2659) cons. *Chenopodium giganteum* (Chenopodiaceae; Amaranthaceae sensu APG) (typ. cons.); (2676) cons. *Lepisorus* (Polypodiaceae), nom. cons., against additional name *Macroplethus*; (2677) cons. *Bromus inermis* (Poaceae: Bromeae) (typ. cons.); (2692) cons. *Zephyranthes* (Amaryllidaceae), nom. cons., against additional name, *Sprekelia*; (2718) cons. *Holothrix* (Orchidaceae: Orchideae), nom. cons., against additional name, *Bartholina*; (2723) cons. *Polypodium adiantiforme* (=*Rumohra adiantiformis*) against *P. adianthoides* (Dryopteridaceae); (2724) cons. *Lepisorus* (Polypodiaceae), nom. cons., against additional names *Lemmaphyllum* and *Neocheiropteris*; (2726) cons. *Pinus halepensis* (Pinaceae) (typ. cons.); (2733) Change conserved type of *Withania*, nom. cons. (Solanaceae) (typ. cons.); (2745) cons. *Mesembryanthemum vanputtenii* (=*Lampranthus vanputtenii*) (Aizoaceae) (orth. cons.); (2746)

cons. *Cereus imbricatus* (=*Opuntia imbricata*, *Cylindropuntia imbricata*) (Cactaceae) (typ. cons.); (2750) cons. *Panicum crus-galli* (=*Echinochloa crus-galli*) (Poaceae, Panicoideae) (typ. cons.); (2774) cons. *Cassytha baccifera* (=*Rhipsalis baccifera*) against *Cactus parasiticus* (Cactaceae); (2782) cons. *Calanthe*, nom. cons., against additional names *Phaius*, *Cyanorkis* and *Gastorkis* (Orchidaceae, Collabieae); (2786) change conserved type of *Ipomoea*, nom. cons. (Convolvulaceae) (typ. cons.); (2805) cons. *Eulophia*, nom. cons., against additional name *Geodorum* (Orchidaceae); (2820) cons. *Potentilla* (Rosaceae: Potentilleae) (typ. cons.); (2861) cons. *Rubus ulmifolius* against *R. creticus*, *R. vulgaris* and *R. inermis* (Rosaceae); (2881) cons. *Triraphis* (Poaceae: Chloridoideae: Triraphideae) (typ. cons.); (2899) cons. *Oxalis eckloniana* C.Presl against *O. eckloniana* F.Dietr. and *O. bifolia* (Oxalidaceae).

Fungi

(1538) cons. *Cantharellus tubaeformis* (Basidiomycota); (1516) cons. *Usnea fulvoreagens* (lichenised Ascomycota, Parmeliaceae) (typ. cons.); (2053) cons. *Megaspora verrucosa* (Ach.) Arcadia & A.Nordin against *M. verrucosa* Hafellner & V.Wirth (lichenised Ascomycota); (2072) cons. *Lichen fuscovirens* (=*Collema fuscovirens*) against *L. pulcher* (lichenised Ascomycota); (2235) cons. *Leptogium* (lichenised Ascomycota) (typ. cons.); (2392) cons. *Physaraceae* against *Fuliginaceae* (Myxomycetes); (2394) cons. *Metschnikowiaceae* against *Nectaromycetaceae* and *Torulopsidaceae* (Ascomycota: Saccharomycetes); (2395) cons. *Metschnikowia* against *Torulopsis* (Ascomycota: Saccharomycetes); (2412) cons. *Peziza medicaginis* against *Sporonema phacidioides* (Ascomycota: Leotiomycetes); (2413) cons. *Peziza cinnamomea* (=*Pezicula cinnamomea*) against *Naemaspora grisea* (Ascomycota: Leotiomycetes); (2415) cons. *Cercospora* (Ascomycota: Mycosphaerellaceae) (typ. cons.); (2417) cons. *Tricholoma sciodes* against *Agaricus hordus* (Basidiomycota); (2418) cons. *Agaricus cingulatus* (=*Tricholoma cingulatum*) against *A. ramentaceus* (Basidiomycota); (2419) cons. *Agaricus psammopus* (=*Tricholoma psammopus*) against *A. concolor* (Basidiomycota); (2425) cons. *Discula* (Diaporthales: Gnomoniaceae) (typ. cons.); (2465) cons. *Blastomyces* Gilchrist & W.R.Stokes against *Blastomyces* Costantin & Rolland (Ascomycota: Onygenales); (2515) cons. *Phyllosticta yuccae* against *Leptodothiorella notabilis* (Ascomycota: Dothideomycetes); (2519) cons. *Tolypocladium inflatum* against *Cordyceps subsessilis* (Ascomycota: Sordariomycetes: Hypocreales); (2520) cons. *Geoglossum uliginosum* Hakelier against *G. uliginosum* (Pers.) P.Crouan & H.Crouan (Ascomycota: Geoglossaceae); (2563) cons. *Lichen ferrugineus* (=*Blastenia ferruginea*) (Teloschistaceae, lichenised Ascomycota) (typ. cons.); (2610) cons. *Ditiola mucida* (=*Holwaya mucida*) against *Acrospermum caliciiforme* (=*Crinula caliciiformis*) (Ascomycota: Leotiomycetes); (2614) cons. *Lichen flavus* Bellardi (=*Pleopsidium flavum*) against *L. flavus* Schreb. (Acarosporaceae: lichenised Ascomycota); (2652) cons. *Lecidea parmeliarum* (=*Abrothallus parmeliarum*) against *Endocarpon parasiticum* (Ascomycota: Dothideomycetes: Abrothallales); (2668) cons. *Apioporthe corni* (=*Aurantioporthe corni*, *Cryptodiaporthe corni*) against *Sphaeronaema aurantiacum* and *Myxosporium nitidum* (Ascomycetes, Diaporthales); (2687) cons. *Phyllopsora* against *Triclinum* and *Crocynia* (Ramalinaceae, lichenised Ascomycota); (2712) cons. *Lichen cervinus* (=*Acarospora cervina*) (Acarosporaceae, lichenised Ascomycota) (typ. cons.); (2722) cons. *Bilimbia* (Ramalinaceae, lichenised Ascomycota); (2794) cons. *Coccotrema* against *Lepolichen* (Ascomycota, Lecanoromycetes, Coccotremataceae); (2835) cons. *Umbilicaria spodochroa* (lichenised Ascomycota) (typ. cons.); (2864) cons. *Microsphaera alphitoides* (=*Erysiphe alphitoides*) (Ascomycota: Erysiphaceae) (typ. cons.); (2867) cons. *Tuber aestivum* Vittad. against *T. aestivum* (Wulfen) Spreng. and *T. blotii* (Ascomycota: Pezizomycetes); (2868) cons. *Tuber magnatum* against *T. griseum* (Ascomycota: Pezizomycetes); (2869) cons. *Tuber melanosporum* against *T. nigrum* (Ascomycota: Pezizomycetes); (2874) cons. *Typhula* (Basidiomycota: Agaricales) (typ. cons.); (2875) cons. *Macrotyphula* against *Sclerotium* (Basidiomycota: Agaricales); (2876) cons. *Phyllotopsidaceae* against *Sclerotiaceae* (Basidiomycota: Agaricales); (2890) cons. *Entoloma sericeum* against *Agaricus pascuus* (=*E. pascuum*) (Basidiomycota); (2891) cons. *Puccinia psidii* (=*Austropuccinia psidii*) against *Caeoma eugeniarum* and *Uredo neurophila* (Basidiomycota: Pucciniaceae); (2955) cons. *Didymium* against *Mucilago* and *Spumaria* (Physarales, Myxomycetes); (2968) cons. *Fuscidea* against *Maronea* (lichenised Ascomycota).

Rejected names

Vascular plants

(2494) rej. *Salvinia adnata* (Salviniaceae); (2509) rej. *Allosorus* (Pteridaceae); (2527) rej. *Kadalia* (Melastomataceae); (2546) rej. *Solanum rubrum* (Solanaceae); (2620) rej. *Poa amabilis* (=*Eragrostis amabilis*) (Poaceae); (2634) rej. *Arctotis ludwigii* (Asteraceae); (2737) rej. *Cleome capensis* (Cleomaceae); (2658) rej. *Atriplex bengalensis* (=*Chenopodium bengalense*) (Chenopodiaceae; Amaranthaceae sensu APG); (2811) rej. *Mollugo triphylla* Burm.f. (Molluginaceae).

