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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*

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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 km^2), small area of occupancy (12 km^2), 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,

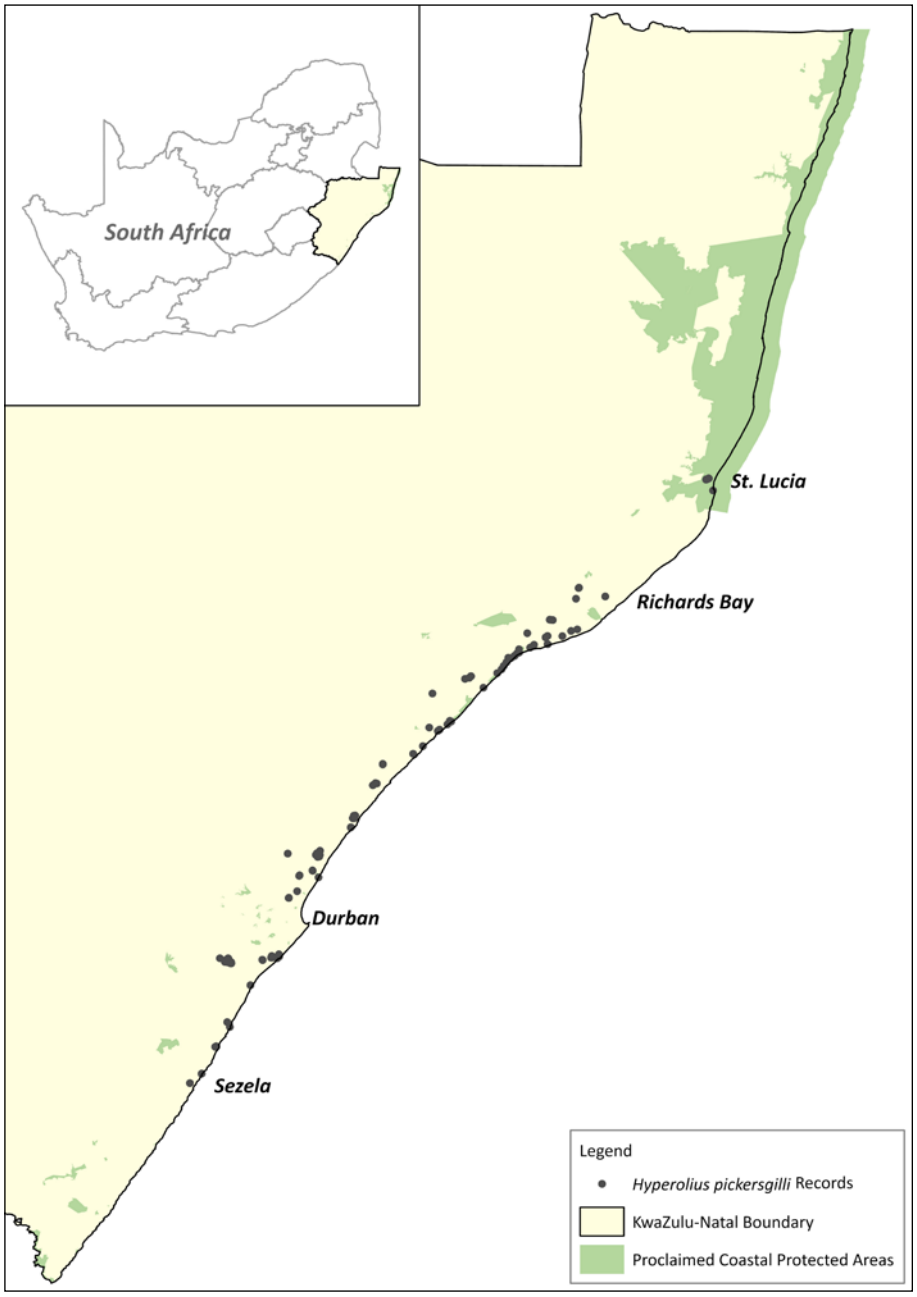

Figure 1. Occurrence records of Pickersgill's Reed Frog, *Hyperolius pickersgilli*, as of 14 July 2023 indicating its coastal distribution.

