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Using predictive modelling to guide the conservation of a critically endangered coastal wetland amphibian

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ABSTRACT

Amphibians are the most threatened Class of vertebrate, with wetland-associated anurans in particular suffering high levels of habitat loss. We used predictive modelling to better understand the distribution of a critically endangered South African endemic (*Hyperolius pickersgilli*) and to guide conservation action. MaxEnt distribution models were produced based on limited occurrence data. Predicted localities with probability of occurrence ≥60% were surveyed. Ten new sub-populations were discovered. The mean probability of occurrence for the species at wetlands where it was detected was greater than that at wetlands where it was not detected or absent. In addition, 17 known historical localities were re-visited and the species deemed absent at 8 of these. The total number of localities at which the species is now known to occur is 18, which is an increase in the known extant sub-populations of six. We recalculate the area of occupancy and extent of occurrence for the species as 108 km^2 and 2081.5 km^2, respectively; both increases on previous estimates. Implications of these changes on the IUCN Red List status of *H. pickersgilli* are discussed. A friction map was created to identify possible linkages between sub-populations, which can be used to guide habitat restoration and population repatriation. Given the degree of isolation of subpopulations and the potentially severe threats to most of these, urgent conservation action for *H. pickersgilli* remains crucial. This study provides a method for use in conservation planning for wetland-breeding amphibians in eastern coastal regions of Africa and elsewhere.

Introduction

The eastern coast of Africa hosts high amphibian species richness and endemism but is also subject to large-scale land transformation and habitat destruction (Driver et al., 2012; Wilson, 2011), the most significant threats to amphibians worldwide (Cushman, 2006; Gascon et al., 2007; Stuart et al., 2008). Two biodiversity hotspots occur in this region: the Coastal Forests of Eastern Africa and the Maputaland–Pondoland–Albany hotspot (Mittermeier et al., 2005). The coastal region of southern Mozambique and of the KwaZulu-Natal Province of South Africa falls within the latter, much of which is experiencing high levels of habitat transformation (Bass, 1966; Russell & Downs, 2012), with some of the coastal terrestrial and wetland ecosystems being classified as Critically Endangered (Driver et al., 2012). The region has few herpetologists and little funding to support the conservation of its amphibian fauna, such that conservation action often has to proceed without detailed information on the ecology and population dynamics of the fauna (Andreone et al., 2008; Measey, 2011; Semlitsch, 2002). Therefore species prioritisation and efficient gathering of associated information is necessary (Fielding & Bell, 1997; Funk, Richardson, & Ferrier, 2005). This study makes use of GIS-based techniques for developing conservation solutions for a highly threatened South African endemic amphibian.

Pickersgill's reed frog, *Hyperolius pickersgilli* (Raw, 1982), is a small Hyperoliid endemic to the KwaZulu-Natal (KZN) coast of South Africa. It is a habitat specialist, favouring dense reed-beds in Coastal Bushveld-Grassveld (Mucina & Rutherford, 2006), and is found at altitudes below 340 m a.s.l. (Bishop, 2004). The species occurs in permanent wetlands and requires a combination of a dense understorey together with taller reed vegetation (Raw, 1982; pers. obs.). Its favoured habitat, cryptic behaviour, small size and inconspicuous call make this species difficult to locate. The use of ecological niche modelling (ENM) may provide an effective tool for directing field surveys and revealing unknown populations of threatened amphibians that inhabit the eastern coastal region of Africa (for other examples see Armstrong, 2009; Guisan et al., 2006; Jackson & Robertson, 2011; Lomba et al., 2010; Stillman & Brown, 1994; Tinoco, Astudillo, Latta, & Graham, 2009).

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As a result of the 2010 IUCN Red-List re-assessment of South African frogs, *H. pickersgilli* was up-listed from Endangered to Critically Endangered B2ab (ii, iii), based on its small Area of Occupancy (AOO), fragmented distribution and continuing decline in habitat (SA-FRoG and IUCN, 2010). Measey (2011) recognised the species as having the highest conservation priority for any frog species in South Africa and a high priority for monitoring and surveillance. Improved knowledge of its distribution, population size, phylogeography and threats were also highlighted as requirements for the successful conservation of the species (Measey, 2011). At the time of the assessment, *H. pickersgilli* was known only from 12 localities along the KZN coast (Bishop, 2004; Measey, 2011). This area has been, and continues to be, under high pressure from agriculture, silviculture and urban development (Armstrong et al., 1998; Armstrong, 2009; Johnson & Raw, 1987; Scott-Shaw, 1999). Only two sub-populations occur within formally protected areas (Bishop, 2004; Measey, 2011).

The aims of this study were to address conservation research priorities for *H. pickersgilli* outlined in Measey (2011) by (1) modelling its predicted distribution using MaxEnt and surveying predicted wetlands with high probability of occurrence; (2) resurveying historical localities to ascertain its presence and determine site status; (3) delimiting potential populations, to guide conservation measures and decisions, and; (4) recalculating its Extent of Occurrence (EOO) and Area of Occupancy (AOO) and re-examining its IUCN Red-List status in the light of these findings.

Methods

Modelling methods

Species occurrence records were obtained from the Frog Atlas (Minter et al., 2004) and the Biodiversity Database of Ezemvelo KZN Wildlife. Twenty-four occurrence records (pre-October 2010) with a spatial accuracy up to 250 m (WGS84 datum) were used in the modelling. Environmental predictors likely to influence the distribution of the species (Armstrong, 2001; Elith et al., 2011) were ascertained from the literature (Bishop, 2004; Du Preez & Carruthers, 2009; Franklin, Wejnert, Hathaway, Rochester, & Fisher, 2009; Poynton, 1964). For the purposes of this model, only continuous variables were used, with categorical variables overlayed at a later stage. The continuous variables used were the means of minimum and maximum daily temperatures and relative humidity for January and July (the hottest and coldest months, respectively), and mean annual temperature and precipitation for KwaZulu-Natal (Table 2). These coverages were developed at a scale of $1' \times 1'$ using the decimal degree Cape (1880) datum by Schulze (2007), and were re-projected to the WGS84 datum, Transverse Mercator lo31 central meridian, and then resampled to a $20\,m \times 20\,m$ ($400\,m^2$) grid based on the Ezemvelo KZN Wildlife 2008 version 1 land-cover coverage (Ezemvelo KZN Wildlife, 2009, 2011). No increase in the resolution accuracy of the climatic variables was assumed. Resampling was performed to allow the incorporation of finer scale data in the form of the wetland and hard transformation (100% loss of native habitat) coverages. Many of the wetlands and associated land transformation would otherwise be lost from the analysis.

MaxEnt version 3.3.3e (Phillips, Dudík, & Schapire, 2004; Phillips, Anderson, & Schapire, 2006) was run to develop an ecological niche model for *H. pickersgilli*. Five replicates were run using the cross-validate setting. The maximum number of iterations was set at 1000 to ensure algorithm convergence; default settings were used for all other relevant parameters. A mask was used to ensure that the background samples were selected from the general region in which the species occurs. This was taken to be the Indian Ocean Coastal Belt of KZN, which spans altitudes between 0 and 450 m a.s.l. (Mucina & Rutherford, 2006). Areas above 450 m altitude were therefore masked out of the background selection. The coverage of the coastal and sub-coastal areas of KZN historically and recently has been relatively good in terms of amphibian distribution records (Minter et al., 2004), so it is not expected that the species will be found currently outside this region. The performance of the model was evaluated by jack-knife tests and the area under the curve (AUC) statistic of the receiver operating characteristic plots (Phillips et al., 2006). MaxEnt has a regularisation method that enables ecologically relevant but correlated variables to be included in the modelling process (Elith et al., 2011).

The probability map and the land transformation and wetlands coverages were overlaid in the Idrisi Geographic Information System (Eastman, 1999). Wetland types suitable for *H. pickersgilli* were determined from an overlay of distribution records on the wetlands coverage, and the probability of occurrence of *H. pickersgilli* in the suitable wetlands obtained from the MaxEnt probability map. Hard-transformed land was subtracted from the MaxEnt probability map to eliminate as many transformed wetlands from the resultant map as possible.