Fungi

(2236) rej. *Lichen conspurcatus* (Roccellaceae); (2507) rej. *Ramularia gibba* (Ustilaginomycotina: Entylomatales); (2713) rej. *Lecidea cornea* (lichenised Ascomycota); (2872) rej. *Huea* (Ascomycota: Teloschistales); (2877) rej. *Sclerotium fulvum* (Basidiomycota:

Agaricales); (2871) rej. *Tuber cibarium* (Ascomycota: Pezizomycetes).

Suppressed works

Bryophyta

(23) Stephani (in Hedwigia 27: 276–302. 1888) as to new generic names in that work; (24) Stephani (in Hedwigia 29: 1–23, 68–99, 133–142. 1890) as to new generic names in that work.

Vascular plants

(27) Diels, *Plantae Chinenses Forrestianae* (in Notes Roy. Bot. Gard. Edinburgh 7: 1–410. 1912–1913).

Fungi

(16–18) Unpaginated index of *Traité des champignons* and two editions of *Tabula plantarum fungosarum* by J.-J. Paulet.

Binding decisions regarding confusable names

Algae

Considered confusable (to be treated as homonyms): (104) *Actinostephanos* Khursevich (Bacillariophyta) and *Actinostephanus* F.Wen & al. (Gesneriaceae).

Considered not confusable: (72) *Cosmarium geminatum* P.Lundell and *C. gemmatum* W.B.Turner (Streptophyta: Desmidiaceae); (76) *Trigonium* Cleve (Bacillariophyta: Trigoniumaceae) and *Trigonum* A.K.Mahato & P.Mahato (Streptophyta: Zygnemataceae); (85) *Argostemma* (Rubiaceae) and *Agrostemma* (Caryophyllaceae).

Vascular plants

Considered not confusable: (48) *Scilla* (Hyacinthaceae subfam. Hyacinthoideae) and *Squilla* (Hyacinthaceae subfam. Urgineoideae).

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Competing interests

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Author’s contributions

R.R.K. (SANBI & University of Pretoria) conceptualised the manuscript, wrote the initial draft, reviewed the literature and summarised decisions from the Nomenclature Section and Permanent Nomenclature Committees. A.M.M. (University of Cape Town) and G.F.S. (Nelson Mandela University) provided additional input and improved several aspects of the manuscript.

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Anthospermum, an unusual name for an African genus of Rubiaceae

Authors
Elmar Robbrecht[1]
Brecht Verstraete[1]

Affiliations
[1]Meise Botanic Garden, Nieuwelaan 38, 1860 Meise, Belgium.

Corresponding Author
Brecht Verstraete; e-mail: brecht.verstraete@plantentuinmeise.be

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The mainly African genus *Anthospermum* L. has an enigmatic name, meaning 'floral seed.' Recent dictionaries of plant names relate the name to the complex reproductive biology of the genus, i.e., male flowers sometimes having ovaries capable of ripening seeds. However, Linnaeus himself mentioned how he coined the name, and he explained it differently. The Italian botanist Giulio Pontedera, who made earlier observations on the genus, confused flower buds with fruits and seeds with anthers. Hence, Linnaeus coined the name by combining the words flower (Greek *anthos*) and seed (Greek *spermum*) and herewith wanted to emphasise this error. *Anthospermum* seems to be another example of an insulting name given by Linnaeus.

Introduction

Ordinarily, researchers make use of scientific names of plants in Latin without ever considering their meaning. This is even more true for members of the general public for whom such names usually make little sense (Jiménez-Mejías et al. 2024). The name *Anthospermum* L. is enigmatic and can be translated as 'flower-seed' or 'floral seed' (Greek *anthos* = flower and *spermum* = seed). While working on a project investigating several aspects of all generic names in Rubiaceae (Verstraete et al. in press), we were struck by contradictions in the etymological interpretation of this name. Dictionaries of plant names relate the odd name with the complex reproductive biology of the genus, but Linnaeus himself gave a totally different explanation. In this paper, we compare the conflicting interpretations with the available literature.

The genus *Anthospermum*

Anthospermum L. is a genus of 39 species in the Rubiaceae family, occurring in Tropical and southern Africa and the Arabian Peninsula (POWO 2024). The southwestern Cape Floristic Region (13 species) and Madagascar (8 species) are notable centres of its diversity (Puff 1986). The genus belongs to the tribe Anthospermeae and is closely related to the southern African genera *Galopina* Thunb. and *Nenax* Gaertn. and the Macronesian genus *Phyllis* L., with which it forms the subtribe Anthosperminae (Thureborn et al. 2019). The South African endemic *Carpacoce* Sond. is in the monogeneric subtribe Carpacocinae. The other genera in the tribe (placed in subtribes Coprosminae and Operculariinae) do not occur on the African continent, except for *Nertera granadensis* (Mutis ex L.f.) Druce, which is also found in Madagascar (POWO 2024). The tribe Anthospermeae is unique in Rubiaceae because it only comprises wind-pollinated taxa; anemophily is otherwise absent from Rubiaceae (Puff 1982). *Anthospermum* plants have a reduced habit (subshrubby and often heather-like, or herbaceous) and are dioecious or polygamous. The genus is further characterised by unisexual or sometimes hermaphroditic flowers, long and feathery stigmata (in the female flowers), 2-locular ovaries with 1 ascendent ovule in each locule, and dry fruits subtended by a bracteolar carpophore, separating in two mericarps, tardively opening with three basal slits (Figure 1; Puff 1986; Robbrecht 2022).

The taxonomic history of the genus begins with the starting point of the nomenclature of angiosperms, i.e., *Species Plantarum* (Linnaeus 1753). In this publication, only *Anthospermum aethiopicum* L. from the Cape, South Africa was included (Linnaeus 1753: 1058), hence making it the type species. In the second edition, *A. ciliare* L. was added (Linnaeus 1763: 1512), while in the Supplement, Linnaeus' son added a third species, *A. herbaceum* L.f. (Linnaeus 1782: 440). A first survey of the genus was already done at the beginning of the 19th century (Cruse 1825), recognising eight species. Additional species were published especially at the end of the 19th and beginning of the 20th century. The genus was subject to a modern taxonomic revision based on extensive field work, adding 14 species to the genus (Puff 1986 and references therein). Recent molecular phylogenetic research demonstrated that the monophyly of *Anthospermum* was not proven, instead it was included in a highly supported *Anthospermum–Nenax* clade (Thureborn et al. 2019). In contrast, the sister genera *Galopina* and *Phyllis* were found to be monophyletic. A subsequent phylogenomic study of the tribe Anthospermeae corroborated the close relationship of *Anthospermum* and *Nenax*, but it could not confirm or reject the monophyly of the genera since only one species of either genus was included (Thureborn et al. 2024).

