Abstract

The frog *Arthroleptides dutoiti* Loveridge, 1935, endemic to Mount Elgon, East Africa was last collected in 1962 and has not been observed since. The species is regarded as Critically Endangered by the IUCN Red List and is a priority species on the Zoological Society of London's EDGE (Evolutionarily Distinct, Globally Endangered) project given its Red List status and phylogenetic distinctiveness. We analyse temporal patterns of abundance (1934-2014) of *A. dutoiti* and the remainder of the Mount Elgon amphibian assemblage to infer the probability of re-encountering *A. dutoiti* and assess whether declines are species-specific to *A. dutoiti*, or if they are an assemblage-wide phenomenon. Our results show that for localities where surveys have been repeatedly conducted, *A. dutoiti* is likely to be locally extinct. Declines are observed in other Mount Elgon amphibians, encompassing both specialists and generalists. Causal factors for declines are unknown but habitat change might be important given the high degree of forest loss in the area, especially since the turn of the 20th century. Urgent sampling of preferred micro-habitats of *A. dutoiti* at the type locality and surrounding areas beyond those included in our study are required to determine whether or not the species is extinct. Impacts on other taxonomic groups would also be useful to understand so that it can be determined how broad the changes are for the Mount Elgon biota.

Introduction

Amphibians have declined dramatically in many areas of the world and this has intensified over the last 25 years (Beebee and Griffiths 2006; Stuart et al. 2005; Nowakowski, et al. 2018). These declines have rendered amphibians one of the most threatened vertebrate classes (32% of assessed species by the IUCN Red List are in threatened categories, compared to 21% (mammals), 18% (reptiles), 13% (fish) and 13% (birds) (IUCN 2020)). Although habitat modification is known to have impacted amphibians for decades (Collins and Storfer 2003) recent research has also investigated other potential causes such as climate and land use change and pathogens (e.g. Sodhi et al. 2008; Ficetola et al. 2014; Hof et al. 2011). The causes of amphibian declines remain complex and in many cases are likely to be the result of multiple factors (Hof et al. 2011; Campbell Grant et al. 2016).

For the continent of Africa there is a lack of studies investigating the temporal abundance of amphibians (Houlahan et al. 2001; Lips 2016) – therefore quantitatively identifying declines has been problematic. Moreover, understanding of the causes of declines for African amphibians has been even more limited compared to other regions globally given the lack of appropriate data to distinguish between various potential causes, though there are some notable exceptions (e.g. Channing and Howell 2006; Gower et al. 2013; Channing and Rödel 2019; Weldon et al. 2020). There remains a worrying dearth of knowledge on most African amphibians and how threatened species might be.

The torrent frog, *Arthroleptides dutoiti* Loveridge, 1935 is Critically Endangered and endemic to Mount Elgon, and has not been observed or collected for over 50 years (IUCN SSC Amphibian Specialist Group, 2016). There has been a recent surge of interest in finding surviving populations of this frog, prioritized for conservation attention by ZSL's EDGE of Existence Programme (Isaac et al. 2012). The species was first collected from Mount Elgon (7,200 feet = 2,195 metres) on the Kenyan side along the Koitobos River by du Toit in 1934 and was subsequently described by Arthur Loveridge in 1935 (see Figure 1). A collection of eight specimens was made by Ronalda Keith in 1962 on the Suam River, near the type locality (ca.10 km, see Figure 1). Since then, numerous field surveys have been conducted in the area without any further specimens being observed (see Lötters et al. 2003). From the original collection data the species appears to be associated with water seeps and fast-flowing streams in montane forest and is therefore likely to be highly restricted in its distribution – as is the case with congeneric species (Channing and Howell 2006; Barej et al. 2010). It remains unclear whether *A. dutoiti* is extinct, or rare and this needs to be determined quantitatively.

For this study we analyse all the collections made in Mount Elgon, Kenya to estimate the contemporary likelihood of encountering *A. dutoiti*. Furthermore, we analysed collection data for all amphibians on Mount Elgon to examine whether declines are evident in other taxa. We specifically address whether forest or open habitat species show differences in abundance over time to detect whether any changes are a species-specific phenomenon or assemblage-wide change.

