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Conserving the unique to save the diverse — Identifying key environmental determinants for the persistence of the viviparous Nimba toad in a West African World Heritage Site

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ABSTRACT

Conservation efforts should be directed to species and areas in particular need. Several concepts for conservation prioritization exist. Following appropriate measures, we determined the World Heritage Site (WHS) “Nimba Mountains” and its flagship-species, the Nimba toad (*Nimbaphrynoides occidentalis*), to be both “irreplaceable” and “vulnerable”. The biodiversity hotspot, Nimba Mountains, is a WHS “in danger”. Conservation efforts are needed to ascertain the long-term persistence of the globally unique viviparous toad and other endemic species. To set the baseline for conservation management, we focussed on the relationships between environmental variables and the current and past toad distribution. With linear, generalised linear, generalised additive and zero-inflation models we analysed the toads' distribution and range limits. Our results show that weather conditions limit the toads to higher elevations. Water impermeable geologic layers seem to be inevitable for adequate dry season dormancy sites, thus being the main factor predicting the patchy aboveground wet season distribution. This emphasises the importance of temporally used (non-breeding) environments. For conservation planning, we thus advise distribution models to include all habitats used by focal species. Human activities may further impact a species' abundance and distribution. Herein, we hypothesised that increased fire frequency and anthropogenic habitat alteration in the recent past changed overall habitat characteristics and thus resulted in decreasing toad numbers and an altered range size. Our ecological models indeed better predicted the past compared to the current toad range. This emphasises the importance to consider recent historical developments, before drawing conclusions from current distribution pattern in a conservation context.

1. Introduction

The preservation of biological diversity is now a well-established goal on the international agenda (CBD, 1992). Nevertheless funds are limited and conservation efforts thus need to be prioritised (Arponen, 2012). Decisions are often based on measures of “irreplaceability” of a taxon or ecosystem in relation to its “vulnerability” (Brooks et al., 2006). For areas, one measure of “irreplaceability” is the concept of “outstanding universal value”, as is used for the definition of World Heritage Sites (WHS, UNESCO, 2015b). Here a measure of “vulnerability” would be if a WHS is considered to be in danger. The concept of evolutionary distinct units is often used to measure the “irreplaceability” of species (Arponen, 2012). Prominent examples are the “living-fossils” *Latimeria* (coelacanth) or *Sphenodon* (tuatara), but more often simply numbers of species per genus (Arponen, 2012) or phylogenetic branch lengths are considered (Safi et al., 2013). To define species' “vulnerability” the IUCN provides precise red list categories (Stanton et al., 2014).

Another concept to prioritise where funding should or needs to go is to link species traits with threat and probability of decline. In mammals, small range size and large body size are the most important traits determining vulnerability (Purvis et al., 2000). In amphibians, species with small ranges have higher extinction risks than species with large ranges, as fewer and/or smaller populations are more prone to suffer from stochastic processes than many (meta-)populations. Moreover, range restricted species are often habitat specialists (Cooper et al., 2008; Hero et al., 2005; Sodhi et al., 2008). In the absence of diseases seven species traits were linked to increased decline and extinction risk (Cooper et al., 2008; Sodhi et al., 2008). Those traits comprise small range size (Sodhi et al., 2008), four life history traits (large body size, small clutch size, low dispersal ability, habitat specialisation), and two characteristics of the species' environments (low mean annual temperature and precipitation seasonality, Cooper et al., 2008; Sodhi et al., 2008). Amphibians with an exclusively terrestrial reproduction usually have small range sizes and few offspring (e.g. the Cuban *Eleutherodactylus cubanus* with

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single egg clutches, Edges & Gonzalez, 1995). They likewise often show high habitat specificity, e.g. the dependency on spray in *Nectophrynoides asperginis* (Channing et al., 2006).

Species distribution models are widely used to determine species' ranges and ecological needs and thus provide crucial data for conservation. Depending on the scale, the location and the species, climate, topography or habitat might differ in their specific importance for a species' distribution (Peterson, 2006). Authors assume that climate is more important on large, coarse scales and habitat on small, fine scales (Pearson & Dawson, 2003). Animal groups may use different environments at different life stages (e.g. aquatic larvae, terrestrial adults). Studies examining amphibian occurrences for example often focuss on breeding (-pond) habitats (Curado et al., 2011). However, that non-breeding terrestrial environments are important for a population's survival is widely acknowledged (e.g.: Regosin et al., 2005; Roznik & Johnson, 2009). Challenges for the interpretation of modelling approaches might be (anthropogenically induced) historical changes of environments and thus modelling results inconsistent with current distributions (Greve et al., 2011).

Consistent with the abovementioned classifying approaches of "irreplaceability" and "vulnerability" the West African Nimba toad (*Nimbaphrynoides occidentalis*) shows most of the determining characteristics. It is "Critically Endangered" (IUCN, 2014) and endemic to the high altitude grasslands of the Nimba Mountains (Lamotte, 1959), a WHS in danger (UNESCO, 2015a). The toad is not only the single species in its genus (Sandberger et al., 2010), but the only known anuran with a matrotrophic (mothers nourish their young during the gestation) and pueriparous (fully developed juveniles are born) reproductive mode (Angel & Lamotte, 1944). Its globally unique reproduction made it the main argument for the Nimba Mountain's declaration as a World Heritage Site (UNESCO, 2015a), and thus the flagship species for any conservation action in the area. The Nimba toad exhibits six of the seven species traits which are associated with decline and extinction risk in amphibians (see above); i.e. it has a very small range (Hillers et al., 2008), few offspring (Angel & Lamotte, 1944), assumed low dispersal ability, and high habitat specificity (Lamotte, 1959), and its environment shows a pronounced seasonality (Leclerc et al., 1955). Hence, Nimba toads and their entire environment, including numerous further narrow range endemics, should be prioritised by conservation efforts.