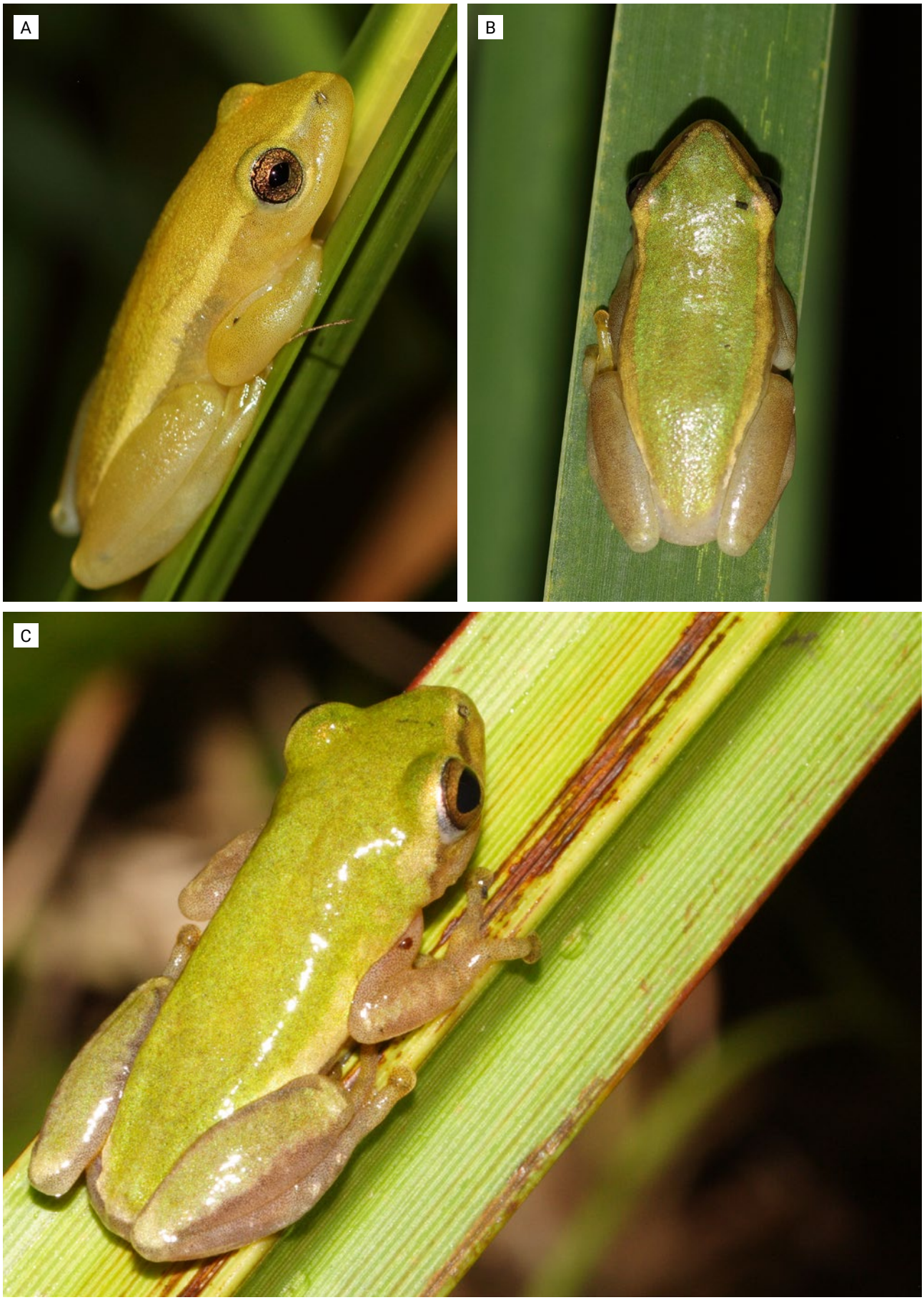

Figure 2. Pickersgill's reed frog, *Hyperolius pickersgilli*, adult males showing colour variations (A, B) and adult female (C). Photographs: A.J. Armstrong.

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

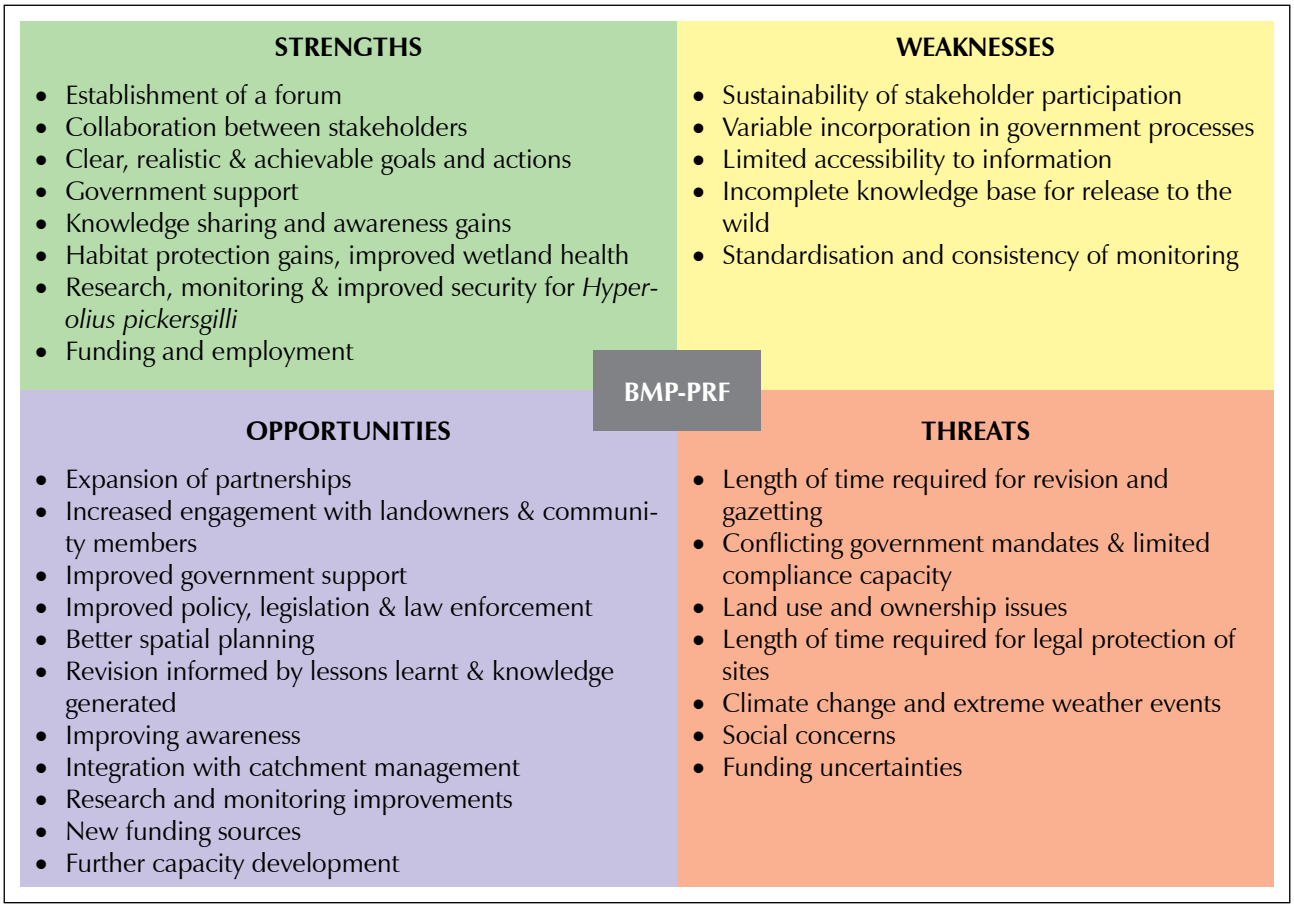

Figure 3. Summary of the results of the analysis of the Strengths and Weaknesses of the first five years of implementation of the Biodiversity Management Plan for Pickersgill's reed frog, *Hyperolius pickersgilli* (BMP-PRF), and of the Opportunities for, and potential Threats to, the revision of this 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