From a previous version of the probability occurrence map, created without the use of a mask and the cross-validate parameter, wetlands with probability of occurrence of ≥60% for *H. pickersgilli* were selected and overlaid with 1:50,000 topographical maps (Chief Directorate: National Geo-spatial Information, Mowbray, Cape Town, South Africa) for the purpose of directing surveys.

Potential populations of *H. pickersgilli* were delimited using RAMAS GIS (Akçakaya, 2005). The scale and size of the final probability of occurrence wetland map was adjusted through pixel thinning to a pixel size of 40 m. The resized map was then reclassed to boolean, with wetlands having a probability of occurrence for *H. pickersgilli* of more than zero being assigned the value of one. Although this may be an overestimate of the extent of occurrence of *H. pickersgilli*, we considered any other cut-off arbitrary. The maximum dispersal distance was estimated to be 2 km, based on observations of *H. pickersgilli* up to 1.6 km from the nearest probable breeding wetland (J. Harvey, pers. comm.). The potential dispersal distance of 2 km that was used in the analysis is less than the maximum dispersal distances for other species reported in Marsh and Trenham (2001), but the adult snout-vent lengths of those frogs are all greater than that of *H. pickersgilli* (Du Preez & Carruthers, 2009). Smith and Green (2005) recorded an average maximum dispersal distance of 2.92 km for 53 species of anuran.

A friction map for the movement of *H. pickersgilli* was developed from the KZN 2008 land-cover coverage, with five arbitrary ease-of-movement classes (1–4 and a barrier class). Class 1 represents habitats that present or are likely to present the lowest friction to movement by *H. pickersgilli*, class 2 represents habitats that are assumed to present somewhat greater friction to movement of the species (landcover classes adjacent to records of the species), class 3 represents habitats that are degraded class 2 habitats and therefore are not likely to be as amenable for *H. pickersgilli* as class 2 habitats, whereas class 4 represents the highest friction to movement but through which the species could conceivably occasionally move (Table 1). Barriers for anurans can include major roads with high traffic volumes, major rivers and other large water-bodies, bare sand, relatively high altitudes for lowland frogs, railway lines with high traffic volumes (e.g. Fahrig, Pedlar, Pope, Tatlor, & Wegner, 1995; Garcia-Gonzalez, Campo, Pola, & Garcia-Vazquez, 2012; Joly, Morand, & Cohas, 2003). The friction map was used to illustrate potential linkages between wetlands for maintaining sub-population dynamics such as dispersal between sub-populations.

Table 1
Assignment of friction classes to land-cover classes used as the basis of a friction map for movement of *Hyperolius pickersgilli* between wetlands; 1 represents land cover classes that are likely to provide least resistance, and 4 land cover classes that are likely to provide very high resistance, to movement. Land cover classes that are likely barriers to movement are also indicated.

Friction class	Land-cover class
1	Wetlands, grassland/bush clumps mix, grassland
2	Natural water, irrigated permanent orchards (banana, citrus), commercial sugarcane, emerging farmers' sugarcane, forest, dense bush (70–100% canopy cover), bushland (<70% canopy cover), woodland, forest glade
3	Golf courses, low density settlement, subsistence (rural), annual commercial crops irrigated, degraded forest, degraded bushland (all types), degraded grassland, old cultivated fields (secondary grassland), old cultivated fields (secondary bushland), smallholdings (grassland), airfields, old plantation (high vegetation), old plantation (low vegetation), rehabilitated mines (high vegetation), rehabilitated mines (low vegetation)
4	Plantation, mangrove wetlands, dry and permanent orchards (cashew nuts), built-up dense settlement, annual dryland commercial crops, KZN main & district roads, KZN railways
Barrier	Clear-felled plantation, permanent dryland pineapples, mines and quarries, bare sand, erosion, bare rock, alpine grass-heath, KZN national roads, dams, estuarine water, sea water, bare coastal sand, outside KZN boundary

Surveying and historical locality verification

Seventy one localities were visited by us and others during the breeding seasons of 2010–2011 and 2011–2012 (see Appendix A and Acknowledgements). Due to time constraints, most sites were visited only once, particularly in cases where the site was deemed unsuitable for *H. pickersgilli*. Seventeen of a total of 19 historical localities were revisited during the survey period to verify *H. pickersgilli* presence. Sites were visited from dusk to some hours after sunset. Presence was detected via male *H. pickersgilli* advertisement calls and, where possible, by visual confirmation. Wetlands at which *H. pickersgilli* was found to be present but that had not been recorded previously were classified as 'new' localities. The behaviour and ecology of the frogs and records of other frog species were also noted. The specific conditions such as plant species, water depth and prevailing weather conditions were recorded at each wetland. Air and water temperatures were recorded using an Extech Instruments waterproof thermometer. Any immediate possible threats, such as alien vegetation, were also noted. Absence of *H. pickersgilli* was presumed in cases in which no suitable habitat was present or where habitat obviously had been destroyed. Where suitable habitat was present but presence could not be ascertained, the locality was revisited where possible.

The probability of occurrence of *H. pickersgilli* at each site visited was obtained from the MaxEnt probability map. The mean probability of occurrence for all the sites where *H. pickersgilli* was present and the mean probability of occurrence for all the sites where the species was not detected were calculated from the corresponding map values.

Extent of occurrence (EOO) and area of occupancy (AOO)

Results from surveying were included to recalculate AOO and EOO as per the IUCN Red List guidelines (Version 9.0, September 2011). The EOO of *H. pickersgilli* was calculated in Cartalinx (Hagan, Eastman, & Auble, 1998) by joining the appropriate distribution locality points (of ≤250 m spatial resolution) to form a minimum convex polygon. The area of this polygon excluding the section that fell over the adjacent Indian Ocean was considered the EOO.

The AOO was calculated in two ways. Firstly, the number of 2 km × 2 km cells with presence points that were used to determine the EOO was calculated, and the total area of these cells computed, as recommended by the IUCN Standards and Petitions Subcommittee (2011). Secondly, the areas of the extant wetlands for which there were one or more distribution records were summed. However, the latter method does not consider dispersal routes or potential over-wintering habitat, and so may be conservative even though *H. pickersgilli* may not occur throughout each wetland.

Results

MaxEnt model

The average test AUC for the replicate runs was 0.970 ± 0.009 S.D., indicating that the model fitted the data very well (Fig. 1; Wisz et al., 2008). The average MaxEnt model indicated that the variable 'July means of daily average relative humidity (%)' was important in describing the realised climatic niche of *H. pickersgilli* (Table 2). The jack-knife tests of variable importance on the training data and on the test data indicated that the variables 'July means of daily average relative humidity (%)' and 'July means of daily minimum temperature (°C)' were the variables that had the most information not present in the other variables. The resultant predicted distribution of *H. pickersgilli* indicates a greater probability of occurrence in suitable wetlands towards the coast and probability of occurrence declines to the North and the South of the central coastal region (Fig. 2).

Field testing of the model

The mean probability of occurrence for *H. pickersgilli* at the sites where it was present (Fig. 3; mean = 0.5373; 90% CI for mean = 0.4057, 0.6689) was greater than the mean probability of occurrence for *H. pickersgilli* at the sites where it was not detected (mean = 0.4177; 90% CI for mean = 0.3399, 0.4955; t = 1.5062, df = 31, p = 0.071; one-tailed test). Of the potential wetlands surveyed, 44.6% have been either degraded (14.1%) or transformed (29.5%) while a further 21% were not suitable to *H. pickersgilli* (Appendix A). As a result, only a relatively small number of localities visited during the surveying appeared suitable for *H. pickersgilli*, and of these, *H. pickersgilli* was detected at only ten new localities (Table 3). The discoveries extend the known range of *H. pickersgilli* to the south by approximately 40 km.

Potential populations

Many potential populations and sub-populations were distinguished by the RAMAS model in terms of suitable wetland habitat (Fig. 3). Although no occurrence records exist for *H. pickersgilli* in the most northern regions of the predicted habitat (Fig. 2), there are few but large potential populations in the region indicated by box 1 of Fig. 2 (see Fig. 3). The largest numbers of potentially suitable wetlands, and therefore potential populations, occur in the central regions (boxes 2 & 3 of Fig. 2), with smaller and more isolated populations occurring in the area of box 4 in the southern part of the distribution (Fig. 3). An example of potential linkages that *H. pickersgilli* could use for dispersing between wetlands within the range of a potential population is presented in Fig. 4. No complete linkages of least friction value between wetlands within that potential population range remain.