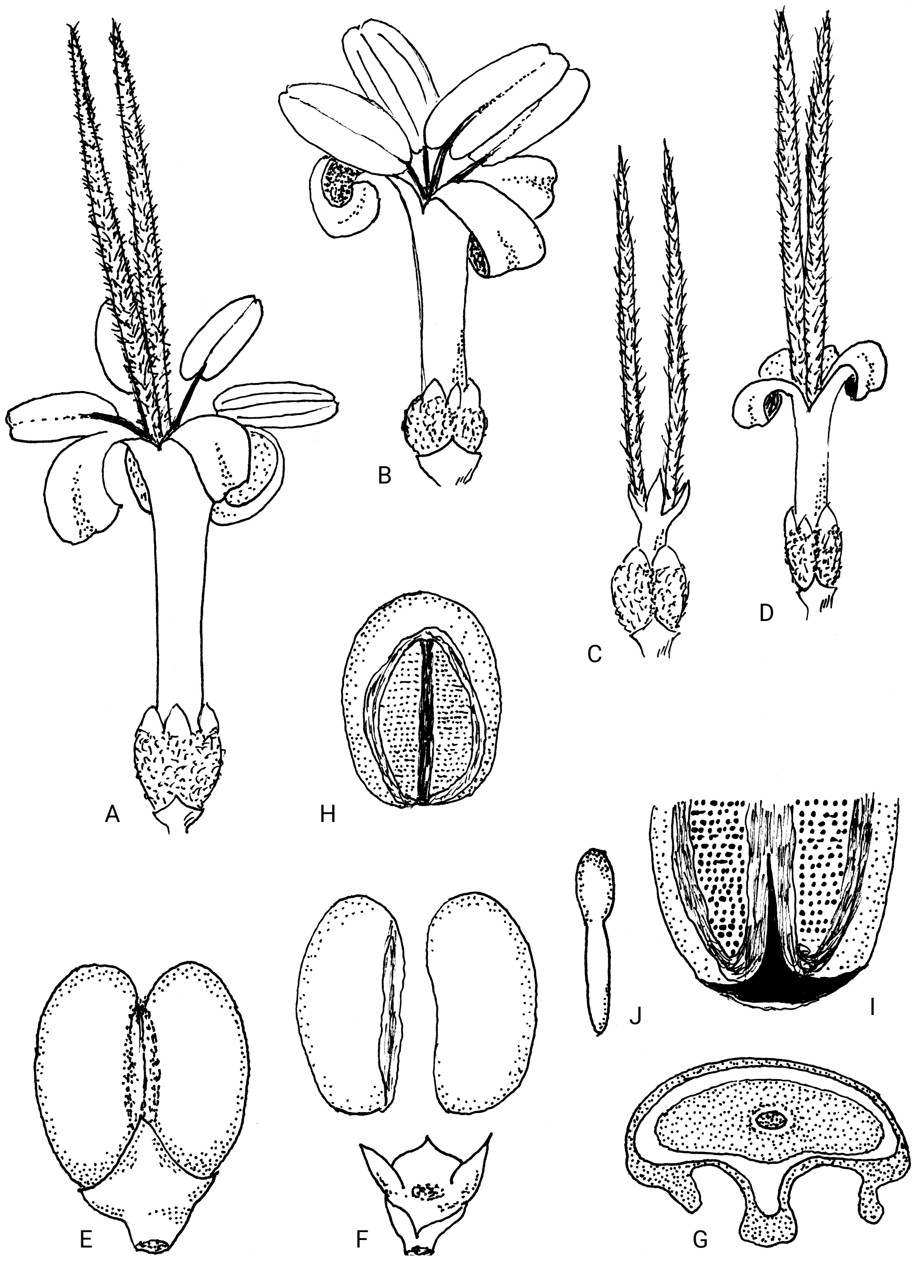


Figure 1. *Anthospermum herbaceum* L.f.; A, hermaphroditic, B, male and C, D, female flowers; E (parts separated in F), fruit and its carpophore; H, mericarp (in cross-section in G and opening at base in I); and J, embryo. Reproduced from Robbrecht (2022): Figure 1.

Materials and methods

The relevant literature, mostly historical, was found available on the internet and consulted. All *Anthospermum* specimens in the Linnean herbarium at the Linnean Society of London were consulted online in September 2024 (https://linnean-online.org/view/type/specimen/Anthospermum.html).

Results and discussion

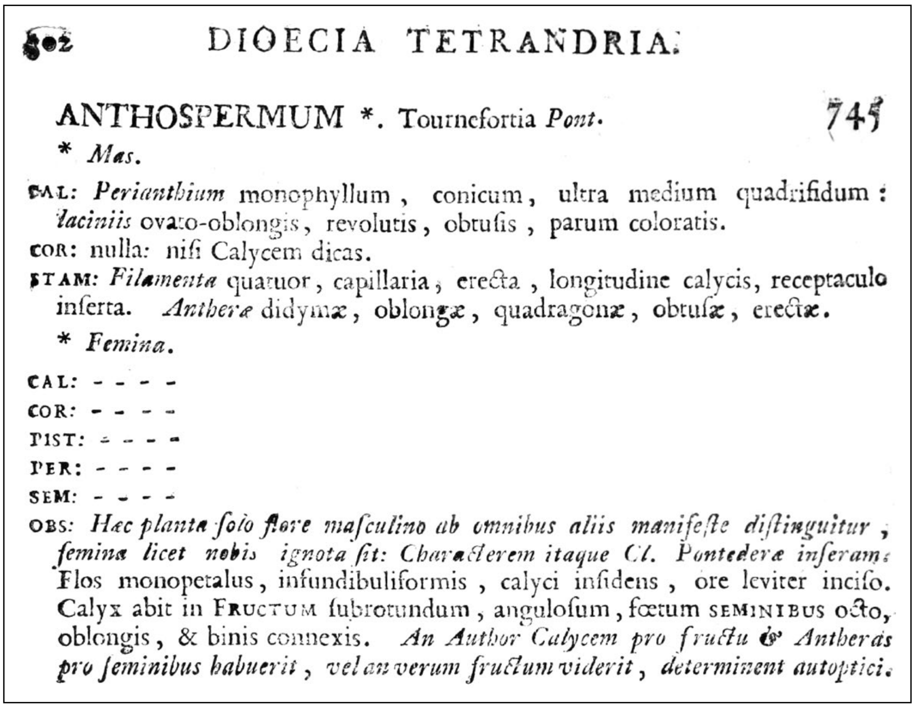
The etymology of the name

The name *Anthospermum* is enigmatic and means 'flower-seed' or 'floral seed' (Greek *anthos* = flower and *spermum* = seed). The *CRC World Dictionary of Plant Names* (Quattrocchi 2000: 161) explained the name as follows: 'the male flowers may produce seeds', while the *Dictionary of southern African Plant Names* (Clarke & Charters 2016: 23) explained it as: 'Although the flowers are usually dioecious – unisexual male and female – 'male' flowers sometimes have ovaries capable of ripening seeds.' Except for the fact that the plants, rather than the flowers, are dioecious, the latter etymology seems plausible. Puff (1986: 134) discussed in great detail the large morphological plasticity of *Anthospermum* species, showing phenomena such as reversion of male flowers to hermaphroditic ones.

However, Linnaeus, who described the genus, explained the etymology in a different way. He already coined the name before publishing his *Species Plantarum* (Linnaeus 1753); he previously used the name in *Genera Plantarum* (Linnaeus 1737a: 302) and *Hortus Cliffortianus* (Linnaeus 1737b: 455, plate 27). In *Genera Plantarum* (Figure 2), he expressed doubt about the earlier work of Giulio Pontedera, who described the plant as *Tournefortia: 'An Author [Pontedera] Calycem pro fructu & Antheras pro seminibus habuerit, vel an verum fructum viderit, determinent autoptici'* [if the Author (Pontedera) took the calyx for a fruit and the anthers for seeds, or observed a genuine fruit, will be ascertained by dissections.] In the *Hortus Cliffortianus*, Linnaeus published a detailed plate (Figure 3), for which the announced dissections were made. He was now certain (Figure 4): *'Femina nobis non nota est, & quem fructum descripsit Cl Pontedera fuit absque dubio flos non explicatus, & semina solum antherae, unde Anthospermum nobis dicatur'* [The female is not known to us, and the fruit, which the Honorable Pontedera described, was without doubt an unfolded flower, and the seeds only anthers, whence we call it *Anthospermum*']. Linnaeus' name thus means 'floral seed' and alludes to Pontedera's wrong interpretation of a flower bud.

Pontedera's error

Pontedera (1718) published his genus *Tournefortia* in a letter to William Sherard, appended to his *Compendium Tabularum Botanicum*: *'Tournefortia est genus Plantae producens Florem Monopetalum, Infundibuliformem, calyci insidentem, & leviter per oras incisum, cujus calyx abit in fructum subrotundum, angulosum, octo seminibus foetum, oblongis, binis & binis dispositis'* [*Tournefortia* is a genus of plants producing a flower with a single petal, funnel-shaped, seated in a calyx, and slightly incised at



302 DIOECIA TETRANDRIA.

ANTHOSPERMUM *. Tournefortia *Pont*. 745

* *Mas.*

CAL: *Perianthium* monophyllum, conicum, ultra medium quadrifidum: *laciniis* ovato-oblongis, revolutis, obtuſis, parum coloratis.