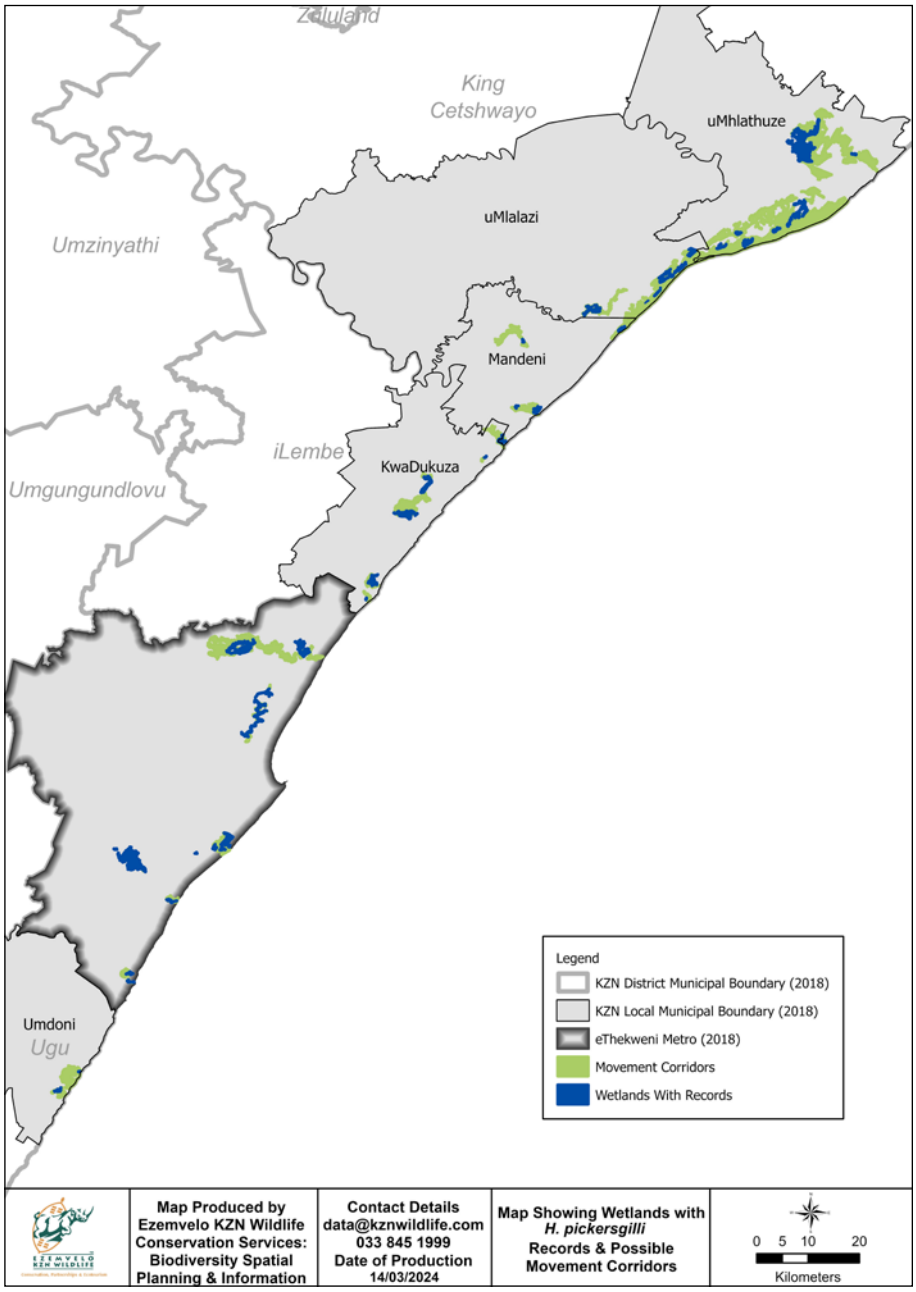

Figure 4. Map of priority habitat for Pickersgill's reed frog, *Hyperolius pickersgilli*, for inclusion in municipal spatial planning tools.