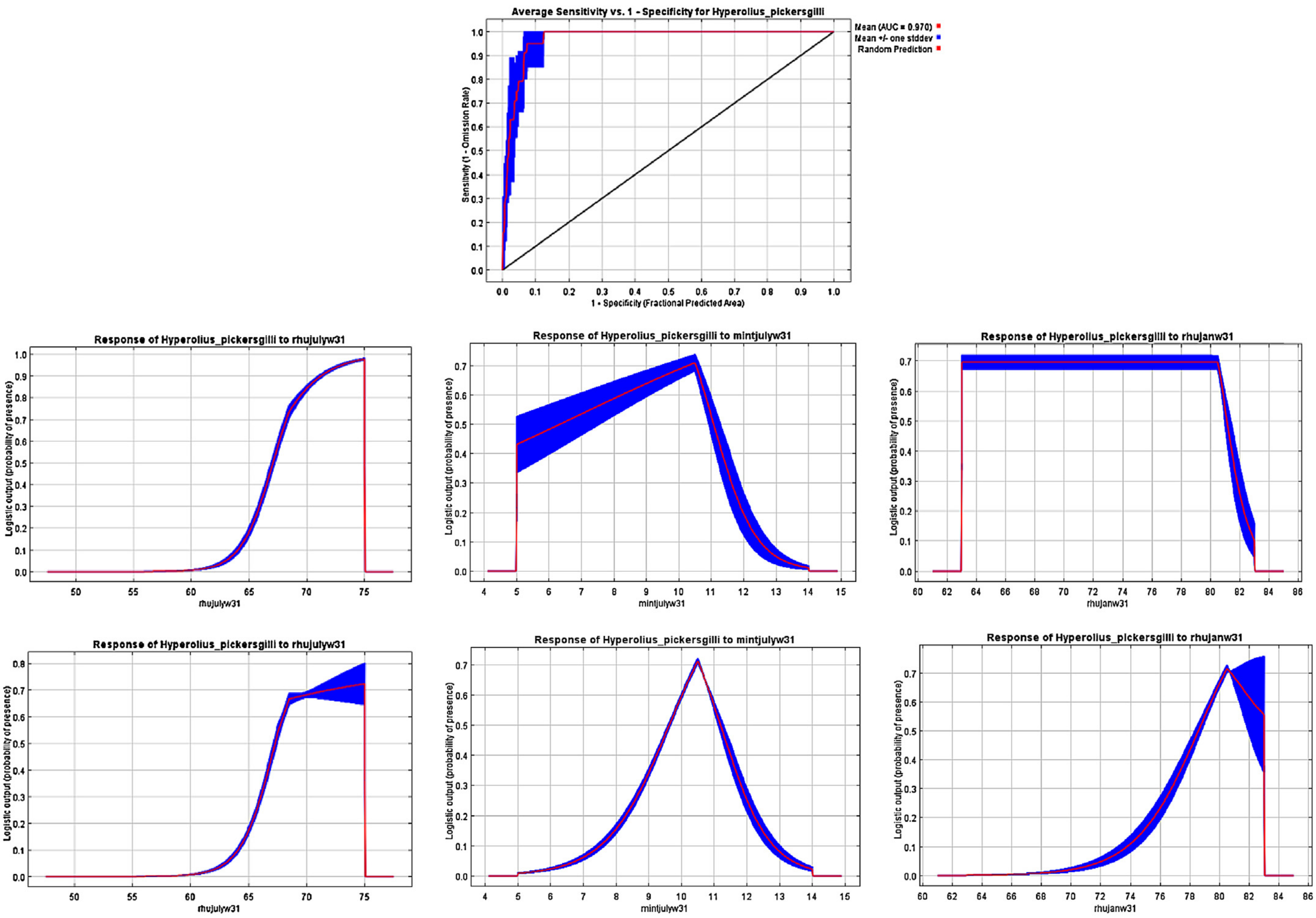

Fig. 1. (a) Receiver operating characteristic (ROC) curve for the data averaged over the five replicate runs; (b) marginal response curves indicating how the logistic prediction changes as the environmental variable (July means of daily average relative humidity (%), July means of daily minimum temperature (°C), and January means of daily average relative humidity (%), respectively) is varied, keeping all other environmental variables at their average sample value; (c) Maxent model created using only the corresponding variable, reflecting the dependence of predicted suitability both on the selected variable (July means of daily average relative humidity (%), July means of daily minimum temperature (°C) and January means of daily average relative humidity (%), respectively) and on dependencies induced by correlations between the selected variable and other variables.

Historical localities

Presence of *H. pickersgilli* was recorded at only 9 of the 17 historical localities revisited (Appendix B). In most cases where the species was not detected, the habitat had either been completely destroyed or was no longer suitable. Habitat at both the original site of discovery of *H. pickersgilli* and the type locality at Avoca (Raw, 1982) appears to have been lost entirely as a result of urbanisation. Habitat at the southernmost historical locality at Warner Beach has also been destroyed by a housing development.

Further north, historical wetlands at Twinstreams are now completely dried, most likely as a result of the extensive surrounding *Eucalyptus* sp. plantations and ongoing drought in recent years, and therefore no longer suitable to *H. pickersgilli*. There are three other extant sub-populations in the Mtunzini area. The *H. pickersgilli* at these localities may form a single population and dispersal could

Table 2
Variables included in the MAXENT climatic niche model for *Hyperolius pickersgilli*.

Variable	Percent contribution	Permutation importance
July means of daily average relative humidity (%)	76.1	85.9
July means of daily minimum temperature (°C)	13.4	1.9
January means of daily average relative humidity (%)	5.8	0.4
January means of daily maximum temperature (°C)	2.4	3.2
Mean annual precipitation (mm)	1.3	0.2
January means of daily minimum temperature (°C)	0.7	2
July means of daily maximum temperature (°C)	0.4	0.3
Mean annual temperature (°C)	0	0
Mask	0	0

Table 3
Details of new localities at which *Hyperolius pickersgilli* populations were recorded during the ground-truthing of the MaxEnt distribution model (North to South), including independent discoveries.

Locality	Date discovered	Coordinates	Elevation (m a.s.l.)	Dominant vegetation	Threats	Size (ha)
St. Lucia Estuary	February 2011	−28.37183°, 32.40335°	4	*Phragmites australis*	Protected but bisected by road	20 ha
Lake Nsezi	December 2011	−28.73917°, 31.96903°	15	*Cyperus papyrus*	Surrounded by *Eucalyptus* plantations	7 ha
Port Durnford	October 2011	−28.90522°, 31.85848°	21	*Phragmites australis*, *Typha capensis*, *Cyperus latifolius*, *Cyclosorus interruptus*	Surrounded by *Eucalyptus* plantations	3 ha
Mahunu	March 2012	−28.92845°, 31.86410°	25	*Typha capensis*, *Cyperus latifolius*	Rural development and resource use	1 ha
Zinkwazi Beach (Nonoti Farm)	January 2012	−29.29659°, 31.41242°	29	*Phragmites australis*	Surrounded by sugar-cane. Potential pesticide run-off.	5 ha
Simbithi Eco Estate	January 2011	−29.51322°, 31.21500°	45	*Phragmites australis*	Increasing surrounding urban development	3 ha
Prospecton	December 2010	−29.98412°, 30.93696°	4	*Phragmites australis*, *Persicaria attenuata*, *Stenotaphrum secundatum*	Will be destroyed as a result of Durban South Port Development	2 ha
Prospecton (Extension)	January 2012	−29.98396°, 30.93425°	4	*Phragmites australis*	Fragmented by N2 highway	2 ha
Umkomaas	January 2012	−30.21717°, 30.79542°	13	*Phragmites australis*, *Persicaria attenuata* and *Cyperus dives*	Proposed housing development. Alien vegetation infestation	2 ha
Sezela	January 2012	−30.40670°, 30.66145°	21	*Cyperus dives*	Surrounded by sugar-cane.	1 ha

occur between the sub-populations. The existence of some of the other historically known sub-populations to the North of Durban appears tenuous (Appendix B).