COR: nulla: niſi Calycem dicas.

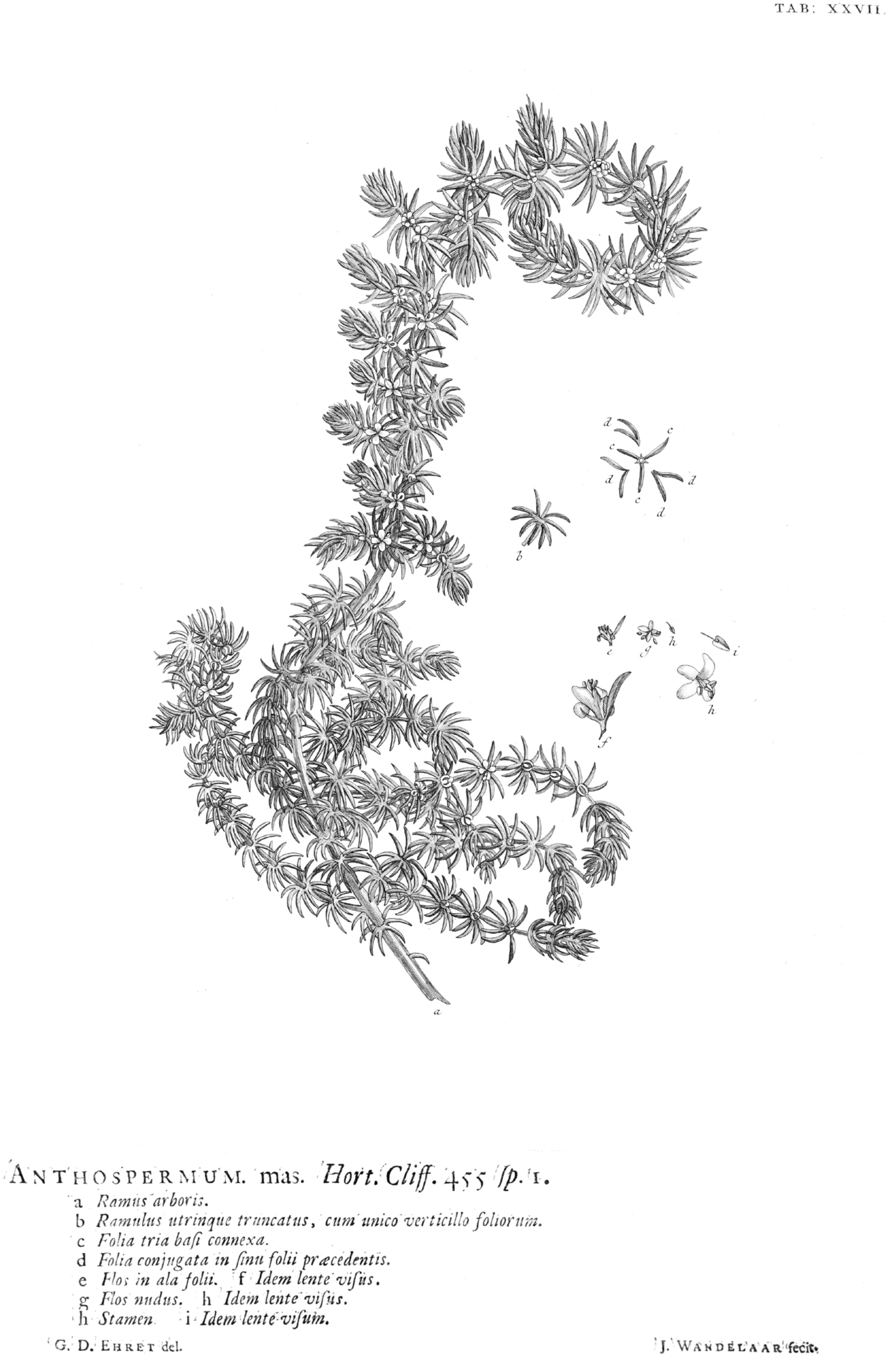
STAM: *Filamenta* quatuor, capillaria, erecta, longitudine calycis, receptaculo inſerta. *Antheræ* didymæ, oblongæ, quadragonæ, obtuſæ, erectæ.

* *Femina.*

CAL: - - - -
COR: - - - -
PIST: - - - -
PER: - - - -
SEM: - - - -

OBS: *Hæc planta ſolo flore maſculino ab omnibus aliis manifeſte diſtinguitur, femina licet nobis ignota ſit: Characterem itaque Cl. Pontederæ inſeram:* Flos monopetalus, infundibuliformis, calyci inſidens, ore leviter inciſo. Calyx abit in FRUCTUM ſubrotundum, anguloſum, fœtum SEMINIBUS octo, oblongis, & binis connexis. *An Author Calycem pro fructu & Antheras pro ſeminibus habuerit, vel an verum fructum viderit, determinent autoptici.*

Figure 2. Linnaeus' treatment of *Anthospermum* in *Genera Plantarum* (Linnaeus 1737a: 302). Smithsonian Libraries and Archives, available through Biodiversity Heritage Library.



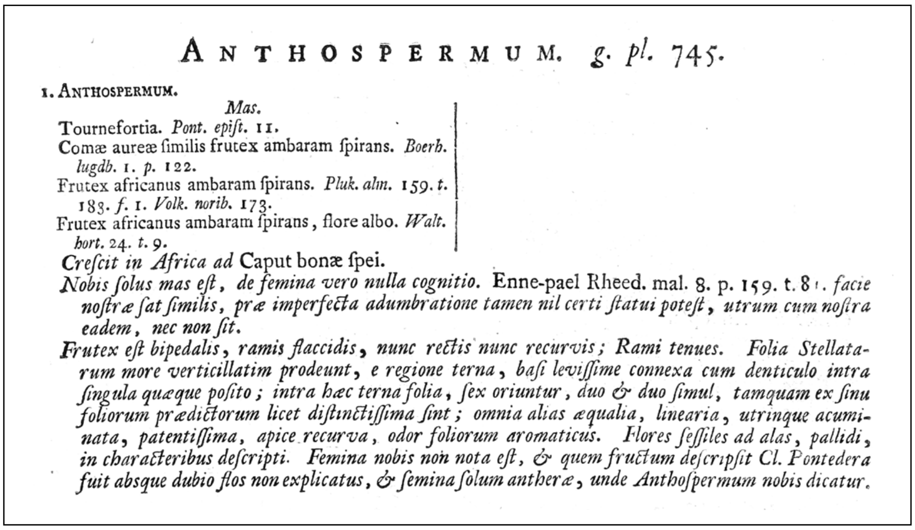
TAB: XXVII.

ANTHOSPERMUM. mas. *Hort. Cliff.* 455 *ſp.* 1.

a *Ramus arboris.*
b *Ramulus utrinque truncatus, cum unico verticillo foliorum.*
c *Folia tria baſi connexa.*
d *Folia conjugata in ſinu folii præcedentis.*
e *Flos in ala folii.* f *Idem lente viſus.*
g *Flos nudus.* h *Idem lente viſus.*
h *Stamen.* i *Idem lente viſum.*

G. D. EHRET del. J. WANDELAAR fecit.

Figure 3. Linnaeus' illustration of *Anthospermum* [*aethiopicum*] in *Hortus Cliffortianus* (Linnaeus 1737b: plate 27). Library of Meise Botanic Garden.



ANTHOSPERMUM. *g. pl.* 745.

1. ANTHOSPERMUM.

Mas.

Tournefortia. *Pont. epiſt.* 11.
Comæ aureæ ſimilis frutex ambaram ſpirans. *Boerh. lugdb.* 1. *p.* 122.
Frutex africanus ambaram ſpirans. *Pluk. alm.* 159. *t.* 183. *f.* 1. *Volk. norib.* 173.
Frutex africanus ambaram ſpirans, flore albo. *Walt. hort.* 24. *t.* 9.