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

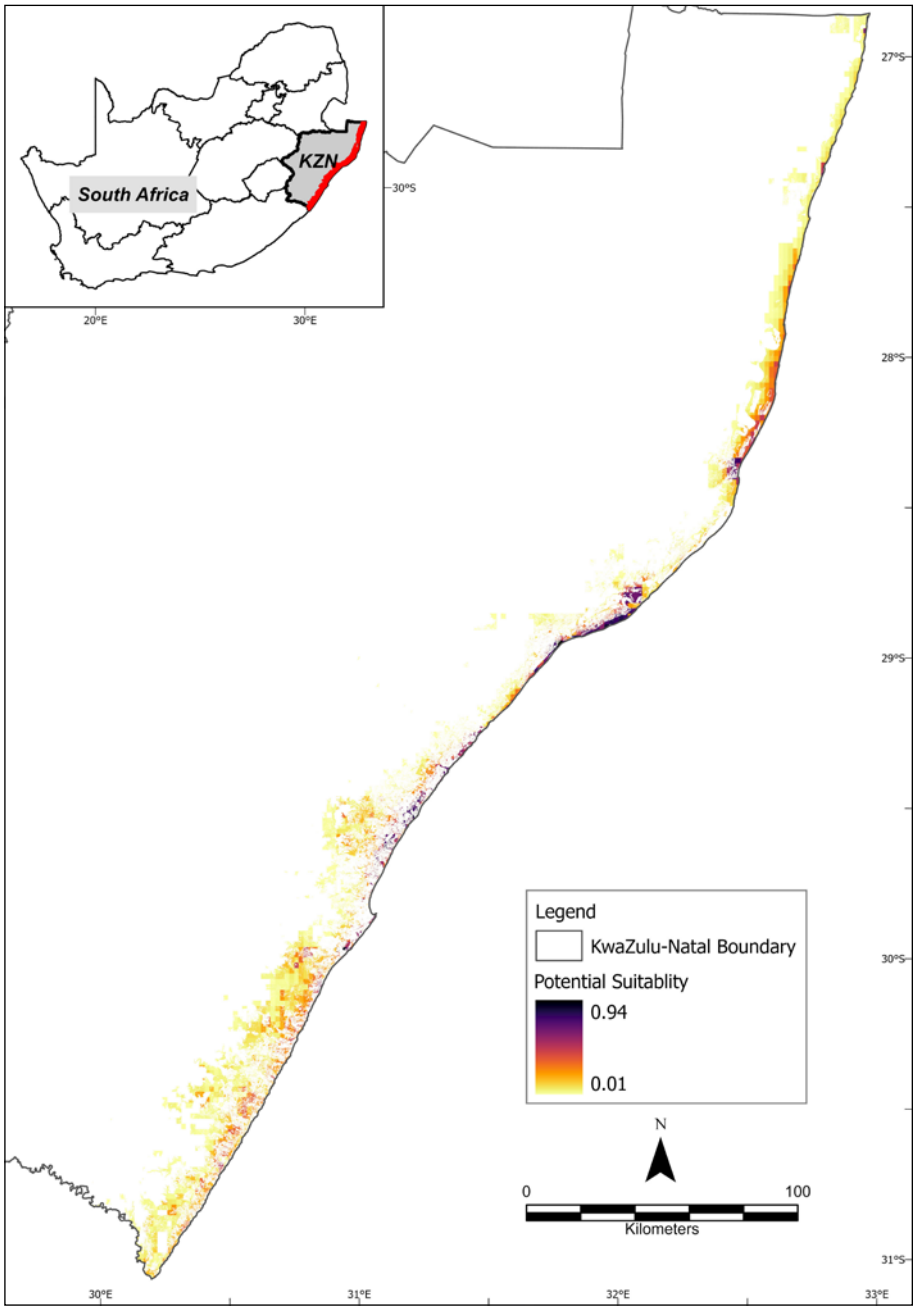

Figure 5. Predicted distribution of Pickersgill's reed frog, *Hyperolius pickersgilli*, in KwaZulu-Natal (KZN). Transformed areas have been removed from the map.

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

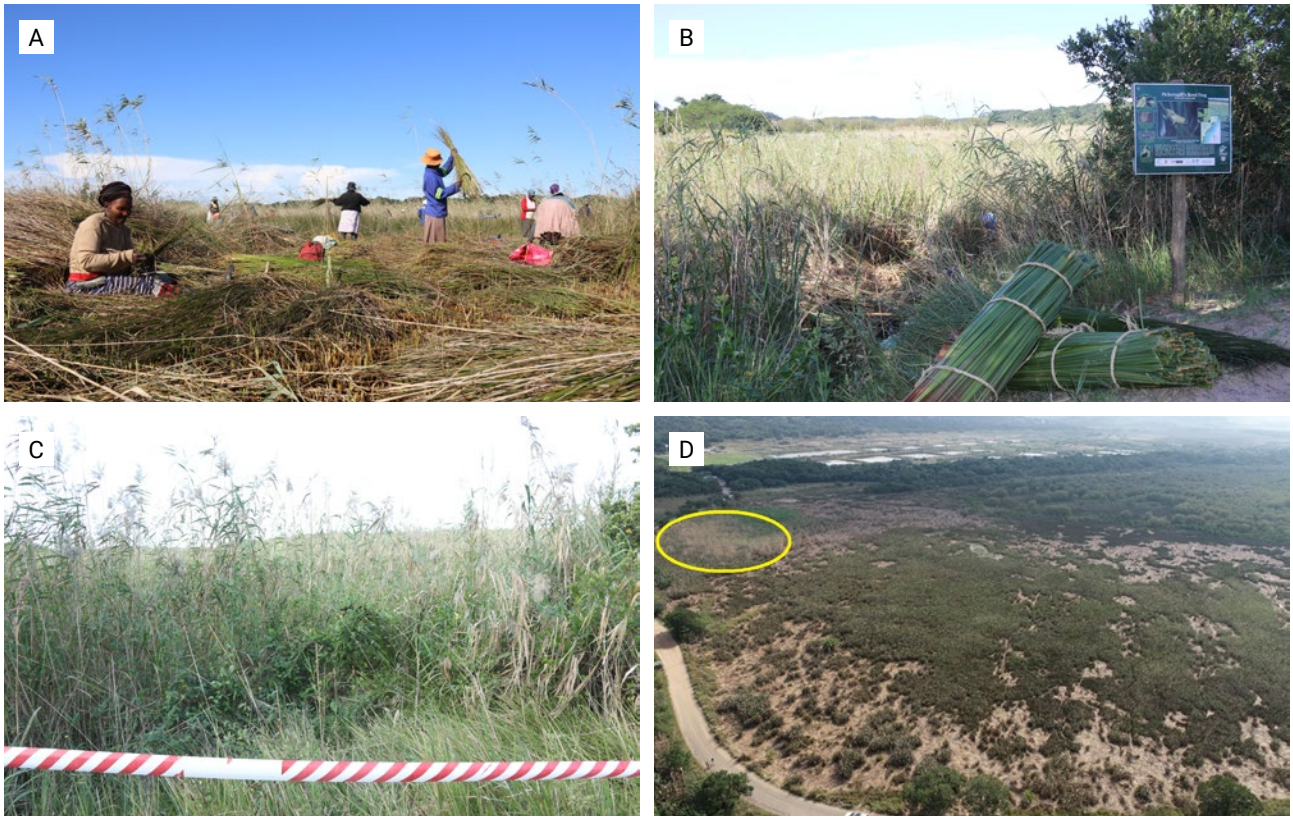

Figure 6. A, harvesters cutting and sorting *Juncus kraussii* in the Umlalazi Nature Reserve wetland; with B, bundles lying next to the Pickersgill's reed frog, *Hyperolius pickersgilli*, information board; C, barrier tape marks the edge of the wetland exclusion plot that protects *Hyperolius pickersgilli* 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).