The three largest threats to the WHS and *N. occidentalis* are mining concessions, the presence of large numbers of refugees (with increasing pressure on the WHS) and weak management capacities (IUCN, 2016), all together resulting in past, current and probably future anthropogenic induced habitat alterations. Determining the environmental factors influencing the presence and abundance of the Nimba mountain endemics is thus important for effective future conservation management. *N. occidentalis* has a consistent lower elevation boundary at 1200 m asl, and a quite consistent and patchy range (Hillers et al., 2008; Lamotte, 1959). It might thus be a good indicator for the endemic biota of the mountains, confined to the high altitude grasslands. Evidence is accumulating, that terrestrial habitat use in amphibians is crucial for successful conservation actions, but often enigmatic (e.g.: Vuorio et al., 2015). Due to their viviparous reproduction, all life-stages of the Nimba toad use the same habitats and allow for determining important characteristics for amphibians in terrestrial habitat. We therefore assessed the correlation of the toads' occurrences and abundances with the respective environmental parameters. As range and abundances of the toad have been recorded since the 1940th (summarized in Lamotte & Sanchez-Lamotte, 1999 and Hillers et al., 2008) the species also offers an opportunity to track and interpret environmental change in the recent past. We herein hypothesised that i) weather variables differ above and below the lower elevation boundary of *N. occidentalis*, but ii) habitat models should correlate better with toad presence and abundance in comparison to weather and geographic models, and that iii) abundance, but not distribution, should differ between the two time periods, as the historical changes (large mining exploration in the 1960s, increased fire frequency and hunting) should have affected the entire mountain chain.

2. Materials and methods

2.1. Study area

The West African Nimba Mountains extend over three countries: Guinea, Liberia and Ivory Coast (7.71° to 7.40° N; 8.61° to 8.32° W). The mountain chain, approximately 40 km long and 8 to 12 km wide, consists of a southwest–northeast oriented, undulating main ridge (altitude between 1400 and 1650 m asl), which bifurcates in the North (Leclerc et al., 1955). The main rock comprises banded iron formations (Billa et al., 1999) which are of high global economic importance (Berge, 1974). At lower elevations the mountain chain is dominated by either savannahs or rainforests. Particularly in the South and along ravines in the North, rainforest may reach high altitudes, but at most high altitudes montane grasslands dominate (Fig. 1, Poilecot & Loua, 2009). The presence of Nimba toads, chimpanzees and a rich and endemic fauna and flora led to the declaration of the Nimba Mountains as a World Heritage Site (WHS) in Guinea in 1981 and Ivory Coast in 1982 (UNESCO, 2015a). Due to mining exploration activities the WHS has been listed as in danger since 1992 (Poilecot & Loua, 2009; UNESCO, 2015a). In 2014 its outlook was considered to be "critical" (IUCN, 2016). Our study was restricted to the Guinean part of the Nimba Mountains, thus excluding the Liberian subspecies of the Nimba toad (Sandberger et al., 2010; Fig. 1). This was due to the fact that i) the habitat of this population was already altered (mined) at the time of its description (Xavier, 1979), and ii) the lack of exact previous abundance and distribution data.

The areas' climate is characterised by first rains in March/April, a rainy season from May to October and a dry season from November to February. Mean yearly temperature is 25 °C in the lowlands (550 m asl) and 19–20 °C at high altitudes (Leclerc et al., 1955). Mean annual precipitation is 2093 mm, but is estimated to range from 1500 mm in the lowlands to 3000 mm on the ridges (Lamotte, 1959). In West Africa, regional climate is mostly influenced by a south-western monsoon during the rainy season. In the dry season the Harmattan, a dry north-easterly wind originating in the Sahara, is dominating. In the inter-seasons, both winds influence the climate (Leclerc et al., 1955). The topography of the Nimba Mountains is responsible that these winds impact different mountain sites differently. Additionally, the climate on complex terrain, on small and large scale, is influenced by thermally driven winds, e.g. slope flows, valley flows and mountain plain flows (Zardi & Whiteman, 2013). All these winds interact with each other and with regional winds (as the monsoon and Harmattan). As we expect that climatic differences are important for Nimba toad presence and abundance we aimed to implement climatic data into our models. Unfortunately respective climate models are not available for our site with the needed resolution. Therefore, we had to use weather data recorded on the sampling locations. However, it is important to keep the regional climatic systems in mind while interpreting the modelling results.

2.2. Study species

The small terrestrial Nimba toad, *N. occidentalis* (Angel, 1943) is endemic to the Nimba Mountains and the only known truly viviparous anuran, with small yolk-poor eggs, matrotrophic tadpoles and birth of fully developed toadlets (for details see e.g.: Angel & Lamotte, 1944). It is active above ground during the rainy season and changes to an underground and presumed inactive life during the dry season (Lamotte, 1959). It emerges with the first rains and in June, when rain becomes more permanent, 4–17 toadlets per female are born (Angel & Lamotte, 1944). The mating season is from September to November.