Creſcit in Africa ad Caput bonæ ſpei.

Nobis ſolus mas eſt, de femina vero nulla cognitio. Enne-pael Rheed. mal. 8. p. 159. t. 81. *facie noſtræ ſat ſimilis, præ imperfecta adumbratione tamen nil certi ſtatui poteſt, utrum cum noſtra eadem, nec non ſit.*

Frutex eſt bipedalis, ramis flaccidis, nunc rectis nunc recurvis; Rami tenues. Folia Stellatarum more verticillatim prodeunt, e regione terna, baſi leviſſime connexa cum denticulo intra ſingula quæque poſito; intra hæc terna folia, ſex oriuntur, duo & duo ſimul, tamquam ex ſinu foliorum prædictorum licet diſtinctiſſima ſint; omnia alias æqualia, linearia, utrinque acuminata, patentiſſima, apice recurva, odor foliorum aromaticus. Flores ſeſſiles ad alas, pallidi, in characteribus deſcripti. Femina nobis non nota eſt, & quem fructum deſcripſit Cl. Pontedera fuit absque dubio flos non explicatus, & ſemina ſolum antheræ, unde Anthoſpermum nobis dicatur.

Figure 4. Linnaeus' treatment of *Anthospermum* in *Hortus Cliffortianus* (Linnaeus 1737b: 455). Library of Meise Botanic Garden.

the edges, whose calyx leads to a sub-rounded, angular fruit, bearing eight oblong seeds, arranged in pairs.]. Especially the eight 'seeds' (anthers) arranged in pairs are difficult to interpret. Note that the *Anthospermum* species studied by Pontedera and Linnaeus (nowadays *Anthospermum aethiopicum*) has tetramerous flowers (with a single whorl of anthers, as is standard in Rubiaceae). Do the eight seeds in fact correspond to the four anthers with two thecae each? Pontedera should not be ridiculed for his mistake because detailed observations of a small flower [the corollas (tube + lobes) of the male flowers are only ± 3 mm long] must have been challenging in the early 18th century, without powerful optical equipment.

Linnaeus' interpretation

It is difficult to imagine how Linnaeus linked the vague and confusing description published by Pontedera to his concept of *Anthospermum*. Pontedera and Linnaeus were probably never in direct contact, and, in any case, the Italian botanist was not an adept of Linnaeus' revolutionary approach (Jönsson 2011). It is more likely that Linnaeus had more than only published evidence to establish the identity of Pontedera's *Tournefortia*. We assume that he also saw specimens used by Pontedera. We consulted Linnaeus' herbarium on the internet for possible specimens with annotations pointing to Pontedera. Puff (1986: 227) cited syntypes labelled *'Habitat in Aethiopiae'* and *'Caput bonae spei'*. He designated *Linn 1233.1* [(BM; herb. Clifford (in herb. Banks)] as lectotype of *A. aethiopicum*. The Linnaean Collections at the Linnean Society of London only have one other identified *A. aethiopicum*, viz. *Linn 1233.2*, consequently the only other syntype. Three other specimens are only identified to genus level, while *Linn 1233.4* and *Linn 1233.5* are identified as *A. ciliare* and *A. herbaceum*, respectively. None of these bear traces of ever having been seen or studied by Pontedera. His Italian collections are in OXF (Vegter 1983). Unfortunately, we were unsuccessful in locating South African specimens seen by him.

Linnaeus' attitude towards the work of Pontedera cannot be known for certain. His son reported that he loved a joke (Blunt 1971: 167), and his sense of humour was reflected in his writing as well as in his teaching (Jönsson 2002). Is there a degree of sarcasm in coining the rather improper name 'floral seed'? Did he perhaps not hold the Italian botanist in high regard? At any rate, Linnaeus refused to pick up *Tournefortia*, the name Pontedera used for this genus of Rubiaceae of the Cape, and he even re-used that name for a totally unrelated and different plant currently in Boraginaceae (*Tournefortia* L.). The young Linnaeus was confronted with heavy criticism on his revolutionary reform of botany by a generation of well-established scientists (Jönsson 2011). As a response, he was not afraid of reacting strongly, among others by giving plant names insulting his opponents (Humar 2024). He named *Dorstenia* L. (Moraceae) after the German botanist Theodor Dorsten, stating that its flowers are insignificant, as if withered and past their time, like the outdated work of Dorsten (1492–1552) (Jönsson 2002). Another German botanist, Johann Georg Siegesbeck (1686–1755), was ridiculed by being 'commemorated' in the name of a smelly little weed *Siegesbeckia* L. (Jönsson 2011; Heard & Mlynarek 2023). Hence, Linnaeus' *Anthospermum* might represent a similar case. Should Linnaeus' insulting names be interpreted in the context of the new regulation on derogatory names in the future Code (Turland et al. 2024)? The Code only envisages names derogatory to a group of people, published on or after 1 January 2026, so the names *Anthospermum*, *Dorstenia* or *Siegesbeckia* are not in danger of future rejection.

Composition of generic names in Rubiaceae

The peculiar etymology of the name *Anthospermum* came to our attention while working on a project considering generic names in the family (Verstraete et al. in press). In Rubiaceae (and likely in most other angiosperm families), the most common way of naming a genus is by looking for a distinctive feature. To continue with African examples, *Carpacoce* refers to the shape of the fruit. Eponyms are the second largest category of generic names in Rubiaceae; *Alberta* E.Mey. is named after Albertus Magnus, a 13th century *'doctor universalis'*. Names may also refer to other names of taxa (e.g., *Paraknoxia* Bremek. refers to a relationship with *Knoxia* L.)., or to a cultural aspect (*Canthium* Lam. is based on a Malayalam name). Other names refer to a geographical origin (*Natalanthe* Sond., a synonym of *Tricalysia* A.Rich., referring to its discovery in Natal). None of these five categories apply to the name *Anthospermum*, which is unique in referring to a wrong observation. In Rubiaceae, we only know one slightly similar case. Achille Richard (in De Candolle 1830; Richard 1834) used the name *Nescidia* A.Rich. for a Mauritian species of *Coffea* L., which he knew only from flowering material. His name refers to the fact that the fruits were unknown to him (Latin *nescire* = not to know).

Conclusion

Quattrocchi (2000) as well as Clarke and Charters (2016) – and maybe other authors – made a wrong assumption when linking the etymology of the strange name *Anthospermum* with the complex reproductive biology of the genus. Instead, Linnaeus was inspired by an erroneous morphological observation made by Pontedera and hence composed this apparently insulting name in a way not paralleled in other generic names of Rubiaceae.

Acknowledgements

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The correct name for *Asparagus fasciculatus* Thunb. (Asparagaceae)

Authors
John C. Manning[1,2]

Affiliations
[1]Compton Herbarium, South African National Biodiversity Institute, Private Bag X7, Claremont 7735, South Africa.
[2]Research Centre for Plant Growth and Development, School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, Private Bag X01, Scottsville 3209, South Africa.

Corresponding Author
John C. Manning; e-mail: J.Manning@sanbi.org.za

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The name *Asparagus fasciculatus* Thunb. (1818) for a South African species in the genus is an illegitimate later homonym of the northern Australian *A. fasciculatus* R.Br. (1810). The later taxonomic synonym *A. consanguineus* (Kunth) Baker is available for the South African taxon and is thus the correct name for it.

Keywords: Africa; *Asparagus consanguineus*; homonym; nomenclature; taxonomy

Introduction

Asparagus Tourn. ex L. (Asparagaceae) comprises at least 215 and possibly up to 300 species widely distributed through Africa and Eurasia with a single species extending through Asia to Australia (Kubitzki & Rudall 1998; Bentz et al. 2024). The genus is well represented in southern Africa, with over 80 species in the region, including *A. fasciculatus* Thunb. (1818) from the Greater Cape Floristic Region (Jessop 1966; Manning & Goldblatt 2012).