References

(includes references for Supplementary Material)

Acker, C., 2022, 'A case study for wetland restoration towards socio-ecological appreciation of natural resources in KwaZulu-Natal (South Africa)', MSc thesis, University of South Africa, Pretoria, https://uir.unisa.ac.za/handle/10500/30492.

Acker-Cooper, C. & Roxburgh, L., 2022, 'Waste monitoring system', Endangered Wildlife Trust, Johannesburg.

Acker-Cooper, C. & Tarrant, J., 2022, 'Simbithi Eco-Estate Pickersgill's reed frog custodian project: monitoring report 2021–2022', Endangered Wildlife Trust, Johannesburg.

Acker-Cooper, C., Little, I. & Roxburgh, L., 2021, 'Environmental compliance management system', Endangered Wildlife Trust, Johannesburg.

Acker-Cooper, C., Musgrave, A., Louw, J., Saville, J. & Arde, B., 2022, 'Umgavusa protected environment management plan', Endangered Wildlife Trust, Johannesburg.

Acker-Cooper, C., Schenck, C., Jordon, L., Van Wyk, L., Nell, C., Tinka-Uys, M., Rose, C., Koen, C., Matandela, F. & Roxburgh, L., 2023, 'A comparative provincial assessment of disposable nappies or diaper system dynamics', in *One Health Forum*, viewed 15 April 2024, from https://www.researchgate.net/publication/371834461.

Acker-Cooper, C., Tarrant, J. & Mbuyisa, S., 2022, 'A comparative study: Amphibian species richness and habitat condition at four wetland sites in eThekwini where the Endangered Pickersgill's Reed Frog occurs', Endangered Wildlife Trust, Johannesburg.

Acker-Cooper, C., Theron, C., Smith, T. & Roxburgh, L., 2019, 'Ecological goods and services toolkit: A participatory approach to environmental management', Endangered Wildlife Trust, Johannesburg.

Armstrong, A.J., 2001, 'Conservation status of herpetofauna endemic to KwaZulu-Natal', *African Journal of Herpetology*, 50(2), 79–96, https://journals.co.za/doi/abs/10.10520/EJC19123.

Berger-Tal, O., Blumstein, D.T. & Swaisgood, R.R., 2020, 'Conservation translocations: a review of common difficulties and promising directions', *Animal Conservation* 23(2), 121–131, https://doi.org/10.1111/acv.12534.

Bowman, R.M., 2011, 'Distribution, Ecology and Biomonitoring Management of Pickersgill's Reed Frog (*Hyperolius pickersgilli*)', Honours Dissertation, North-West University, Potchefstroom.

Boyero, L., López-Rojo, N., Bosch, J., Alonso, A., Correa-Araneda, F. & Pérez, J., 2020, 'Microplastics impair amphibian survival, body condition and function', *Chemosphere* 244, 125500, https://doi.org/10.1016/j.chemosphere.2019.125500.

Browning, E., Gibb, R., Glover-Kapfer, P. & Jones, K., 2017, *Passive acoustic monitoring in ecology and conservation*, WWF Conservation Technology Series 1(2), United Kingdom, viewed on 22 April 2024, from https://repository.oceanbestpractices.org/handle/11329/1370.

CBD, 2022, *Monitoring framework for the Kunming-Montreal global biodiversity framework*, CBD/COP/15/L.26, Montréal, viewed on 16 May 2025, from: https://www.cbd.int/doc/c/179e/aecb/592f67904bf07dca7d0971da/cop-15-l-26-en.pdf.

Davis, J.M. & Stamps, J.A., 2004, 'The effect of natal experience on habitat preferences', *Trends in Ecology & Evolution* 19(8), 411–416, https://doi.org/10.1016/j.tree.2004.04.006.

Department of Forestry, Fisheries and the Environment, 2021, National web based environmental screening tool and data used in the national web based environmental screening tool, viewed 22 March 2024, from https://screening.environment.gov.za/screeningtool/#/pages/welcome.

Drews, C., 2002, 'Attitudes, knowledge and wild animals as pets in Costa Rica', *Anthrozoös*, 119–138, http://dx.doi.org/10.2752/089279302786992630.

Du Plessis, I., Armstrong, A., Becker, C., Malepa, P.L., Grobben, D., Kanengoni, A.T. & Grey, C., 2022a, *Husbandry Guidelines: Pickersgill's Reed Frog* - (*Hyperolius pickersgilli*), viewed 16 May 2025, from https://www.amphibianark.org/fileadmin/uploads/aark/Husbandry_Library/2017_Hyperolius-pickergilli-Husbandry-manual-2022.pdf.

Du Plessis, I., Armstrong, A., Malepa, P.L., Kanengoni, A.T., Price, C. & Downs, C.T., 2022b, 'Developmental life stages of the Pickersgill's reed frog (*Hyperolius pickersgilli*) in an ex-situ environment at Johannesburg Zoo's captive breeding facility, South Africa', *Zoo Biology* 41, 533–543, https://doi.org/10.1002/zoo.21688.

Du Preez, L. & Carruthers, V., 2009, *A complete guide to the frogs of southern Africa*, Struik Nature, Cape Town.

Du Toit, R., 2020, 'Unique acoustic identifiers in frog calls and how they can be used to distinguish species', Honours dissertation, School of Life Science, University of KwaZulu-Natal, Durban.

Eastman, J.R., 2020, *TerrSet2020 Geospatial Monitoring and Modeling System Manual,* Clark Labs, Worcester, MA, viewed 16 May 2025, from https://s45055.pcdn.co/centers/geospatial-analytics/www-content/blogs.dir/7/files/sites/354/2024/11/Terrset-2020-Manual.pdf.

Edwards, R., Pike, T. & Mncwabe, K., 2023, 'The Widenham Wetland in eThekwini Municipality, KwaZulu-Natal: Wetland Rehabilitation Plan', Version 2, Report VE22-27-02, Verdant Environmental, Pietermaritzburg.

