Frogs and climate change in South Africa

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ABSTRACT

This article explores the relationship between frog declines and climate change, discusses the possible impact of climate change on the South African frog fauna, and highlights the necessity for increased research and monitoring of our frog populations.

INTRODUCTION

For several decades, amphibian declines and climate change have been subjects of great concern and heated debate both in scientific circles and in the media. This interest appears justified as frog species continue to disappear at an alarming rate, global temperatures rise and the incidence of extreme weather events increases. When one considers that the human population is fast approaching 7 billion,[1] the extent to which we have altered natural habitats and the cumulative effect, on the atmosphere, of deforestation, agriculture and the burning of fossil fuels, it is not surprising that we are implicated in both of these phenomena.

CLIMATE CHANGE: WHAT TO EXPECT

The Pleistocene, a period of about 2 million years in duration, consisted of a series of about 20 glacial-interglacial cycles, terminating in the Last Glacial Maximum about 13 000 years ago. The last 10 000 years (Holocene) represents a warm, relatively stable interglacial period. The 20th century was the warmest of the last millennium with the most rapid warming occurring in the last 30 years.[2] The rate of warming between 1980 and 2005 was approximately double the rate of increase between 1905 and 2005.[3] This warming trend is attributed to greenhouse-gas emissions[3,4] and has led to range shifts and changes in the phenology of numerous species[5] in a wide range of environments.[6] Climate projections for South Africa[7,8] are summarised and discussed in this issue[9] and elsewhere, by Joubert.[10,11] Essentially, precipitation in the south-western winter rainfall region is expected to decrease, while the eastern summer rainfall areas receive more rain. Flooding (rainfall intensity) and droughts (duration of dry spells) will occur more frequently. By mid-century, temperatures are expected to rise along the coast by 1-2°C, and in the interior by 2-3°C. After 2050 a worst-case scenario predicts these rising by 3-4°C and 6-7°C respectively by the end of this century.[7,8]

AMPHIBIAN DECLINES: CANARIES IN THE COALMINE?

By 1990, more than two-thirds of the area of two of the world's 14 major terrestrial biomes and more than half of the area of four other biomes had been converted to agriculture,[12] and by 2005 a quarter of earth's terrestrial surface was being used for this purpose.[13] The loss of biodiversity in the last century is reflected in a dramatic rise in extinction rates to levels 1000 times higher than the norm.[12] Projections based on the current rate at which biodiversity is being lost, and mounting evidence of man's participation in the extinction of the Pleistocene megafauna[14-16] suggest that we are witnessing an extinction event (6th extinction)[17,18] of our own making, comparable in magnitude to the five major extinction events in earth history. Among the vertebrates, amphibians have the doubtful privilege of leading the march to extinction.

Amphibian declines began to arouse concern in the late 1980s and were soon recognised as a global phenomenon.[19,20] The Global Amphibian Assessment (GAA) published in 2004, found that 1 893 of 5 881 species (31%) of amphibians assessed, were threatened with an extremely high (Critically Endangered), very high (Endangered), or high (Vulnerable) risk of extinction in the wild. Although only 34 species were listed as officially 'Extinct', 130 of the 455 species in the 'Critically Endangered' category were considered to be 'Possibly Extinct'.[12]

The GAA found that for those species faced with possible extinction, habitat loss and fragmentation posed the most serious threat, followed by pollution and disease.[12] Whereas declines caused by habitat loss and fragmentation occur at a slower rate, and extinction may be avoided by appropriate conservation intervention, disease has caused sudden and dramatic declines and probable extinctions. The disease most often implicated in declines is chytridiomycosis, caused by a novel fungal pathogen *Batrachochytrium dendrobatidis (Bd)*[21-23] which spreads rapidly when introduced into amphibian populations.[24-28]

Studies of chytridiomycosis epidemics in Central and South America[24,25] found evidence of three separate introductions of *Bd* into South America,[25] supporting the spreading-pathogen hypothesis[22-25] that declines are caused by the introduction of a novel (exotic) strain of *Bd* that spread rapidly from its point of origin. They found no evidence to support the climate-linked epidemic hypothesis[29,30] that declines are driven by cli-