Asparagus fasciculatus Thunb. was described by the Swedish botanist Carl Peter Thunberg from an herbarium specimen prepared from plants collected by the Scottish horticulturist Francis Masson, between 1772 and 1774, for the Royal Botanic Gardens at Kew (Jessop 1966). The species is endemic to the northern parts of the Greater Cape Floristic Region (Manning & Goldblatt 2012). The name *A. fasciculatus* R.Br. (1810) had, however, been published earlier for an Australian plant that Scottish botanist Robert Brown collected in northern Australia in 1802. This name is now considered to be conspecific with the widespread *A. racemosus* Willd., which ranges from southern and tropical Africa through Asia to northern Australia (Clifford & Conran 1987). Its existence, however, renders *A. fasciculatus* Thunb. an illegitimate later homonym (ICN *Art. 53*.1, Turland et al., 2018).

Fortunately, there exists a later synonym for the South African species in its current circumscription in the form of the combination *A. consanguineus* (Kunth) Baker (1875). This species was described under the name *Asparagopsis consanguinea* by Kunth (1850) from a specimen collected by Johann F. Drège, who travelled widely in the southern and eastern parts of South Africa between 1826 and 1834 (Glen & Germishuizen 2010). Kunth provided no locality information for his species, but his description is adequate to identify it (Jessop 1966), and type material located at Kew confirms this decision. The name was subsequently transferred to the genus *Asparagus* by Baker (1875), and this becomes the earliest legitimate name for the taxon.

Results

Asparagus consanguineus *(Kunth) Baker* in J. Bot. Linn. Soc., Bot. 14: 615 (1875). *Asparagopsis consanguinea* Kunth, Enum. Pl. [Kunth] 5: 76

(1850). Type: South Africa, without precise locality or date [Western Cape, Piketberg], *Drège s.n.* (KIEL, holo.; K000255699—image!, L0041372—image!, iso.).

Asparagus fasciculatus Thunb., Fl. Cap. (Thunberg) Ed. 1a, 2: 329 (1818), nom. illeg., non R.Br. (1810). Type: South Africa, 'Cap Bonae Spei', without precise locality or date, *Masson s.n.* (UPS, holo.).

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Asparagus fasciculatus R.Br., Prodr. Fl. Nov. Holland: 281 (1810). Type: Australia, Carpentaria Islands, Groote Eylandt, 14 Dec. 1802, *Brown 5663* (BM000990612, holo.—image!; E0068205, ?iso.—image!)

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On the occurrence of *Nephrangis filiformis* (Orchidaceae) in Kenya and Tanzania

Authors
Benny Bytebier

Affiliations
Bews Herbarium, Centre for Functional Biodiversity, School Life Science, University of KwaZulu-Natal, P/Bag X01, 3209 Scottsville, South Africa.

Corresponding Author
Prof. Benny Bytebier,
E-mail: bytebier@ukzn.ac.za

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Nephrangis filiformis is a rare epiphytic African orchid growing in wet upland tropical forest. In all recent floristic treatments and botanical websites its distribution is reported as Liberia, Côte d'Ivoire [Ivory Coast], Democratic Republic of the Congo (DRC), Rwanda, Burundi, Zambia, Uganda, Kenya and Tanzania. Here I show that its alleged occurrence in Kenya and Tanzania is based on a misidentification in a book published in 1968, which has been carried over ever since. Since there is no physical or photographic evidence to the contrary, I conclude that *Nephrangis filiformis* does not occur in Kenya or Tanzania.

Accurate distribution data are critical for threat assessment. Both overestimating and underestimating the distribution range of a species can lead to an incorrect IUCN Red List category (IUCN 2022). *Nephrangis filiformis* (Kraenzl.) Summerh. is a rare, epiphytic, tropical African forest orchid known from less than 50 herbarium specimens (22 at BR, 12 at K, 2 at MO and WAG and 1 at EA; acronyms according to Thiers [2024]).

Nephrangis filiformis was described as *Listrostachys filiformis* Kraenzl. based on a single specimen, *Stuhlmann 2229*, collected at 1 900 m in the '*Njavekesi-Berge*', south of Lake Edward in the DRC (Kraenzlin 1895). Schlechter (1918) transferred the species to *Tridactyle* Schltr. in the monotypic subgenus *Nephrangis* Schltr., but commented that it might eventually prove to represent a distinct genus. His doubt about its taxonomic position arose from the fact that he had only Stuhlmann's specimen at his disposal, of which the flowers were mostly over. Summerhayes (1948), after examining half a dozen specimens, some of which preserved in spirit, confirmed Schlechter's view and raised his subgenus to generic rank. In his opinion this was warranted due to the remarkable lip shape, the absence of basal auricles characteristic of *Tridactyle*, and differences in pollinarium structure. Simo-Droissart et al. (2018) showed that *Nephrangis*, now comprising two species, forms a clade within the African angraecoid orchids.

In the second edition of Orchids of East Africa, Piers (1968) reported *Nephrangis filiformis* from Uganda ('common in rain forest'), and for the first time from Kenya ('common in the forests of the Lake Province, e.g. Kakamega forest') and Tanzania ('forests near Muheza and the in the West' [sic]), but does not mention any associated specimens. Cribb (1989) in *Flora of Tropical East Africa*, confirms this taxon for Uganda on the basis of several specimens, but refers to Piers (in lit.) with regard to its presence in Tanzania and Kenya. Since then, the distribution in East Africa has been copied in several other regional floras such as *Flore d'Afrique Centrale* (Geerinck 1992), *Orchids of Kenya* (Stewart 1996), *Flora Zambesiaca* (La Croix & Cribb 1998), *Orchidaceae of Ivory Coast* (Szlachetko 2008), *The Orchids of Rwanda* (Fischer et al. 2010a) and *Orchidaceae of West-Central Africa* (Szlachetko et al. 2021). At present, *Nephrangis filiformis* is considered to have a disjunct distribution on the western side of the African continent in Liberia and Côte d'Ivoire and on the central to eastern side of the continent in the DRC, Rwanda, Burundi, Zambia, Uganda and as far east as Kenya and Tanzania (POWO 2024).

However, it is clear from the description in Piers (1968) that the purported occurrence of *Nephrangis filiformis* in Kenya and Tanzania is based on a misidentification. Piers (1968) describes the lip as follows, 'The most conspicuous part is the lip which is of an unusual shape: "*hastate*" at the base, i.e. with two pointed lobes extending back to the column, and a triangular front lobe, drawn out into a fine point.' This description fits the lip of *Tridactyle filifolia* (Schltr.) Schltr. and not that of *N. filiformis*, which is unguiculate and concave at the base, abruptly dilated into two reniform, rounded lobes, hence the name *Nephrangis*. Both species are illustrated in Cribb (1989). Vegetatively they are almost indistinguishable. Indeed Summerhayes (1948) comments that 'In the vegetative state it is difficult to distinguish the species [*N. filiformis*] from var. *subulifolia* of *Tridactyle tridentata* (Harv.) Schltr. (=*Tridactyle filifolia*).'

In this case it is clear that the presence of this species in Kenya and Tanzania is based on a misidentification and that this distribution record was carried over since 1968 from one source to the next. Neither the East African Herbarium (EA), nor the Royal Botanic Gardens Kew (K), the two most important herbaria with regard to East Africa, hold any specimens collected from Kenya or Tanzania. Furthermore, no Kenyan or Tanzanian records of this species are reported on GBIF (https://www.gbif.org/species/2832418). Fisher et al. (2010b), in their extensive checklist of the vascular plants of Kakamega Forest in Kenya, also did not record this species. *Tridactyle filifolia*, however, is widely distributed in tropical Africa and is known to occur in Kenya and Tanzania (POWO 2024).

Consequently, and until proof to the contrary, we must assume that *Nephrangis filiformis* does not occur in Kenya and Tanzania.

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Competing interests

The author declares that he has no financial or personal relationship that may have inappropriately influenced him in writing this article.

Author contributions

BB performed the research and authored the paper.

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SANBI
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South African National Biodiversity Institute

African Biodiversity & Conservation
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These guidelines provide an overview of the structure and style of articles to be submitted to the South African National Biodiversity Institute (SANBI)'s peer-reviewed journal:
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Full length articles report on complete, comprehensive pieces of original research, as well as reviews, strategies or innovative case studies in any field of work aligned with the scope of the journal. Full length articles include a maximum of 10 000 words and 60 references.