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. & Yates, C.J., 2011, 'A statistical explanation of MaxEnt for ecologists', *Diversity and Distributions* 17, 43–57, https://doi.org/10.1111/j.1472-4642.2010.00725.x.

Ezemvelo KZN Wildlife, 2014a, *KZN Average Summer Monthly Means of Daily Maximum Temperature (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [AVSUM_MNDMAXTEMP_06_20M_W31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014b, *KZN Average Summer Monthly Means of Daily Average Relative Humidity (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2

Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [AVSUM_MNDAVRH_06_20M_W31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014c, *KZN Average Winter Monthly Means of Daily Average Relative Humidity (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [AVWIN_MNDAVRH_06_20M_W31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014d, *KZN Average Winter Monthly Means of Daily Maximum Temperature (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [avwin_mndmaxtemp_06_20m_w31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014e, *KZN Mean Annual Precipitation (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [kznmap_06_20m_w31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014f, *KZN Summer Months Average Monthly Means of Daily Minimum Temperature (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [AVSUM_KZNMNDMINTEMP_06_20M_W31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014g, *KZN Total Annual Rain Days Greater than or equal to 10mm (W31)* [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [kznannrandayge10mm06_20m_w31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2014h, *KZN Winter Months Average Monthly Means of Daily Minimum Temperature (W31) [Derived from South African Atlas of Climatology and Agrohydrology 2006], Resampled to* E KZN W 2008v2 Land Cover Parameters - 2014 Modelling Suite, Unpublished GIS Coverage [avwin_kznmndmintemp_06_20m_w31_9999.zip], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Ezemvelo KZN Wildlife, 2020, *KZN 2017 Landcover - Equivalent (W31)* [Derived from Ezemvelo KZN Wildlife & GEOTERRA Image (2018) KZN Land-Cover 2017 v1 (Equivalent)], Windowed to E KZN W 2008v2 Land Cover Parameters - 2020 Modelling Suite, Unpublished GIS Coverage [KZN_EQVLC17V1_W31_BF20M_9999], Conservation Services, Ezemvelo KZN Wildlife, Pietermaritzburg.

Falaschi, M., Melotto, A., Manenti, R., Ficetola, G.F., 2020, 'Invasive species and amphibian conservation', *Herpetologica* 76(2), 216–227, https://doi.org/10.1655/0018-0831-76.2.216.

Fisher, M.C. & Garner, T.W.J., 2020, 'Chytrid fungi and global amphibian declines', *Nature Reviews Microbiology* 18(6), 332–343, https://doi.org/10.1038/s41579-020-0335-x.

Germano, J.M. & Bishop, P.J., 2009, 'Suitability of amphibians and reptiles for translocation', *Conservation Biology* 23(1), 7–15, https://doi.org/10.1111/j.1523-1739.2008.01123.x.

González-del-Pliego, P., Freckleton, R.P., Edwards, D.P., Koo, M.S., Scheffers, B.R., Pyron, R.A. & Jetz, W., 2019, 'Phylogenetic and trait-based prediction of extinction risk for data-deficient amphibians', *Current Biology* 29, 1557–1563, https://doi.org/10.1016/j.cub.2019.04.005.

Grant, E.H.C., Miller, D.A.W. & Muths, E., 2020, 'A Synthesis of evidence of drivers of amphibian declines', *Herpetologica* 76(2), 101–107, https://doi.org/10.1655/0018-0831-76.2.101.

Green, D.M., Lanoo, M.J., Lesbarrères, D. & Muths, E., 2020, 'Amphibian population declines: 30 years of progress in confronting a complex problem', *Herpetologica* 76(2), 97–100, https://doi.org/10.1655/0018-0831-76.2.97.

Harfoot, M.B.J., Johnston, A., Balmford, A., Burgess, N.D., Butchart, S.H.M., Dias, M. P., . . . & Geldmann, J., 2021, 'Using the IUCN Red List to map threats to terrestrial vertebrates at global scale', *Nature Ecology and Evolution* 5(11), 1510–1519, https://doi.org/10.1038/s41559-021-01542-9.

Hayes, T.B., Khoury, V., Narayan, A. Nazir, M., Park, A., Brown, T., . . . & Gallipeau, S., 2010, 'Atrazine induces complete feminization and chemical castration in male African clawed frogs (*Xenopus laevis*)', *Proceedings of the National Academy of Sciences of the United States of America*, 107(10), 4612–4617, https://doi.org/10.1073/pnas.0909519107.

Hughes, A.C., Marshall, B.M. & Strine, C.T., 2021, 'Gaps in global wildlife trade monitoring leave amphibians vulnerable', *eLife* 10, e70086, https://doi.org/10.7554/eLife.70086.

IUCN SSC Amphibian Specialist Group & South African Frog Re-assessment Group (SA-FRoG), 2016, '*Hyperolius pickersgilli*', The IUCN Red List of Threatened Species 2016: e.T10644A77165927, viewed 8 June 2023, from https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T10644A77165927.en.

Jewitt, D., 2018, 'Vegetation type conservation targets, status and level of protection in KwaZulu-Natal in 2016', *Bothalia* 48(1), 1–10, https://doi.org/10.4102/abc.v48i1.2294.

Jewitt, D., Erasmus, B.F.N., Goodman, P.S., O'Connor, T.G., Hargrove, W.W. & Maddalena, D.M., 2015, 'Climate induced change of environmentally defined floristic domains: A conservation based vulnerability framework', *Applied Geography* 63, 33–42, https://doi.org/10.1016/j.apgeog.2015.06.004.

Jewitt, D., Goodman, P.S., Erasmus, B.F.N., O'Connor, T.G. & Witkowski, E.T.F., 2015b, 'Systematic land-cover change in KwaZulu-Natal, South Africa: Implications for biodiversity', *South African Journal of Science* 111 (9/10), 9, http://dx.doi.org/10.17159/sajs.2015/20150019.