Extent of occurrence (EOO) and area of occupancy (AOO)

We calculate the EOO for this species as 2081.5 km^2 and the AOO as 108 km^2. The area of the extant wetlands known to have been inhabited by *H. pickersgilli* is 15.05 km^2.

Discussion

MaxEnt model

H. pickersgilli has been highlighted as a species requiring improved knowledge on its distribution and population size (Bishop, 2004; Measey, 2011). Although the predictive model was developed from relatively few presence records, support was given to the model by the surveying exercise. The mean probability of occurrence for *H. pickersgilli* at sites where the species was recorded was higher than the mean probability of occurrence for the species where it was not detected. Although the 90% confidence intervals for the means overlap to some degree, we consider that a statistical probability of $p < 0.071$ when testing for differences between these mean occurrence probabilities is suggestive of a strong trend in support of the model because of the rarity of the *H. pickersgilli* caused by the widespread yet unpredictable synergistic effects of human-mediated land transformation and degradation on the habitat of the species. As with other studies that had numbers of small occurrence records (e.g. Jackson & Robertson, 2011; Pearson, Raxworthy, Nakamura, & Townsend Peterson, 2007; Tinoco et al., 2009), these results show that geographical predictions are indeed valuable for directing field surveys with the aim of discovering unknown sub-populations.

High relative humidity was an important variable influencing the distribution of *H. pickersgilli*, according to the MaxEnt model. This may be explained by the facts that *H. pickersgilli* is a small frog that occurs in warm, humid areas (Du Preez & Carruthers, 2009; Raw, 1982), so high relative humidity is likely to assist with reducing evaporative vapour loss. Small frogs are prone to higher rates of evaporative water loss than larger frogs because boundary layer resistance decreases with decreasing body size and surface-to-volume ratios increase with decreasing body size (Wells, 2007). In this way, MaxEnt models are also useful in understanding probable limiting factors for species' distributions (e.g. Murray et al., 2011; Raxworthy, Ingram, Rabibisoa, & Pearson, 2007). Prolonged drought may have caused the decline or extinction of populations of aquatic-breeding frogs in some places (Marsh & Trenham, 2001; Semlitsch, 2002; Wells, 2007), which may be the case for *H. pickersgilli* which appears to be confined to permanent wetlands that have survived prolonged periods of drought, particularly in the northern region (Bruton & Cooper, 1980). Movement of metamorphs or adults between wetlands may occur mainly during wet weather since *H. pickersgilli* lacks granular areas on the belly that assist with water uptake from damp surfaces, and drought conditions could curtail such movement.

Newly discovered or rediscovered populations

The coastal lowlands area of KZN has been fairly well surveyed in terms of amphibian fauna, but even experts in the field overlooked populations of this species due to its inconspicuous nature (Bishop, 2004). Imperfect detection is highly likely for a species such as *H. pickersgilli* due to its inconspicuous behaviour and soft calling which may be strongly influenced by temporal variation and environmental factors that can affect detectability (Bishop, 2004; Bridges & Dorcas, 2000; Mackenzie et al., 2002; Oseen & Wassersug, 2002). Raw (1982) noted that within the distributional range of *H. pickersgilli* "only an infinitesimal amount would actually be suitable habitat for this species". Despite extensive surveying of sites with ≥60% predicted occurrence probability during this study, only ten new localities were discovered. Due to time constraints

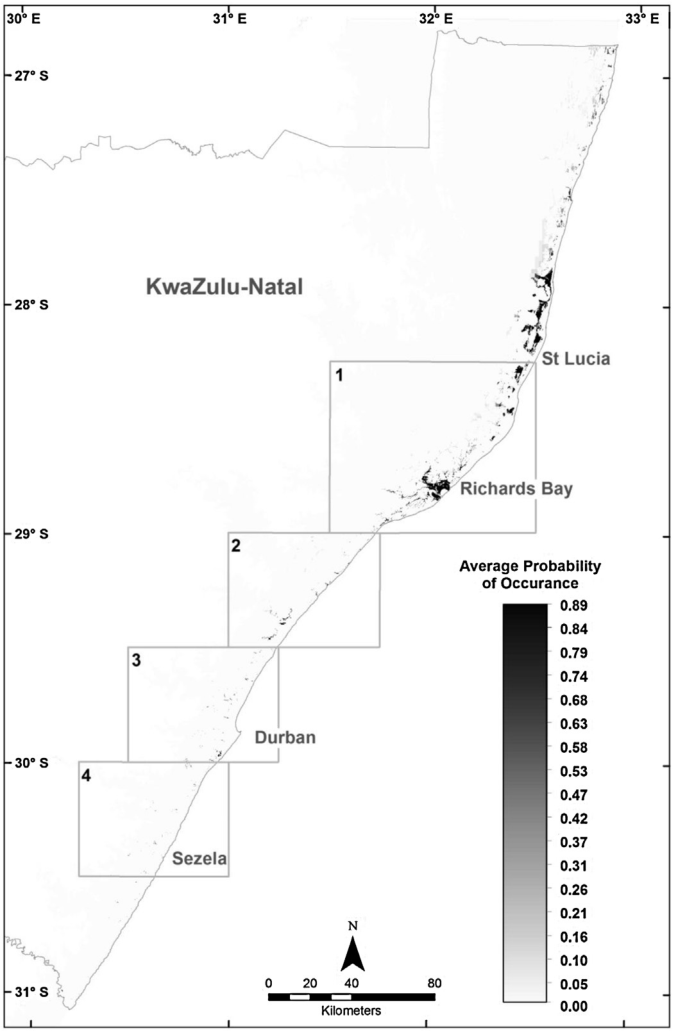

Fig. 2. Map of the probability of occurrence of *Hyperolius pickersgilli* in wetlands of suitable type in KwaZulu-Natal. The map indicates that *H. pickersgilli* may be restricted to the central coastal region of the province. The boxes refer to those of Fig. 3.

approximately 15% of sites with ≥60% occurrence probability were not surveyed. However, the new discoveries indicate that additional surveys, including of sites with probability lower than 60% probability, may reveal additional sub-populations of *H. pickersgilli*.

Most of the known localities are isolated within a landscape of otherwise largely unsuitable habitat. More than half of the wetlands visited during this study have been degraded or transformed (Appendix A), in the main as a result of drainage for sugar cane (*Saccharum officinarum*) (Johnson & Raw, 1987) and urban development. Habitat destruction and fragmentation may have serious consequences for the survival of amphibian species, through reduced availability of suitable terrestrial and aquatic habitat, and through reduced population connectivity by hindering dispersal, respectively (Di Minin & Griffiths, 2011; Griffiths, Sewell, & McCrea, 2010; Marsh & Trenham, 2001; Semlitsch, 2002). Incorporation of information on dispersal patterns and terrestrial habitat use, particularly for range-restricted species, is therefore crucial to the success of conservation plans (Akçakaya, Mills, & Doncaster, 2007). The overwintering habitats of *H. pickersgilli* are unknown. Therefore, we did not include terrestrial buffers around wetlands in this study but rather concentrated on potential linkages between sub-populations. In addition, use of distribution models in conservation plans can assist in preventing further habitat loss for threatened species (Jackson & Robertson, 2011).

Taking into account the few localities for *H. pickersgilli*, loss of any site has serious implications for the total population. There appears to be much variation in the probability of occurrence of *H. pickersgilli* at sites where it was detected and at sites where it was not detected. This may be a result of deterministic anthropogenic factors such as wetland drainage, pollution, introduction of alien plants, etc., or else stochasticity in occurrence at the sites (Marsh & Trenham, 2001). The former seemed most likely at some of the wetlands surveyed for *H. pickersgilli* (Appendix A).

Status of historical localities

Most of the seven localities listed in the original description of *H. pickersgilli* have been destroyed. Loss of the type locality is scientifically important, and represents a disturbingly growing trend in amphibian declines worldwide (Coloma et al., 2004; Hansen & Stafford, 1994). The potentially suitable wetlands for *H. pickersgilli* in the southern and central portions of its known distribution range, where many of the lost historical sites were situated, are smaller and more isolated than those in the northern part of its known range (Fig. 3), because these regions are the most transformed (Driver et al., 2012).