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> JK (University of Pretoria) was the project leader, LMN (University of KwaZulu-Natal) and A.B. (Stellenbosch University) were responsible for experimental and project design. LMN performed most of the experiments. PR (Cape Peninsula University of Technology) made conceptual contributions and ST (University of Cape Town), UV (University of Cape Town) and CD (University of Cape Town) performed some of the experiments. SM (Cape Peninsula University of Technology) and VC (Cape Peninsula University of Technology) prepared the samples and calculations were performed by CS (Cape Peninsula University of Technology).

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- **Books**

    Little, R. & Bainbridge, W., 1992, *Birds of the Natal Drakensberg Park,* Wildlife Society of Southern Africa (Natal Branch).

    Taylor, P., 1998, *The small mammals of KwaZulu-Natal*, University of Natal Press, Pietermaritzburg.

    Willdenow, C.L., 1799, *Species plantarum*, ed. 4, vol. 2(1), Nauk, Berlin.

- **Books published as numbers in a monograph series, Flora or Fauna**

    Bates, M.F., Branch, W.R., Bauer, A.M., Burger, M., Marais, J., Alexander, G.J. & De Villiers, M.S. (eds), 2014, Atlas and Red List of the Reptiles of South Africa, Lesotho and Swaziland, *Suricata* 1, 1–485.

    Cribb, P.J., 1989, 'Orchidaceae (Part 3)', in R.M. Polhill (ed.), *Flora of Tropical East Africa*, A.A. Balkema, Rotterdam.

    Glen, H.F. & Germishuizen, G., 2010, Botanical Exploration of southern Africa, Ed. 2., *Strelitzia* 26, South African National Biodiversity Institute, Pretoria.

    La Croix, I. & Cribb P.J., 1998, 'Orchidaceae (part 2)', in G.V. Pope (ed.), *Flora Zambesiaca*, vol. 11, part 2, Flora Zambesiaca Managing Committee, London.

    Manning, J.C. & Goldblatt, P., 2012, Plants of the Greater Cape Floristic Region 1, the Core Cape Flora, *Strelitzia* 29, South African National Biodiversity Institute, Pretoria.

- **Book chapters**

    Bronner, G.N., 2013, '*Chlorotalpa sclateri*, Sclater's Golden Mole', in J. Kingdon, D. Happold, M. Hoffmann, T. Butynski, M. Happold & J. Kalina (eds) *Mammals of Africa. Volume I. Introductory Chapters and Afrotheria* (pp. 210–215)*,* Bloomsbury Publishing, London.

    Carbutt, C., 2020, 'The imperilled alpine grasslands of the Afrotropic realm, in D.A. DellaSala & M.I. Goldstein (eds*), Imperilled: The Encyclopedia of Conservation* (pp. 243–255), https://dx.doi.org/10.1016/B978-0-12-821139-7.00012-X.

- **Reports**

  Bredenkamp, G.J. & Brown, L.R., 2003a, 'Habitat types of North-West province', in North West Province Biodiversity Site Inventory and Database Development, Technical Report, Strategic Environmental Focus (Pty) Ltd, Pretoria, South Africa.

  Day, J.A., Harrison, A.D. & De Moor, I.J., 2002, 'Guides to the freshwater invertebrates of southern Africa, Volume 9: Diptera', Water Research Commission Report no. TT 201/02, Pretoria, South Africa.

  Gubb, A.A., 1980, 'Vegetation map of the Northern Cape province', Report, McGregor Museum, Kimberley, South Africa.

- **Articles in peer-reviewed journals (please add DOIs where available in the format shown)**

  Englund, W.F., Njoroge, L., Biström, O., Miller, K.B., Bilton, D.T. & Bergsten, J., 2020, 'Taxonomic revision of the Afrotropical *Agabus raffrayi* species group with the description of four new species (Coleoptera, Dytiscidae)', *ZooKeys* 963, 45–79, https://doi.org/10.3897/zookeys.963.53470.

  Fischer, E., Rembold, K., Althof, A., Obholzer, J., Malombe, I., Mwachala, G., Onyango, J.C., Dumbo, B. & Theisen, I., 2010, 'Annotated checklist of the vascular plants of Kakamega Forest, Western Province, Kenya', *Journal of East African Natural History* 99(2), 129–226, https://doi.org/10.2982/028.099.0205.

  Hamer, M. & Martens, K., 1998, 'The large Branchiopoda (Crustacea) from temporary habitats of the Drakensberg region, South Africa', *Hydrobiologia* 384, 151–165.

  Kotzé, J., Mc Lean, C. & Van Tol, J., 2023, 'Digitally mapping soil carbon of the uThukela headwater catchment in the Maloti-Drakensberg, a remote Afromontane mountain region', *South African Geographical Journal* 106(4), 498–517, http://dx.doi.org/10.1080/03736245.2023.2272896.

- **Theses**

  Martin, S.A., 2017, The aardvark as an ecological engineer in the Eastern Karoo: dig patterns and emergent processes, MSc thesis, Nelson Mandela Metropolitan University.

  Midgley, J.M., 2012, Quantifying the structure of epigaeic invertebrate communities along an altitudinal gradient on the Great Escarpment, South Africa, PhD thesis, Rhodes University, Grahamstown.

- **Non-peer reviewed articles (magazines)**

  Schields, M., 2024, 'What climate change means for South Africa and its people', Quest 20,3, 11–13.

  Treurnicht, M., Ebrahim, I. & Becker-du Toit, C., 2024, 'Safeguarding our succulents', Veld & Flora June 2024, 10–11.

- **Non-peer reviewed articles (online)**

  Civil Aviation Authority of Botswana (CAAB), 2019, Civil Aviation Authority of Botswana, Newsletter, Issue 1/2019, viewed 20 June 2020, www.caab.co.bw/wp-content/uploads/CAAB-Newsletter-2019-18-21.pdf.

  Calonje, M., Stevenson, D.W. & Osborne, R, 2023, viewed 7 July 2023, 'The world list of cycads, online edition', http://www.cycadlist.org.

- **Website-based databases**

  Avenant, N., Wilson, B., Power, J., Palmer, G. & Child, M.F., 2019, *Mystromys albicaudatus*. The IUCN Red List of Threatened Species, viewed 13 October 2024, https://dx.doi.org/10.2305/IUCN.UK.2019-1.RLTS.T14262A22237378.en.

  Baxter, R., Taylor, P., & Child, M.F., 2017, *Otomys auratus*. The IUCN Red List of Threatened Species, viewed 22 August 2023, https://dx.doi.org/10.2305/IUCN.UK.2017-2.RLTS.T110662638A110662647.en.

- Software

  Chen, H., 2022, *VennDiagram*: Generate High-Resolution Venn and Euler Plots. R package version 1.7.3., https://CRAN.R-project.org/package=VennDiagram.

  Hsieh, T.C., Ma. K.H. & Chao, A., 2022, *iNEXT*: Interpolation and Extrapolation for Species Diversity, R package version 3.0.0, https://chao.shinyapps.io/iNEXTOnline/.

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African Biodiversity & Conservation publishes taxonomic findings where these align with the scope of the journal (see Vision and Scope of *African Biodiversity & Conservation*). For such works the following headings should be used:

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- Basionym (the first name validly published, which has priority over other names later given to the same species): **Name** (bold, not italicised), *author citation* (italicised), author/s of paper in which basionym stated (if different from original author, not italicised).
- Name of the journal/publication written out in full (not italicised), volume: page number/range (date of publication), fig/s.
- Type locality: COUNTRY (upper case), as provided in the original description, **Province** (bold). Type specimen/s: date of collection, *collector (italicised), collector number* (italicised) (where available), institution code (using global acronym), catalogue number (where available), status (holotype, isotype/ syntype, lectotype). If specimen was examined, this is indicated by a '!' after the specimen status.
- Additional references, in chronological order, with author: page (year of publication), figure number/s reflected (e.g. Boris et al.: 14 (1966); Boris: 89 (1967), fig. 9.).
- List of synonyms in chronological order, arranged in groups of nomenclatural synonyms (i.e. homotypic synonyms (based on the same type), followed by heterotypic synonyms (based on a different type), arranged chronologically), with references cited as author, page (year of publication), and figure number/s listed in chronological order.
- Identification of illegitimate names in the nomenclatural component must be accompanied by an appropriate indication of the reason for their illegitimacy. The type details for each heterotypic synonym should be included (institution code followed by catalogue number where available and type status), and those specimens examined by the author/s must be indicated by an exclamation mark. The full reference for citations must be included in the Reference List.