Kotze, A., Ralph, T.M.C., Barrow, L.N., Tarrant, J., Du Preez, L.H., Thabang, M. & Dalton, D.L., 2019, 'Lack of phylogeographic structure in the endangered Pickersgill's Reed Frog; *Hyperolius pickersgilli* (Raw, 1982)', *African Journal of Herpetology* 68(1), 1–17, https://doi.org/10.1080/21564574.2018.1462064.

Lee, T.S, Randall, L.A., Kahal, N.L., Kinas, H.L., Carney, V.A., Rudd, H., . . . & Duke, D., 2022, 'A framework to identify priority wetland habitats and movement corridors for urban

amphibian conservation', *Ecological Solutions and Evidence* 3, e12139, https://doi.org/10.1002/2688-8319.12139.

Lees, C.M., Rutschmann, A., Santure, A.W. & Beggs, J.R., 2021, 'Science-based, stakeholder-inclusive, and participatory conservation planning helps reverse the decline of threatened species', *Biological Conservation* 260, 109194, https://doi.org/10.1016/j.biocon.2021.109194.

Li, Y., Cohen, J. M. & Rohr, J.R., 2013, 'Review and synthesis of the effects of climate change on amphibians', *Integrative Zoology* 8(2), 145–161, https://doi.org/10.1111/1749-4877.12001.

Luedtke, J.A., Chanson, J., Neam, K., Hobin, L., Maciel, A.O., Catenazzi, A., . . . Stuart, S.N., 2023, 'Ongoing declines for the world's amphibians in the face of emerging threats', *Nature* 622, 308–314, https://doi.org/10.1038/s41586-023-06578-4.

Macfarlane, D.M, Kotze, D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P. & Goge, C., 2009, *WET-Health: A technique for rapidly assessing wetland health*, Wetland Management Series, Water Research Commission, Report TT 340/09, viewed 22 April 2024, from https://www.wrc.org.za/wp-content/uploads/mdocs/TT%20340-09.pdf.

Measey, G.J. (ed.), 2011, Ensuring a future for South Africa's frogs: a strategy for conservation research, *SANBI Biodiversity Series* 19, South African National Biodiversity Institute, Pretoria.

Measey, J., Tarrant, J., Rebelo, A., Turner, A., Du Preez, L., Mokhatla, M. & Conradie, W., 2019, 'Has strategic planning made a difference to amphibian conservation research in South Africa?', *Bothalia* 49(1), a2428, https://doi.org/10.4102/abc.v49i1.2428.

Minter, L.R., Burger, M., Harrison, J.A., Braack, H.H., Bishop, P.J. & Knoepfer, D., 2004, *Atlas and red data book of the frogs of South Africa, Lesotho and Swaziland*, SI/MAB Series No. 9, Smithsonian Institute, Washington, DC, https://www.researchgate.net/publication/48378776_Atlas_and_Red_Data_Book_of_the_Frogs_of_South_Africa_Lesotho_and_Swaziland.

Mnisi, M.C., Taioe, M.O., Mokgokong, P., Dalton, D.L., Du Plessis, I., Armstrong, A., Tarrant, J., Kotze, A. & Du Plessis, M., 2024, 'The bacteriome of the Endangered South African endemic Pickersgill's Reed Frog (*Hyperolius pickersgilli*)', *African Journal of Herpetology*, 74, 1–8, https://doi.org/10.1080/21564574.2024.2422429.

Padayachee, T., 2020, 'Passive Acoustic Monitoring as a tool to assess the presence/absence of the Endangered frog species, *Hyperolius pickersgilli*', Honours dissertation, School of Life Science, University of KwaZulu-Natal, Durban.

Phillips, S.J. & Dudik, M., 2008, 'Modelling of species distributions with MaxEnt: New extensions and a comprehensive evaluation', *Ecography* 31, 161–175, https://doi.org/10.1111/j.0906-7590.2008.5203.x.

Phillips, S.J., Anderson, R.P. & Schapire, R.E., 2006, 'Maximum entropy modeling of species geographic distributions', *Ecological Modelling,* 190, 231–259, https://doi.org/10.1016/j.ecolmodel.2005.03.026.

Raw, L.R.G., 1982, 'A new species of reed frog (Amphibia: Hyperoliidae) from the coastal lowlands of Natal, South Africa', *Durban Museum Novitates* 13(9), 117–126, https://journals.co.za/doi/abs/10.10520/AJA0012723X_2275.

Schulze, R.E., 2007, *South African Atlas of Climatology and Agrohydrology*, Water Research Commission, Pretoria.

Scott-Shaw, C.R. & Escott, B.J. (eds), 2011, *KwaZulu-Natal Provincial Pre-Transformation Vegetation Type Map*, rasterized to E KZN W 2008v2 Land Cover Parameters - 2020 Modelling Suite. Unpublished GIS Coverage [kznveg05v2_4_11_inhouse_w31_03022020_20m_9999.zip], Biodiversity Conservation Planning Division, Ezemvelo KZN Wildlife, Pietermaritzburg.

Semlitsch, R.D. & Bodie, J.R., 2003, 'Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles', *Conservation Biology*, 17(5), 1219–1228.

Silver, T., 2020, 'Testing the acoustic resource partitioning hypothesis: Do South African frogs partition the acoustic space?', Honours dissertation, School of Life Science, University of KwaZulu-Natal, Durban.

Sodhi, N.S., Bickford, D., Diesmos, A.C., Lee, T.M., Koh, L.P., Brook, B.W., Sekercioglu, C.H. & Bradshaw, C.J.A., 2008, 'Measuring the meltdown: Drivers of global amphibian extinction and decline, *PLoS ONE* 3(2), e1636, https://doi.org/10.1371/journal.pone.0001636.

Stamps, J.A. & Swaisgood, R.R., 2007, 'Someplace like home: Experience, habitat selection and conservation biology', *Applied Animal Behaviour Science* 102(3–4), 392–409, https://doi.org/10.1016/j.applanim.2006.05.038.