Use of the model for finding unknown sub-populations

The main strength of the distribution model in guiding survey effort was in the choice of regions that should be surveyed, not necessarily what specific wetlands should be surveyed. Our model indicates that the probability of occurrence was higher towards the coast, and that potentially suitable habitat could be found both North and South of its previous known distribution. Indeed, two new subpopulations were discovered to the South of the known range. However, no new subpopulations have been discovered to the North. The St Lucia Estuary in the north may be a barrier to the species due to the estuary's large size and relatively high salinity. Furthermore, *H. pickersgilli* has also not been recorded more than 16 km from the coast and therefore the species may not have been able to move far enough westwards for it to reach suitable habitat north of the estuary.

Use of the potential populations map

Information about meta-populations can assist with the conservation of species that exist in fragmented landscapes (Hanski & Gilpin, 1991; Semlitsch, 2002). Heard, Scroggie, & Malone (2012) showed that the population dynamics of an Endangered species of aquatic-breeding hylid frog conforms to classical meta-population theory, and therefore could be used to guide conservation planning for the species and potentially for many other species of aquatic-breeding amphibians. Although the population dynamics of *H. pickersgilli* have not yet been tested in this respect, the urgency for conservation planning for this species makes it improbable that this test will be done before conservation decisions have to be made. The fact that *H. pickersgilli* only inhabits wetlands of particular habitat structure that are often isolated within a transformed landscape, coupled with the occasional record of an individual of the species well away from the closest suitable breeding wetland (J. Harvey pers. comm.; M. Pickersgill pers. comm.), indicates that some movement between wetlands is likely to occur. Therefore it appears prudent to assume that this species may occur in sub-populations within a patchy population or even meta-populations, and plan accordingly when certain conservation decisions have to be made.

Inclusion of ecological and evolutionary processes for re-introductions and translocations is crucial for the success of such procedures (Akçakaya et al., 2007; Moritz, 1999). Population

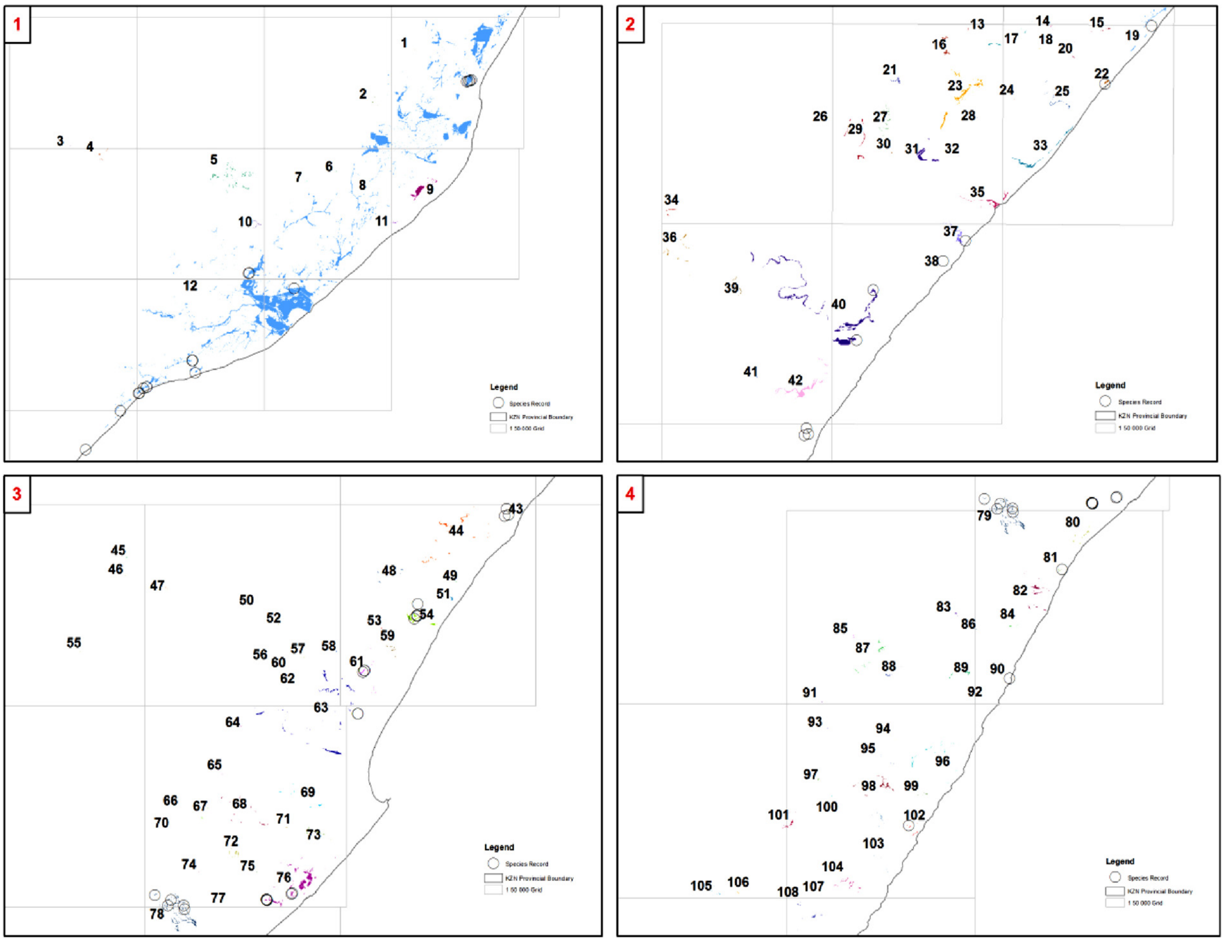

Fig. 3. Potential populations of *Hyperolius pickersgilli* along the KwaZulu-Natal coast. Each potential population is represented by a different colour and is numbered. Circles represent occurrence records for *Hyperolius pickersgilli*. Grid lines indicate 1:50,000 map extents. Refer to Fig. 2 for the location of the boxes.

dynamics such as movement between sub-populations, especially where the species are of low vagility, are adversely affected by habitat fragmentation. Re-introductions to rehabilitated wetlands within meta-population areas or within the distribution of a patchy population must also take into consideration the availability of adjacent suitable terrestrial habitat and potential for dispersal between other suitable wetlands, rather than to isolated wetlands with no viable remaining links (Semlitsch, 2002). Otherwise, repeated translocations may be necessary to avoid extinctions of sub-populations (Marsh & Trenham, 2001). Protection of groups of wetlands and suitable adjacent terrestrial habitat for dispersal and over-wintering is a conservation priority for various amphibian species (Di Minin & Griffiths, 2011; Marsh & Trenham, 2001; Semlitsch, 2002). The potential population map and the friction map are therefore useful for judging whether the habitat and dispersal requirements of *H. pickergilli*, both aquatic and terrestrial, will be met when a re-introduction of the species to a specific wetland is considered. Linkages of suitable land cover through which individuals of the species can move between wetlands within the same patchy population distribution or meta-population region can be protected through land use planning processes by reference to the potential population map and friction layer (Fig. 3).

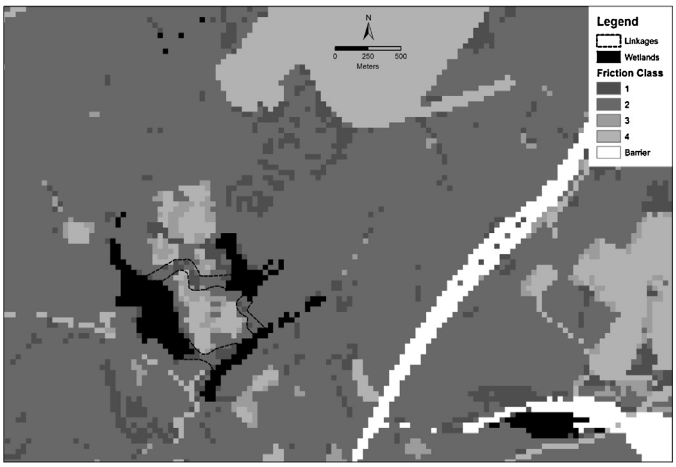

Fig. 4. An example of wetland habitat for a potential population of *Hyperolius pickersgilli* (population 54 of Fig. 3) indicating linkages (areas delimited by dotted lines) between three of the wetlands via low friction pathways. Wetlands are coloured black, land cover classes are indicated in grey-scale according to their assigned friction classes (dark grey = lowest resistance to movement, light grey = highest resistance to movement), and barriers to movement are white.