  Examples:

  1. **Eremiolirion amboense** (*Schinz*) *J.C.Manning & C.A.Mannheimer* in Bothalia 35: 117 (2005), fig. 4. Type: South West Africa [NAMIBIA], Amboland [**Ovamboland**], Ongangua [Ondongwa], without date, *Ruatanen 344* (Z.holo!).
  2. **Walleria gracilis** (*Salisb.*) *S.Carter* in Kew Bulletin 16: 189 (1962). *Androsyne gracilis* Salsb.: 61 (1866). Type: SOUTH AFRICA, **Western Cape**, *William Marsden* [BM, holo!; drawing in Salisbury mss.8: 818 (BM)].

     W. armata Scltr. & K.Krause in Krause: 235 (1921). Type: SOUTH AFRICA, [**Western Cape**, near Klawer], [Farm] Windhoek, 8 July 1896, *R. Schlechter 8074* (B, holo [not seen]; BM!, BR!, COI!, GRA!, K, MO!, PRE!, S!. iso).
  3. **Plagiotaphrus improvisus** *(Attems 1934) Hoffman* in Revue de Zoologie et de Botanique Africaines, 83 (3–4): 209 (1971), fig. 2. *Megaskamma improvisa:* Attems: 16: 13 (1934), figs 14–17. Type: **ANGOLA**, near Cuanza River, Biëi District, Jan. 1932, *F. Haas* (SMF 1694, holo. [not seen] 1 male).
- Lectotypes or neotypes should be chosen for correct names without a holotype. It is not necessary to lectotypify synonyms. When a lectotype or neotype is newly chosen, this should be indicated by using the phrase 'here designated'. If reference is made to a previously selected lectotype or neotype, the name of the designating author and the literature reference should be given. In cases where no type was cited, and none has subsequently been nominated, this may be stated as "not designated".

Description of new taxa (second-level heading):

- All newly described taxa and newly proposed synonyms and new combinations should be explicitly designated as such, e.g. *fam. nov., trib. nov., gen. nov., sp. nov., nom. nudem., syn. nov., comb. nov.*

  Name (bold, not italicised) *authority* (italicised; if different to the authors of the manuscript), *sp. nov.* (italicised)

  TYPE/S: (holotype followed by paratype/s) (COUNTRY (upper case), **province** (bold), locality as given by original collector (if in foreign language or using archaic or outdated place names then these must be placed in inverted commas, with modern equivalent of collecting locality in square brackets (if relevant)), geographic co-ordinates (if the geographic co-ordinates were not provided on the specimen label or provided by the collector, and were identified by the author using a gazetteer or Google Earth, this must be indicated by including the co-ordinates in square brackets, altitude, habitat or other available, relevant collecting details, date of collection, *collector's name (italicised), collector's number (italicised*) (if available), (institution where specimen is housed (using global acronyms for these), catalogue number (if available), number of specimens by male and female (where relevant)).

Examples:

1. **Lasiosiphon rigidus** *J.C.Manning & Boatwr., sp. nov.*

   TYPES: SOUTH AFRICA, **Northern Cape**, Tankwa [Tanqua] Karoo National Park, SW foot of Leeuberg, along drainage lines, [32°18,2'S / 20°0.3'E, 414 m a.s.l.], 20 Jun. 2012, *Manning 3363* (NBG, holo., MO, PRE, iso).

2. **Doratogonus microsetus** *sp. nov.*

   TYPES: SOUTH AFRICA, **Mpumalanga**: Wakkerstroom, 27.36670°S / 30.01670° E, 20 Dec, 2000, *D. Forbes (*NMSA 21786, 1 male holo.; NMSA 21787, 2 males, 1 females, para.).

Third-level headings for taxonomic treatments:

- Description (with third-level headings if required, and according to diagnostic characters for the particular taxon)
- Distribution and habitat
- Ecology
- Etymology
- Local name/s
- Uses / economic value
- Diagnosis and relationships
- Conservation status – comment on whether included in existing Red Lists, or whether the species would potentially qualify as threatened and describe current and potential threats.
- Other material examined (country (upper case), province (bold): locality as given by original collector, modern equivalent of collecting locality in square brackets (if relevant), co-ordinates (degrees, minutes decimal) (in square brackets if gazetteer or Google Earth used by author), approximate altitude, date of collection, *collector's name (italics), collector's number* (italics) (if available) (institution where specimen is housed (using international acronym or code for these), catalogue number (if available), number of specimens by male and female (where relevant)).
- List of specimens must be arranged alphabetically by country, and within countries, by province in alphabetical order, and within provinces, alphabetically by locality name, and as far as possible keeping those specimens from the same locality together, then in chronological order by collection date.
- Herbarium acronyms follow Index Herbariorum [Thiers, B. [continuously updated]. Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/ih/]. The accepted acronyms for other institutions can be obtained from the Global Registry of Biorepositories (GRBio) (http://grbio.org).
- Original locality information in a foreign language or using archaic/outdated place names should be indicated using inverted comas, with any relevant corrections for modern usage, including conversions to metric units, added in square brackets.
- The date of collection is to be presented as day, month of the year (abbreviated as Jan., Feb., Mar., Apr., May, Jun., Jul., Aug., Sept., Oct., Nov., Dec.), and year in full.
- Geographic co-ordinates must be presented as taken from a GPS, or from an online gazetteer or georeferencer in degrees, decimal minutes (DDM). Records must also indicate the hemisphere (E or W and N or S, and the estimated/approximate altitude. If the geographic co-ordinates and approximate altitude were not provided on the specimen label or provided by the collector, and were identified by the author, this must be indicated by including the co-ordinates in square brackets.
- For species that may be threatened by over-collecting, the co-ordinates can be degraded to reflect only the degrees and minutes. In the case of old specimens where the exact locality is unknown the degree and minutes or equivalent, or the degree or quarter degree grid square can be provided.

Examples:

1. SOUTH AFRICA, **Western Cape**: Near Eendekuil, western foot of Piekenierskloof Pass, [32°37.136'S / 18°57.525'E 476 m a.s.l.], 28 Aug. 2009, *Magee, Boatwright, Manning and Goldblatt 161* (NBG, PRE, K, BOL); roadside near Gouda, [33°37.136'S / 19°2.044'E, 85 m a.s.l.], 09 Sept. 1951, *Esterhuysen 18840* (BOL [3 sheets], K, PRE). Tulbagh, 33°17.126'S / 19°8.257"E, 162 m a.s.l., Sept. 1919, *Bolus 16734* (BOL);
2. SOUTH AFRICA, **KwaZulu-Natal:** Nkandhla Forest, in forest along dirt road, 28°43'38.592"S / 31°07'58.281"E, 1 121 m a.s.l., 19 Nov, 2001, *A. Armstrong & H. Murray* (NMSA 21970 [1 male, 1 female]).

Language for these sections must be as concise as possible, using principles instead of verbs.

The remaining first-level headings (Discussion, Conclusions, Acknowledgements and References) must follow the same format as for full length articles, as detailed above.

Images – low-resolution version in the text file AND high-resolution files – correctly labelled – as separate JPG, TIF or EPS files.

Identification keys: Dichotomous keys must use sequential numbering, with the two parts of the couplet numbered 1a, b; 2a, b etc. New species included in keys must be bolded and not italicised, and sp. nov. must be stated, while other species names must not be bolded, must be italicised, and must include the species authority in the correct format.

Illustrations for taxonomic works: Descriptions of new plant species should include a photograph of the holotype specimen, unless there is a good reason for not providing this. For all taxa, descriptions of new species and taxonomic revisions should include annotated illustrations that clearly show and indicate diagnostic characters.

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