Stolton, S., Dudley, N. & Hockings, M., 2021, *METT Handbook: A guide to using the Management Effectiveness Tracking Tool (METT)*. Second edition guidance for using METT-4, WWF, Gland, Switzerland, viewed 22 April 2024, from https://wdpa.s3.eu-west-1.amazonaws.com/PAME/METT/METT_4_Handbook.pdf.

Tarrant, J., 2012, 'Conservation assessment of threatened amphibians in KwaZulu-Natal, and a national assessment of chytrid infection in South African threatened species', PhD thesis, North-West University, Potchefstroom, https://repository.nwu.ac.za/handle/10394/8490.

Tarrant, J. & Armstrong, A.J., 2013, 'Using predictive modelling to guide the conservation of a critically endangered coastal wetland amphibian', *Journal for Nature Conservation*, 21, 369–381, https://doi.org/10.1016/j.jnc.2013.03.006.

Tarrant, J. & Armstrong, A.J., 2017, Biodiversity management plan for Pickersgill's reed frog (*Hyperolius pickersgilli*), Government Gazette, 624 (No. 40883), 184–222, viewed 22 April 2024, from https://www.gov.za/sites/default/files/gcis_document/201706/40883gen423.pdf.

Tarrant, J., Kruger, D. & Du Preez, L. H., 2016, 'Do public attitudes affect conservation effort? Using a questionnaire-based survey to assess perceptions, beliefs and superstitions associated with frogs in South Africa,' *African Zoology*, 51(1), 13–20, https://doi.org/10.1080/15627020.2015.1122554.

Tarrant, T., 2021, 'Report 1: Specialist amphibian surveys at the Mount Moreland wetlands on behalf of King Shaka International Airport, Durban KwaZulu-Natal', Endangered Wildlife Trust, Midrand.

Trenor, M., 2015, 'Using spatially explicit call data of *Anhydrophryne ngongoniensis* to guide conservation actions', Msc thesis, North-West University, Potchefstroom, https://repository.nwu.ac.za/handle/10394/31302.

Warkentin, I.G., Bickford, D., Sodhi, N.S. & Bradshaw, C.J., 2009, 'Eating frogs to extinction', *Conservation Biology* 23(4), 1056–1059, https://doi.org/10.1111/j.1523-1739.2008.01165.x.

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

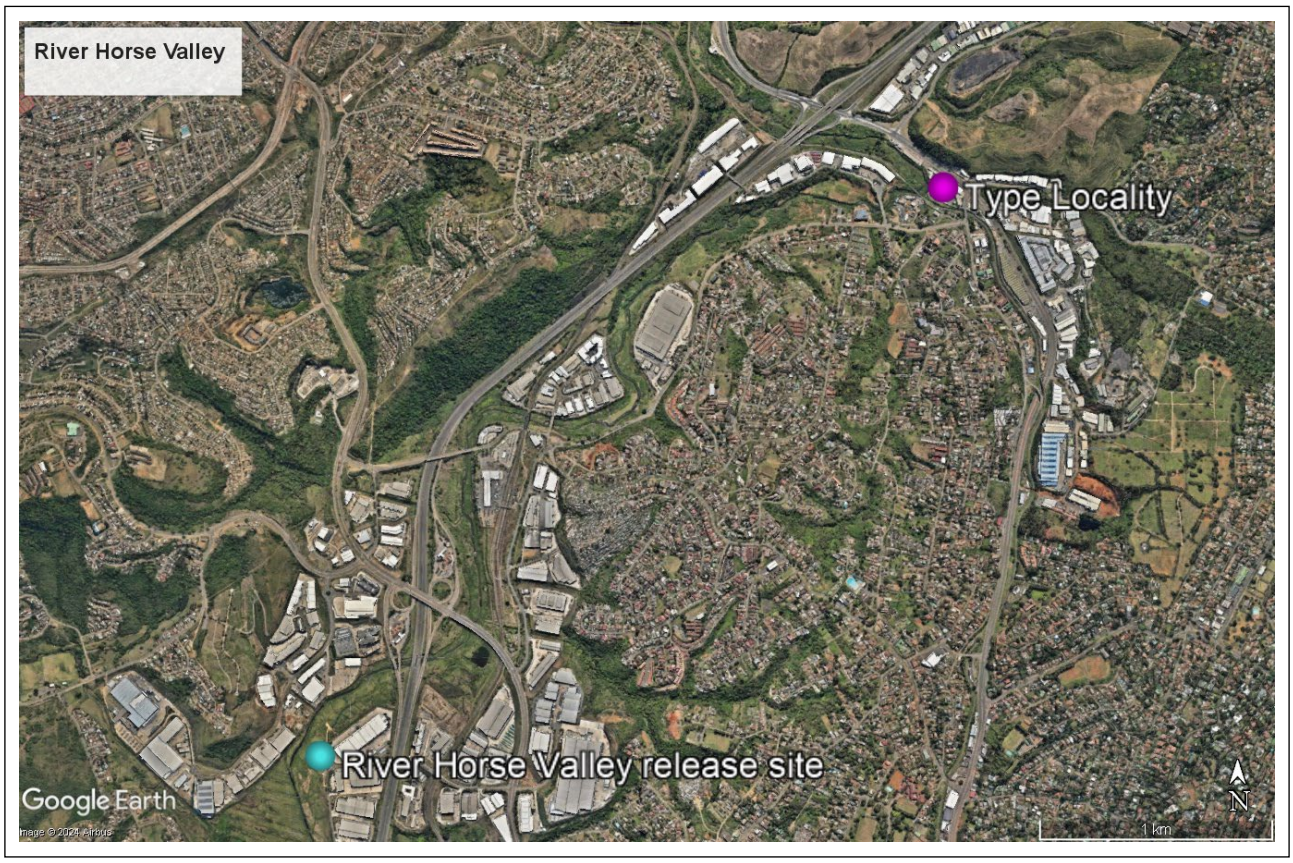

Figure S1. The site (cyan dot) at River Horse Valley, Durban, South Africa, where captive-bred Pickersgill's reed frogs *Hyperolius pickersgilli* were released in relation to the type locality (magenta dot).

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.