Fig. 5a indicates the position of the proposed dug-out port in the Durban South area (Prospecton), together with the spatial extent of the assumed patchy population there. Should the development be approved, and protection of the wetland in situ is not deemed feasible, a biodiversity offset in terms of translocation and re-introduction of the *H. pickersgilli* from the dug-out port development footprint may be the only solution for preserving this sub-population. The results from the population map produced here can be used to guide this process, with translocation to one or more rehabilitated or reconstructed wetlands within

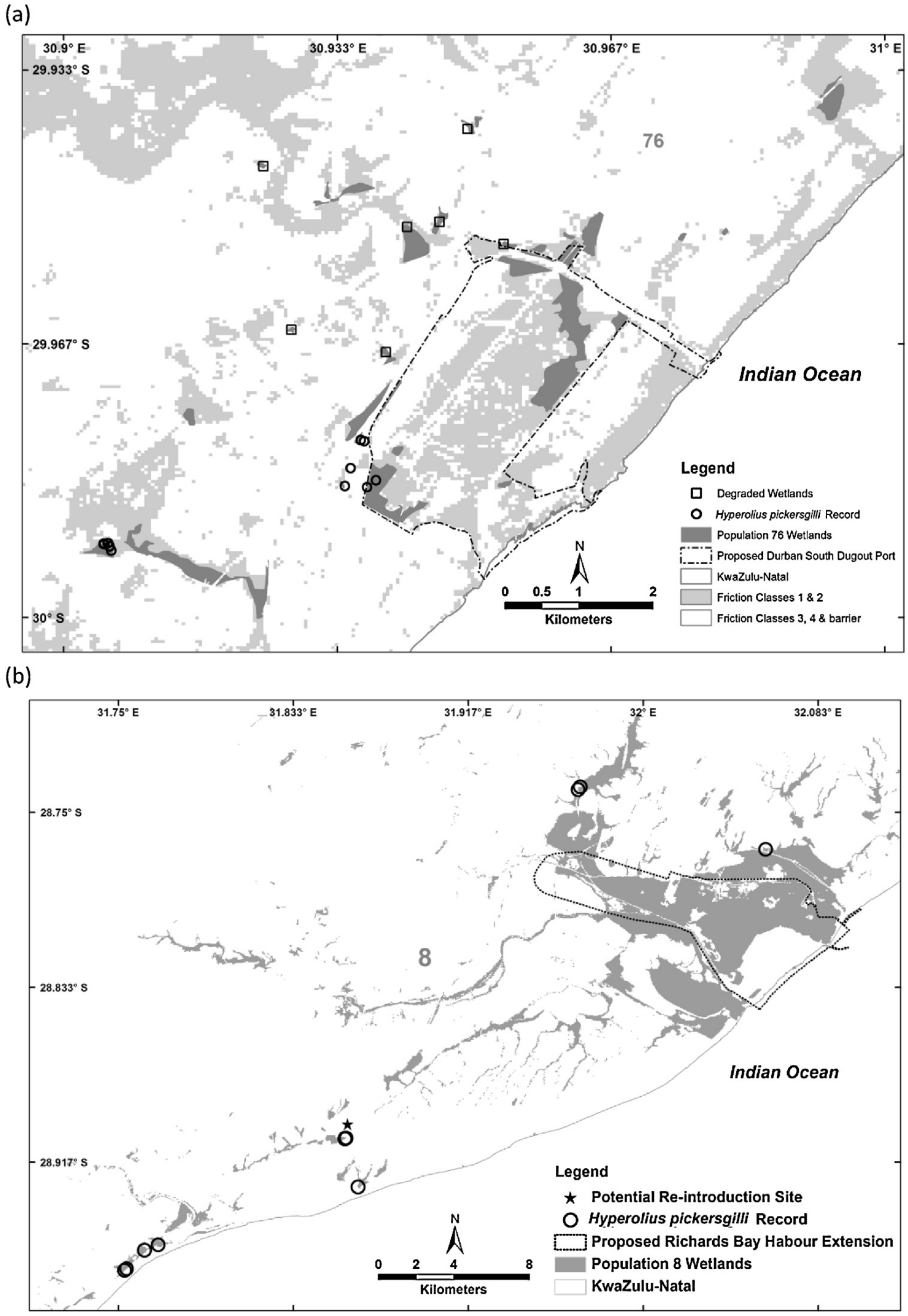

Fig. 5. (a) The location of the proposed dugout port in the South Durban area of KwaZulu-Natal in relation to known and potential wetland habitat for *Hyperolius pickersgilli* (potential population 76 of Fig. 3; probability of occurrence in the wetlands prior to degradation range from 0.45 to 0.91). Areas of low friction to movement of the species (landcover classes assigned friction values of 1 and 10) are indicated. (b) The location of a potential re-introduction site in the Port Durnford area of KwaZulu-Natal in relation to known sub-populations of *Hyperolius pickersgilli*.

the same population extent that have high probabilities of occurrence for *H. pickersgilli* and in accordance with the IUCN Guidelines for re-introductions (IUCN, 2012a). This should prevent potential mixing of genetic haplotypes and increase the chances that the rehabilitated habitat will be suitable for the species because the environmental conditions necessary for the survival of the frog will be present (Semlitsch, 2002). The wetlands to which the frogs are translocated will need to have linkages of suitable land cover to other suitable wetlands to allow dispersal of metamorphs and adults. For the sub-population on the proposed Durban South dug-out port footprint, the larger degraded wetlands in the north-central portion of Fig. 5a should be investigated as to their suitability for purchase, rehabilitation, protection and long-term management, because some connectivity exists between them and another potentially suitable wetland to the north-east, and potentially suitable terrestrial habitat lies adjacent to parts of their perimeters. Should this habitat not be suitable for rehabilitation and re-introduction of *H. pickersgilli*, other sites further afield will need to be identified, again as guided by the maps produced in this study.

Fig. 5b indicates a potential re-introduction site for *H. pickergilli*. The area was formerly under *Eucalyptus* sp. plantation but was cleared and is in the process of reverting to wetland. *H. pickersgilli* may naturally disperse to this wetland from the nearby sub-population, or individuals from any of the known sub-populations within the same potential population could be translocated there if necessary. If the Richards Bay harbour extension goes ahead (Fig. 5b), any *H. pickersgilli* occurring within the extension footprint could be relocated to this potential re-introduction site. Such information will also be useful for guiding re-introductions of progeny of *H. pickersgilli* from the ex situ programme being conducted by the Johannesburg Zoo (Visser, 2011). Re-introductions of ex situ stock may be directed to wetlands within the same population or meta-population range from which the parental stock was taken. The need for surveillance monitoring and a phylogeographic study of *H. pickersgilli* to determine management units was also highlighted in Measey (2011). This study provides the baseline for surveillance to detect changes in AOO and EOO and also a first approximation to delimiting populations and therefore management units for use in conservation decision-making. It afforded the opportunity for tissue collection from throughout the range of *H. pickersgilli* that can contribute to phylogeographic analysis, and priority sites for long-term monitoring can be selected using the knowledge obtained during the study.

Red list status of H. pickersgilli

The IUCN threat category of *H. pickersgilli* was re-assessed in 2010 based on B2 criteria (i.e. geographic range, South African Frog Re-assessment Group, 2010; IUCN, 2012b). Based on results from this study, the species qualifies for a down-listing to Endangered according to this criterion (EN B1ab(iii) + 2ab(iii)).The AOO now exceeds 10 km^2, but the population remains severely fragmented, and habitat area, extent and quality are continuing to decline (cf. IUCN Red List Guidelines Committee 2011). Increases in known range size are expected with increased survey intensity, potentially resulting in updates to Red List status (Botts, Erasmus, & Alexander, 2012; Driver, Raimondo, Maze, Pfab, & Helme, 2009). However, down-listing the threat category of a species according to the B criterion runs the risk of being detrimental to the species as population size and viability are not taken into account. Criterion A3, based on a suspected population reduction in the future as a result of likely ongoing habitat loss should also be considered. Our findings on the status of historical sites (8 of 17 extirpated over the past 30 years) is additional justification for erring on the side of caution in terms of down-listing this species' threat category. It is therefore recommended that *H. pickersgilli* remains listed as Critically Endangered until the next official Red List assessment is conducted in 2020. In the interim, additional knowledge on population estimates should be accumulated to assist with this re-assessment.