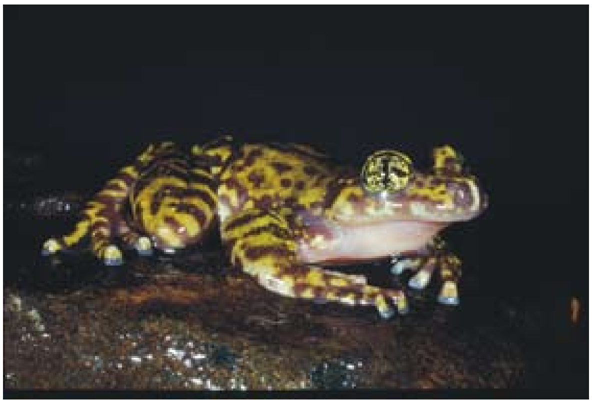

Fig. 1. Natal ghost frog, Hadromophryne natalensis, *associated with streams along the eastern escarpment and Drakensberg.*

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mate change that creates optimum conditions for endemic *Bd* to 'emerge from a dormant state or switch from a facultative saprobe to a pathogen as the environment becomes warmer'.[25]

A recent genetic analysis of a global sample of 59 *Bd* strains attributes the current outbreak of *Bd* to the recent emergence of a single successful (virulent) diploid lineage that was spread from its point of origin by the pet trade, scientific research or food production followed by direct frog-to-frog transmission.[28] Of the 59 *Bd* strains sampled, one from Maine in the eastern USA was considered the most likely candidate. The North American bullfrog, *Lithobates catesbeianus*, which is resistant to chytrid, may have acted as a vector for this strain as it is a highly invasive species that has been introduced into Asia, Europe, western North America and South America. The transfer of the strain to Africa and Australia remains unexplained.

The introduction of this *Bd* lineage into amphibian populations had a variety of outcomes: some host populations collapsed, others crashed and then recovered, while many were apparently unaffected.[28] This suggests that other factors such as host immunity and environmental factors may affect the outcome of the disease.[28]

THE ROLE OF CLIMATE CHANGE IN AMPHIBIAN DECLINES

It is generally accepted that amphibians, at the individual, population and community level may be affected in many ways by climate change. Temperature (extreme heat or cold) and precipitation (irregular rainfall patterns or drought) have a direct effect on amphibian populations and declines occur when species' physiological tolerances to these factors are exceeded, resulting in mortality.[31] Indirect effects of climate change on amphibian populations include: changes in breeding phenology (timing), reproductive success, rate of development, dispersal of metamorphs, immune function, disease dynamics, exposure to increased UV-B levels, ecological factors such as habitat loss or alteration (of vegetation, soil, hydrology), food availability, predator-prey relationships, competition within communities, and loss of genetic diversity and fitness.[25,31-34]

While correlations between declines and factors such as temperature variation or drought may suggest a direct link, it is still necessary to demonstrate a causal relationship[31-33] because in the natural environment a number of different (potentially causative) factors may be operating concurrently. This could be achieved in a controlled environment where single variables can be experimentally manipulated and their effects observed. However, some factors may interact synergistically, e.g. humidity and temperature, or host, pathogen and climate variables.[25] making it difficult to ascribe effects to individual factors. Unfortunately, in the case of most declines not enough is known about the physiological tolerances of the affected species, or its ability to adapt to environmental change, to prove causality.

A re-analysis of climate and decline data for the genus *Atelopus*[35] found that 83% of the temporal variation in these declines could be accounted for by two factors: increased regional temperature variability associated with El Niño climatic episodes, and the spatiotemporal pattern associated with epidemic spread. This is consistent with previous findings that temperature variability compromises amphibian immune defences, and that disease outbreaks frequently occur during extreme temperature events. The authors put forward a climate-variability hypothesis which predicts that the increasing intensity and frequency of extreme climatic events resulting from anthropogenic climate change might exacerbate amphibian declines.

Fig. 2. The torrent tadpole of Hadromophryne natalensis *has a large, sucker-like, oral disk which helps it to adhere to rocks in fast-flowing streams.*

Fig. 3. Northern forest rain frog, Breviceps sylvestris. *A sticky secretion glues mating pairs together before they burrow into the soil to lay and fertilise a batch of eggs.*

While the respective roles of climate change and disease in amphibian declines is still the subject of debate, there are instances where declines can be attributed to *Bd* in the absence of climate change,[25] and to climate change in the absence of *Bd*.[36] There is little doubt that climate change, both directly and indirectly, represents a serious threat to amphibian populations, particularly in areas where the natural habitat has been altered, fragmented or polluted, or where pathogens are present.