Methods

Data on Mount Elgon amphibians were collated from Loveridge's original description of his surveys in Kenya and Uganda (Loveridge 1935) (see Supplementary Information 1 for further details) and complemented by du Toit's collection in Mount Elgon around the same time. Nearly thirty years later, Ronalda Keith visited Mount Elgon on the Kenyan side in April 1962. An excerpt of her description of the collection of *A. dutoiti* is given in the Supplementary Information 2. We were able to gather and collate data on other Mount Elgon amphibians collected by Keith from records held at the American Museum of Natural History (AMNH). Keith only visited the Suam River (spelt Suan River in her field book) (7,000 ft. = 2,135 m) and not the original locality visited by du Toit (7,200 feet) (see Figure 1). Since 1962, surveys on Mount Elgon resumed between 2001 and 2014. See Supplementary Table 1 and 2 for further details on the precise details of dates, person hours collecting time, and number of specimens collected.

Statistical modelling

The likelihood of *A. dutoiti* remaining extant around Mount Elgon was inferred from a sighting history containing both presence and absence records. We calculated the probability of re-sighting *A. dutoiti* in the period 2000-2014 given that the species was extant using a model that measures sighting rate as a function of survey effort (Boakes et al. 2016). The model is suitable for low numbers of sightings and does not require survey effort to remain above zero as do the majority of models used to infer extinction (Boakes et al. 2015). We assumed that sightings of a particular species in a particular spatial region occur in a Poisson process with rate $\lambda(t) = \lambda_0 e(t)$ where $e(t)$ reflects the balance between sampling effort and species detectability and is assumed known and λ_0 is a constant (unknown) that will vary with region and species. Time varies continuously and we assume a sampling window (0,*T*]. The unknown λ_0 can be estimated by $\hat{\lambda}_0 = N(T)/I(T)$ where $N(T)$ is the total number of sightings observed in the sampling window, and $I(T)$ the total effort, $\int_0^T e(u)du$ (where *u* is a dummy variable representing an arbitrary time between 0 and T). The probability that there are no sightings in an interval $(\tau, T]$ can be estimated as $\exp\left\{-\hat{\lambda}_0[I(T)-I(\tau)]\right\}$ where $I(T)-I(\tau)$ is the total effort over $(\tau, T]$. In discrete time, the probability *p* that there will be no sightings in the years $\tau+1, ..., T$ is approximated by $\prod_{t=\tau+1}^{T}(1-\hat{\lambda}_0 e(t))$. Effort was measured by the number of person-hours spent surveying and the year τ taken to be 2000. We calculated the re-sighting probability of *A. dutoiti* both including and excluding the 1934 survey given uncertainty in sampling timings and locations. See Supplementary Information 3 for the calculation.

Change in abundance (sightings per person hour of survey time) of amphibian species over time was assessed by fitting models in a generalised additive modelling (GAM) framework with a Gaussian distribution and an identity link using the *MGCV* package (Wood, 2006) in *R v. 3.2.3* (R Development Core Team 2010). Only three species had sufficient data to allow their abundance to be modelled individually. To model the trend in abundance of the remaining species, species were pooled into habitat specialists or generalists (see Supplementary Information, Table 2).

Results

The calculated probability of there being no sightings of *A. dutoiti* on the sampled areas on Mount Elgon during the period 1962, and 2000-2014 given the null hypothesis that the species is extant was 2.5×10^{-5} (95% CI 1.07×10^{-8} – 3.12×10^{-3}). If including the 1934 survey data, including the collection of the type series, then the probability is 4.34×10^{-4} (95% CI 1.27×10^{-6} – 0.145). It is therefore extremely unlikely that *A. dutoiti* persists at the sites surveyed.

Analysis of encounter data with GAM using sightings pooled across study sites showed for (1) *Xenopus borealis* Parker, 1936, a highly significant decline in abundance since the 1960s (t = 9.15, P <0.001), (2) *Amietia nutti* Boulenger, 1896, a significant increase in abundance since the 1960s (t = 8.01, P = 0.003), (3) *Ptychadena nilotica* Seetzen, 1855, a near significant linear increase in abundance (t = 2.18, P = 0.07) (see Figure 2). For the period 1934-2014, habitat specialists underwent a significant linear decrease in abundance (t = 4.04, P = 0.006) and habitat generalists a significant hump-shaped trend with sightings increasing to and then decreasing from the 1960s (t = 4.95, P = 0.007) (see Figure 2).