The findings of this study can be incorporated into the proposed Biodiversity Management Plan for *H. pickersgilli* (intent registered with the Department of Environmental Affairs) and provide guidance in terms of conservation decisions, including long-term monitoring, habitat restoration, possible translocations and re-introductions and the role of ex situ breeding in establishing an assurance population. Habitat destruction and land transformation is threatening various wetland-inhabiting amphibian species along the eastern coastal region of Africa (Andreone et al., 2008). A first approximation of potential populations for a species can be made from a ground-truthed predicted distribution map, based on empirically derived dispersal distances or on dispersal distances for similar species in the literature. Using available knowledge of the habitat preferences, ecology and life history of the species, a friction map to indicate suitable habitat or potential dispersal connections between suitable wetland habitat can be developed and used to make conservation planning decisions. Examples of such decisions include: (1) the wetlands, terrestrial habitat and potential linkages that should be protected through land use planning mechanisms, and; (2) which degraded wetlands could be rehabilitated and used as re-introduction sites because they had high probabilities of occurrence for the species prior to degradation and because these wetlands are within the same potential population range as extant sub-populations. Implementation of this methodology will test it and will allow refinements to be made. The methodology also allows for the Red-listing of threatened species that have not yet been evaluated and for developing a baseline against which changes in the EOO and AOO of the species can be tracked.

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Appendix A. Wetlands with ≥60% occurrence probability for *Hyperolius pickersgilli* as predicted by the initial MaxEnt model. These sites were ground-truthed between October 2010 and January 2012. The species was detected at only 9 sites out of a total of 71 surveyed. The species was deemed absent at 24 sites where wetland habitat had been completely eliminated. A further 14 sites appeared unsuitable for the species (Unlikely) and the species was not detected at 24 sites which may have been suitable for the species.

Date	Area	Lat.	Long	Site description	Likelihood of presence of *H. pickersgilli*
28/10/2010	Umlazi	−29.94502°	30.92430°	Degraded. The general area is heavily built up with industrial, commercial and residential land-use.	Unlikely
28/10/2010	Umlazi	−29.96492°	30.92770°	Transformed. Not suitable (wetland no longer present, housing built in the vicinity).	Absent
28/10/2010	Umlazi	−29.94790°	30.93428°	Degraded. Wetland adjacent to Mlazi river. Disturbed by road works for new road. Other species heard calling (*A. fornasinii*, *H. marmoratus* and *L. natalensis*) but does not appear suitable to *H. pickersgilli*	Not detected
28/10/2010	Umlazi	−29.96765°	30.93925°	Transformed. Wetland no longer present.	Absent
28/10/2010	Umlazi	−29.95243°	30.94182°	Degraded. Large wetland area below newly constructed pedestrian bridge. Partially transformed by footbridge construction and subsistence gardening.	Unlikely
28/10/2010	Umlazi	−29.95179°	30.94577°	Transformed. Possible a historical wetland – no longer suitable. Housing built in the area.	Absent
28/10/2010	Umlazi	−29.94049°	30.94918°	Degraded. Wetland partially disturbed by rubbish dumping and other human activities.	Not detected
28/10/2010	Umlazi	−29.95450°	30.95357°	Transformed. Not suitable. Wetland no longer present.	Absent
11/11/2010	Roosfontein	−29.85733°	30.92598°	Not suitable. Conservation area with wetland surrounded by grassland, but no standing water or reed beds as required by *H. pickersgilli*.	Not detected
11/11/2010	Cato Manor	−29.86012°	30.93706°	Transformed. All Cato Manor sites in low-income housing development areas. Wetlands either no longer in existence or badly littered.	Absent
11/11/2010	Cato Manor	−29.84708°	30.93947°	Degraded. Site completely dry.	Absent
11/11/2010	Cato Manor	−29.85707°	30.94135°	Transformed. Not suitable.	Absent
11/11/2010	Cato Manor	−29.85969°	30.95382°	Transformed. Not suitable.	Absent
11/11/2010	Cato Manor	29.85642°	30.95999°	Transformed. Not suitable.	Absent
11/11/2010	Cato Manor	−29.85908°	30.96174°	Transformed. Not suitable.	Absent
18/11/2010	Mobeni/Clairewood	−29.90414°	30.95785°	Dry river bed – not suitable	Absent
18/11/2010	Mobeni/Clairewood	−29.90785°	30.97150°	Not suitable. Wetland no longer present.	Absent
09/12/2010	Prospecton	−29.98412°	30.93696°	Extensive reed bed comprised of suitable vegetation adjacent to Prospecton Rd. Drainage line running through centre. Call & sighting.	Present
17/12/2010	Nyoni River, Amatikulu NR	−29.13370°	30.59369°	River system – visited by boat. Numerous other hyperolid species calling, but not suitable for *H. pickersgilli*	Not detected
18/12/2010	Amatikulu NR	−29.13461°	31.59398°	Not suitable. Wetland area completely dry.	Unlikely
18/12/2010	Amatikulu NR	−28.95706°	31.76307°	Coastal dune thicket, mostly undisturbed. Very dry – only a small amount of reed vegetation present (*Papyrus* and *Phragmites*).	Unlikely
18/12/2010	Amatikulu NR	−29.01413°	31.69252°	Swamp forest along small river, no proper wetland or veg. Very dry. Surrounded by pine and gum plantation.	Unlikely
18/12/2010	Amatikulu NR	−29.00727°	31.65930°	Forested stream within sugar cane fields. No reed vegetation.	Unlikely
18/12/2010	Amatikulu NR	−29.03838°	31.66700°	Swamp forest ravine within gum plantation	Unlikely
12/10/2011	Twinstreams	−28.99461°	31.72471°	Degraded. Dry reed bed below *Eucalyptus* plantation.	Unlikely
12/10/2011	Twinstreams	−29.00095°	31.71548°	Degraded. Possible historical wetland. Very dry. Area burnt in 2006.	Unlikely
12/10/2011	Twinstreams (Gwalagwala campsite)	−29.00679°	31.7152°	Transformed. Destroyed wetland; grass now.	Absent
12/10/2011	Port Durnford	−28.90522°	31.8585°	New site. Many calling in large reed *Phragmites australis* & sedge wetland with deep stagnant water. Call and sighting.	Present
12/10/2011	Port Durnford	−28.90942°	31.8182°	Reed and sedge wetland	Not detected
02/02/2011	iSimangaliso	−28.20162°	32.48896°	Short bulrush wetland with deep standing water	Not detected
02/02/2011	iSimangaliso	−28.20802°	32.49292°	Short-grass & sedge wetland	Not detected
02/02/2011	iSimangaliso	−28.19836°	32.5027°	Reed wetland	Not detected
02/02/2011	iSimangaliso	−28.17175°	32.49435°	Dry short-grass & sedge wetland	Unlikely
13/10/2011	Umlalazi Nature Reserve	−28.96965°	31.755°	Reed wetland in the Siyaya River at the bridge	Not detected
13/10/2011	iSimangaliso	−28.34985°	32.41107°	Part of estuary within walking distance from Croc centre. Along river system. Not ideal.	Unlikely
13/10/2011	iSimangaliso	−28.29722°	32.43881°	"Space" site. Dense reed bed of tall sedges and ferns.	Not detected
13/10/2011	iSimangaliso	−28.31048°	32.44502°	Vlei Loop.	Not detected
13/10/2011	Lake Teza, Umfolozi	−28.48532°	32.16041°	Large lake surrounded by emergent vegetation (*Phragmites* and *Papyrus*)	Not detected
22/10/2011	Amanzimtoti, San Gabriel Ave.	−30.07431°	30.86199°	Coastal forest. Close to "Warner Beach" (1982) historical site	Not detected
22/10/2011	Clansthal	−30.239145°	30.768241°	Transformed. Drained wetland within sugar cane plantation.	Absent
22/10/2011	Clansthal	−30.24007°	30.768241°	Transformed. Drained wetland within sugar cane plantation.	Absent
22/10/2011	Clansthal	−30.24785°	30.767896°	Transformed. Drained wetland within sugar cane plantation.	Absent
22/10/2011	Scottburgh/Park Rynie	−30.30501°	30.728704°	Transformed. Dry and surrounded by sugar cane.	Absent