THE RESPONSE TO CLIMATE CHANGE: PAST EXPERIENCE

Amphibians have survived the rapid, high magnitude climate changes of the last glacial-to-interglacial transition 20 000 to 12 000 years ago,[37] which indicates that they have an intrinsic capacity for adapting to changes in climate. Ecological and biogeographic response to climate change over the last 20 000 years is well documented and includes repeated re-organisation of terrestrial communities, changes in the location and size of species' ranges and rapid fluctuation in local and regional population sizes.[38] Phenotypic plasticity, microevolution and the ability to disperse locally to suitable habitats have allowed some populations to adapt to climate change in situ or to persist in small populations and microhabitats. Others have adapted by dispersing along habitat gradients or by long-distance migration. Some species have undergone severe population declines, passing through genetic bottlenecks, and as a result exhibit low genetic diversity.[37]

The vegetation of the Cape Mediterranean Region, South Africa, the Cape Floristic Kingdom, is exceptionally rich in species in the Fynbos (8 600 species, 70%

endemic) and adjacent Succulent Karoo (5 000 species, 40% endemic) biomes. Both biomes are classified as biodiversity hotspots. Bioclimatic modelling was used to reconstruct vegetation shifts between the Last Glacial Maximum, 13 000 years ago, and the present.[38] This showed that the diverse topography facilitated distribution shifts along altitudinal gradients, and fragmentation, and provided ample opportunity for allopatric speciation through vicariance. The authors suggest that glacial/interglacial climate oscillations during the Quaternary, or at least the last 2 million years, acted as a species pump: new species derived from populations isolated in refugia during glacial periods expanded their ranges during interglacials and were isolated again in refugia during the following glaciation.

The responsiveness of the South African fauna to climate change was investigated in a study that modelled the effect of a 2°C increase in temperature on a sample of 179 mammals, birds, reptiles and insect species.[39] The model predicted range expansion in 17% of the species and range contractions of 4-98% in 78% of the species, while 3% showed no response and 2% became locally extinct. Range contractions took place from west to east along an aridity gradient causing species richness to decrease in the drier west, while in the east (KwaZulu-Natal), ranges contracted along an east-to-west altitudinal gradient.

These studies show that climate change itself does not necessarily result in a loss of biodiversity, but may have the opposite effect by providing opportunities for speciation. However, in the present situation, transformed landscapes will act as a barrier to range shifts and could lead to local extinction. As populations shrink, their genetic variation decreases, resulting in reduced fitness and lack of adaptability to a changing environment and increasing the likelihood of extinction.[34,39] Populations in decline are also more vulnerable to disease: yet another factor that could result in extinction.

Fig. 4. Spotted shovel-nosed frog, Hemisus guttatus*, a fossorial Zululand endemic.*

Fig. 5. Painted reed frog, Hyperolius marmoratus*, recently introduced to the Western Cape.*

THE SOUTH AFRICAN FROG FAUNA

South Africa has 118 described species of frog: several newly discovered cryptic species await description and there are, undoubtedly, others that have yet to be discovered. The greatest species richness occurs in the north-east, along the moist sub-tropical coastline of KwaZulu-Natal.[40] The fauna is rich in endemics (43%) comprising one endemic family, 9 genera and 51 species! Ranging in size from 18 mm (micro frog) to 245 mm (giant bullfrog) they display an amazing variety of colour, form and behaviour, and occupy aquatic, terrestrial, fossorial and arboreal habitats (Figs 1-6).

Notable examples include: the ghost frogs *(Heleophryne)*, restricted to mountain streams, with their torrent-adapted tadpoles; the common platanna (*Xenopus laevis*), that was once exported world-wide for pregnancy testing; the giant bullfrog *(Pyxicephalus adspersus)*, fiercely aggressive when mating and displaying highly developed parental care; the foam nest frog *(Chiromantis)*, that lays its eggs in large foam nests suspended above water; and rain frogs *(Breviceps)*, that are completely terrestrial, laying their eggs underground.

The 2004 amphibian red list for South Africa, Lesotho and Swaziland[40] was re-assessed in December 2009, and conservation research priorities were set for the threatened species.[41] Seventeen species were assigned to IUCN categories of threat as follows: Critically Endangered (5), Endangered (7) and Vulnerable (5).[42] Thus only 14.3% of South Africa's frog fauna is threatened, compared with 30.4% globally. Although *Bd* has been detected in a number of our species, it has not yet caused serious declines.

A biogeographic analysis of distribution data generated by the South African Frog Atlas Project[40] divided the fauna into eastern and western biogeographic subregions, which were further divided into biogeographic districts and assemblages.[43] These divisions are characterised by particular indicator species and correspond, to a varying degree, to existing vegetational biogeographic units. This implies that a redistribution of these vegetation units as a result of climate change should be accompanied by a similar shift in the distribution of the frog species currently associated with those units.