Discussion

Based on our quantitative analysis, the likelihood of *A. dutoiti* being present today in sampled sites on the Kenyan side of Mount Elgon is extremely low. Although *A. dutoiti* is possibly extant, we suggest that based on field studies where it was formerly present, that it is now locally extinct. Recent surveys were conducted in the same locality in the Suam River where the species was last recorded in 1962, across different seasons including the same time of year when previous surveys encountered specimens. The result is supported whether 1934 data is included/or removed in our quantitative analysis and provides strong evidence that the species is likely to be locally extinct.

The reasons for the apparent decline and possible extinction of *A. dutoiti* are not known, but a likely factor is the change in the habitats in the area (National Museums of Kenya Centre for Biodiversity 2007) given the species' close association with montane forest streams. Although parts of the habitat in the species last known area of distribution appear to be generally in good condition, *A. dutoiti* may be adversely impacted by logging and general loss of the forest on Mount Elgon (see Aleman et al. 2018). This is particularly clear in Suam River, where in 1962 Keith reported a dense moist forest (see Supplementary Information 2) but today it has been cleared for farming. In view of the rapid disappearance of other montane stream-dwelling species elsewhere in the humid tropics (e.g. Lips et al. 2005) there is a strong concern that *A. dutoiti* is extinct.

The potential extinction of *A. dutoiti* appears to be symptomatic of a general decline in the amphibian assemblage of Mt. Elgon. For broad categories we show decreases in both specialists and generalists. The patterns fit with a trend of a specialist (e.g. *A. dutoiti*) showing decline or even potential extinction. However, we show that some species, where available data allow, have undergone decline (*X. borealis*), others have increased (e.g. *A. nutti* and *P. nilotica*). It is interesting to note that one specialist species (*A. nutti* has increased, though it is not intuitively clear why, particularly given the general decline of the amphibian assemblage as a whole. One factor might include biases in sampling of riverine habitats in the search for *A. dutoiti* that shares the habitat of *A. nutti*. It might also be that the decline of *A. dutoiti* might have opened up an opportunity for the increase in other riverine species but which might be more tolerant to habitat change or other unknown stressors (such as *A. nutti*). Increases in *A. nutti* started at least around the year 2000 though likely before (between 1962-2000), which might correspond to an extinction (or substantial decline) event in *A. dutoiti*. In contrast, the generalist *P. nilotica*, has been steadily increasing over the survey period potentially linked to change in habitats (to more open areas) more suited to these generalist species. Further studies are required to understand the compositional change of the amphibian assemblage of Mount Elgon that might shed light on the factors driving population changes.

The overall decline in amphibian abundance in Mount Elgon, and most worryingly the absence of the only endemic species known from the area, *A. dutoiti*, is of high conservation concern. An urgent priority is to sample other suitable areas around Mount Elgon (particularly on the poorly surveyed areas on the Ugandan side) that may represent microrefugia, and that will facilitate a conclusive test of the species possible extinction. Our data might be biased by the less precise knowledge of historic sampling effort, particularly from du Toit's 1934 survey where limited field notes exist. However, Keith's 1962 survey is well-documented and we suspect our estimation provides a good test of "then" and "now" in Mount Elgon. Further ecological sampling of the amphibian assemblage, and surveys of emerging diseases (see Kielgast et al. 2010), and habitat modification, needs to be conducted to understand potential factors causing amphibian population changes in this threatened montane forest habitat. Our study showed the value of using timed searches for investigating population changes in Amphibians where few data exists on the African continent.

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Figure legends

Figure 1. Map of East Africa with insert of Mount Elgon showing sampling localities.

Figure 2. Generalised additive modelling trends (lines) for the period 1934-2014 fitted to abundance (as sightings per person hour of searching) data for a) *Xenopus borealis*, b) *Amietia nutti*, c) *Ptychadena nilotica*, d) the other habitat specialist frog species and e) the other habitat generalist frog species.