Date	Area	Lat.	Long	Site description	Likelihood of presence of *H. pickersgilli*
22/10/2011	Scottburgh/Park Rynie	−30.31426°	30.724542°	Degraded. On sugar cane farm. Limited access.	Unlikely
22/10/2011	Park Rynie	−30.32047°	30.764368°	Degraded. Very small sedge wetland surrounded by sugar cane.	Unlikely
22/10/2011	Park Rynie	−30.33508°	30.731506°	Degraded. Small drainage line in sugar cane.	Unlikely
08/11/2011	Amanzimtoti, Fynn Road	−30.03964°	30.879553°	Transformed. Steep slope dominated by Spanish reed. Housing built in area of historical wetland.	Absent
08/11/2011	Amanzimtoti, Fynn Road	−30.03154°	30.87915°	Transformed. Dominated by Spanish reed. Not suitable	Absent
08/11/201106/12/2011	Croc world - South of Scottburgh	−30.25825°	30.76772°	*Phragmites* reed bed below Crocworld grounds. Appeared suitable at initial visit, but none on second night visit, possibly due to insufficient ground-cover.	Not detected
08/11/2011	Hibberdene	−30.57091°	30.57537°	Reed bed wetland	Not detected
08/11/2011	Hibberdene, near turn-off	−30.55847°	30.58248°	Sedge and dwarf papyrus reed bed wetland	Not detected
08/11/2011	Karridene	−30.12364°	30.82865°	Dry and surrounded by sugar cane	Not detected
08/11/2011	Karridene	−30.12706°	30.82451°	Reeds adjacent to road	Not detected
06/01/2012	Umkomaas	−30.21717°	30.79542°	Dense reed bed of *Typha*	Present
06/01/2012	Umkomaas	−30.22707°	30.78991°	Wetland	Not detected
09/01/2012	Port Durnford	−28.90403°	31.8680°	Vlei with dwarf sedges. Not suitable for *H. pickersgilli*	Not detected
10/01/2012	Amatikulu	−29.07870°	31.63973°	*Phragmites* and *Typha* wetland. Suitable	Not detected
10/01/2012	Zinkwazi Beach (Nonoti)	−29.29659°	31.41242°	Perennial wetland densely vegetated with *Phragmites*. Highly suitable	Present
19/01/2012	Elysium	−30.44585°	30.61935°	Transformed. Drained wetland within sugarcane plantation (furrowed)	Absent
19/01/2012	Elysium	−30.46386°	30.63477°	Transformed. Drained wetland within sugarcane plantation (furrowed)	Absent
19/01/2012	Sezela	−30.40612°	30.63641°	Spartan reed bed	Not detected
19/01/2012	Sezela	−30.40827°	30.64943°	Transformed. Drained wetland within sugarcane plantation (furrowed)	Absent
19/01/2012	Sezela	−30.40679°	30.64038°	Scraggly reed bed	Not detected
19/01/2012	Mpenjati	−30.97502°	30.28037°	Wetland with bulrushes *Typha capensis*, ferns and reeds *Phragmites australis* but little standing water	Not detected
20/01/2012	Sezela	−30.40670°	30.66145°	Medium wetland. Very dense: *Cyprus*, *Persicaria* and *Phragmites*	Present
20/01/2012	Sezela	−30.39988°	30.67799°	Transformed. Drained wetland within sugarcane plantation (furrowed)	Absent
20/01/2012	Sezela	−30.40208°	30.67404°	Transformed. Drained wetland within sugarcane plantation (furrowed)	Absent
20/01/2012	Prospecton	−29.97837°	30.93617°	Dense reed bed running parallel to N2	Present
20/01/2012	Prospecton	−29.98182°	30.93495°	Dense *Phragmites australis* reed bed running parallel to N2	Present
20/01/2012	Prospecton	−29.98396°	30.93425°	Dense *Phragmites australis* reed bed running parallel to N2	Present
20/01/2012	Prospecton	−29.97851°	30.9366°	Dense reed bed running parallel to N2	Present

Appendix B. Details of historical localities for *Hyperolius pickersgilli* revisited during this study (2008–2012).

Site name, date of discovery and source	Date re-visited	Coordinates	Threats	Size (ha)	Apparent population status	*Hyperolius pickersgilli* detected
Warner Beach, 1978 (Raw, 1982)	Nov 2011, Jan 2012	−30.07644°, 30.86504°	Habitat loss (possible wetland drainage); proximity to road; urbanisation	n/a	Extinct	No
Adam's Mission, 2001 (Minter et al., 2004)	Jan 2011	−30.00276°, 30.80039°	Rural urbanisation; proximity to road	5 small populations within 4 km of each other ~3 ha	Poor	Yes
Isipingo, 2007 (Ezemvelo KZN Wildlife Biodiversity Database)	Frequently 2008–2012	−29.99133°, 30.90555°	Within highly industrialised area; pathway through wetland; partially drained for subsistence farming; alien invasive vegetation	2 ha	Good	Yes
Avoca, 1981 (Type locality) (Raw, 1982)	Oct 2011	−29.76006°, 31.02199°	Complete habitat loss; urban development	n/a	Extinct	No
Mt Edgecombe, 1977 (Raw, 1982)	Oct 2011	−29.70835°, 31.02867°	Habitat loss; urbanisation; cultivation	n/a	Extinct	No
Mt Moreland, 2007 (Ezemvelo KZN Wildlife Biodiversity Database)	Frequently 2008–2012	−29.63818°, 31.09750°	Vicinity to King Shaka International Airport and concomitant development; Surrounding cultivation	17.2 ha	Good	Yes
Stanger, 2002 (Minter et al., 2004)	Dec 2010	−29.33314°, 31.31020°	Rural urbanisation; soil dredging	~2 ha	Poor	Yes
Charlottedale, 1982 (Johnson and Raw, 1987)	Dec 2010, Feb 2011	−29.39611°, 31.28556°	Rural settlement nearby	~1 ha	Poor	Yes

Site name, date of discovery and source	Date re-visited	Coordinates	Threats	Size (ha)	Apparent population status	*Hyperolius pickersgilli* detected
Tugela River Mouth, 1983 (Lambiris, 1989)	Dec 2010	−29.20872°, 31.46642°	Sugarcane	n/a	Extinct	No
"Senla" Tongaat-Hulett Sugar Estate, 1982 (Johnson and Raw, 1987)	Jan 2012	−29.27120°, 31.44533°	Surrounded by sugarcane; pesticide runoff	3 ha	Intact	No (Only visited during the day)
Amatikulu Prawn farm, 2007 (Ezemvelo KZN Wildlife Biodiversity Database)	Jan 2012	−29.07472°, 31.64889°	Habitat alteration; water drainage; contamination from industrial activities on premises	2 ha	Poor	No
"Twinstreams", Mtunzini, <1982 (Raw, 1982)	Multiple visits	−28.98900°, 31.72646°	Eucalyptus plantations; drought	n/a	Extinct	No
Forest Lodge, Mtunzini, 1994 (Minter et al., 2004)	Oct 2011	−28.96770°, 31.75321°	None perceived	2 ha	Intact (protected within a conservancy)	Yes
Raphia Palms, Mtunzini, 2001 (Minter et al., 2004)	Multiple visits	−28.95853°, 31.76228°	Drought	<0.5 ha	Intact (protected within a conservancy)	Yes
Umlalazi Nature Reserve, 1997 (Minter et al., 2004)	Dec 2010	−28.95805°, 31.76472°	Sewage run-off; reed harvesting	5 ha	Protected	Yes
Port Durnford area, 1997	See Table 3	Unknown				
Richards Bay, 1977 (Raw, 1982)	Jan 2012	−28.76762°, 32.05841°	Habitat loss; dumping of refuse	2 ha	Intact	No
Monzi, 1978 (Raw, 1982)	Not visited	Unknown				
St. Lucia Estuary, <1982 (Raw, 1982)	See Table 3	Unknown				

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