Most of South Africa's threatened species are concentrated in centres of endemism in the Western Cape, KwaZulu-Natal and the Eastern Cape. The topographic complexity of the Western Cape fold mountains and the eastern escarpment of KwaZulu-Natal and Eastern Cape has provided opportunities for allopatric speciation by vicariance, resulting in a number of range-restricted species. The genera *Arthroleptella* and *Capensibufo*[44] are examples of groups of species that originated on separate mountain ranges and peaks in the Western Cape during the Miocene and Pleistocene.

Preparing for climate change: how will our frogs respond?

Increased aridification in the Northern Cape will progressively displace the Succulent Karoo and Fynbos biomes southwards and eastwards, while the Nama

Karoo biome will shift eastwards. *Breviceps macrops*, currently assigned to the Vulnerable category of threat, occurs along the coast, where its habitat has been reduced by strip-mining for diamonds. A number of other arid-adapted species also occur in this part of the Succulent Karoo, and their survival will depend on their dispersal ability and the rate at which climate change takes place.

The endemic and largely range-restricted species of the Cape Peninsula and Cape folded mountains to the south, many of which are already 'red data' listed, are in real danger of extinction. The warming and drying trend is expected to drive montane species higher up mountain slopes along altitude gradients. This would further reduce their ranges and population sizes and their habitats would be subjected to an increased fire risk. Should temperatures continue to rise for a long enough period, these species could ultimately find themselves with nowhere to go!

KwaZulu-Natal and the Eastern Cape are expected to experience higher rainfall and increasing temperatures, which might also drive species up altitudinal gradients. Tropical species may move southwards from Mozambique resulting in new species assemblages with unknown ecological consequences.

The Grassland and Savanna biomes of the Free State, Gauteng and Limpopo provinces are expected to shift eastwards, and the frog species will also probably move in this direction. However, these provinces are largely transformed by agriculture, which may hamper the movement of frogs seeking suitable habitat, causing local extinctions.

HOW PREPARED ARE WE?

The importance of research and monitoring in understanding and dealing with the effects of climate change, in order to minimise its effect on species, is repeatedly emphasised in the scientific literature [31-33,37,39] and acknowledged by government.[8] A workshop held at Kirstenbosch in December 2009, carefully and systematically prioritised red-listed frog species for conservation and ecological research, specifying which aspects needed investigation and identifying individuals or institutions that would take responsibility for the research over the following 5 years.[45] The workshop also listed and prioritised threatened species and species assemblages that should be monitored and the threats that they were facing.[46] Recommendations with regard to monitoring techniques were given. The existing monitoring sites were clearly inadequate in their coverage of threatened species, species assemblages and biomes. In view of the dire shortage of trained herpetologists in South Africa, attention was also given to the question of education and capacity-building.[47]

Amphibian monitoring in South Africa currently comprises three long-term monitoring sites that are maintained by CapeNature in the mountains of the Western Cape, while a group from North-West University is monitoring the prevalence of chytrid in two high-altitude frog species in the north-western Drakensberg mountains. Other monitoring efforts are targeting species such as the Table Mountain ghost frog, the micro frog and the western leopard toad. However, all of these monitoring projects are hampered and constrained by a lack of capacity (trained staff) and inadequate funding.[46]

Although the Department of Science and Technology has undertaken to support effective observation and monitoring over the next 10 years,[8] this apparently does not include the establishment of new long-term monitoring sites for amphibians. Also, none of the field centres (nodes) established by the South African Environmental Observatory Network (SAEON) for long-term monitoring of terrestrial ecosystems is monitoring amphibian populations.

Fig. 6. Giant bullfrog, Pyxicephalus adspersus*, attacking an intruder.*

CONCLUDING REMARKS

It is clear that a need exists for dedicated funding to establish and maintain new, long-term monitoring sites for amphibians in South Africa, and that the *'Observation of biological and ecological changes and their attribution to climatic change as distinct from other drivers is in its infancy in South Africa, and Africa as a whole.'*[8] It is essential that such sites be established without delay if we wish to 'confirm the impacts of measured climate shifts and to gauge the sensitivity of species and ecosystems to their impacts,[8] and to detect declines in time to avoid the loss of our threatened frog species.

Declaration of conflict of interest

The author declares no conflict of interest in respect of the content of this article.

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