“AMPHIBIAN BIODIVERSITY IN TAITA HILLS, KENYA”

Dissertation

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CONTENTS

1 GENERAL SUMMARY

Species richness varies greatly across geographical regions along latitudinal and altitudinal gradients. Eastern Arc Mountains (EAM) of Kenya and Tanzania is one of the global biodiversity hotspots due to the high concentrations of endemic species of flora and fauna. Despite this, high species diversity the explanatory factors have remained largely unexplored. Herein, this study first investigated the regional amphibian species richness patterns in the EAM and particularly the reasons for the low richness in Taita Hills. It examined whether the low richness is due to past forest loss or generally is due to its unique geographical location and low rainfall regime. Regression results demonstrated that the regional species richness pattern was influenced largely by mean annual rainfall, an indirect measure of primary productivity. Remaining forest area did not significantly explain amphibian species richness in the EAM. Results of cluster analysis showed a Taita Hills amphibian assemblage distinct from the other blocks. Therefore there is no evidence that the low Taita Hills amphibian species richness is due to anthropogenic forest loss.

Secondly, using the 26 currently recorded amphibians in the Taita Hills, it investigated the relationship between amphibian species composition along anthropogenic habitat disturbance and elevation gradients. It tested the hypothesis that sites with similar environmental characteristics (temperature, rainfall and elevation), in close proximity and with similar disturbance levels (habitat types) harbour similar species composition. It was found that amphibian species richness differed among the three habitat types (forests, plantations, farms) with clear distinct species assemblages in terms of elevation. This was explained by both temperature and rainfall well known surrogates of primary productivity with high species richness at low to mid-elevations and a decrease at high elevations. Generally amphibian species richness decreased with increasing elevation and habitat disturbance from forests to plantations. Reproductive mode guild richness *e.g.* direct developers decreased with increasing disturbance from forests to farms while open site breeders exhibited the opposite trend. This is a reflection of their varying natural history characteristics and their response to habitat change. Therefore there is evidence that sites with similar environmental characteristics, disturbance levels and in close proximity geographically have similar amphibian composition. These results suggest that in montane ecosystems, water and energy directly or indirectly via plant productivity represents the primary predictors of amphibian species richness.

Thirdly, diagnostic characters, distribution, basic life history characteristics and conservation status of all currently known amphibians in the Taita Hills were provided. Both global and local conservation status of a number of species was revised in light of the current study. Notable cases were Taita Hills' endemic *Callulina* sp proposed to be categorised as Critically Endangered (CR) B1a&b(ii,iii) and *Boulengerula taitana* as Vulnerable (VU). B2a&b(ii,iii) This was necessitated by the continuous need to acquire more information to address the global amphibian populations decline at the local scale.

Finally, the first long term life history, population and ecological characteristics of an endemic Taita Hills brevicipitid frog (*Callulina* sp) was provided and examined how the information can be exploited towards the conservation of the species and its habitat. This species medium size terrestrial and arboreal frog was found to be restricted to high altitudes above 1400 m only in indigenous forests within Dawida and Mbololo. Its abundance and distribution was found to be influenced by both mean monthly temperature and altitude but not mean monthly rainfall or forest fragment size. Consequently it was found to be abundant during the warm and/or moderately humid months and rare or absent during the cold season. It breeds during the long dry season when eggs are laid on the forest floor ground nest and brooded by the mother. Growth and development into sexual maturity is rapid and is attained in less than a year. While this frog can survive in indigenous forests patches irrespective of their size, their population viability may only be short term due to the typical low amphibian dispersal rates without connectivity *e.g.* corridors to big forest fragments. The results of this study strongly recommend the upgrading of the current protection status of all the three large indigenous forest fragments (Mbololo, Ngangao and Chawia) from trust lands to at least national forest reserve. It is also recommendes at least replanting all the plantation forests with indigenous trees to enhance the conservation of indigenous forest associated amphibians such as *Callulina* sp, *Arthroleptis xenodactyloides, Boulengerula taitana* and *Boulengerula niedeni*. In addition efforts should be made to promote through education and encourage the local people to continue preserving all indigenous forest patches including planting more indigenous trees over the exotics on their land. If all this can be achieved, the long term conservation of Taita Hills' amphibians would be realized.

2 GENERAL INTRODUCTION

Geographical variation in global biodiversity is one of the most conspicuous patterns in biology (Heaney 2001) and has intrigued ecologists and biogeographers for years (see Rosenzweig 1995, Hawkins *et al.* 2003b, Watkins *et al.* 2006). One of the oldest patterns known to occur in majority of taxonomic groups is the increase in biological diversity from polar to equatorial regions (see Willig *et al.* 2003, Brayard *et al.* 2005). The other pattern is the elevational gradient in species richness that has observed either a monotonic decrease in richness with increasing elevation or a "humped" distribution, with species richness highest near the middle of the gradient (*e.g.* Rahbek 1997, Watkins *et al.* 2006). Developing an understanding of this observed variation in species richness distribution has played a central role in biology for years (Rosenzweig 1995).

Recently, the need to document and understand species richness distribution patterns has taken a new urgency as the current threats to biodiversity have become more widely recognized (see Heaney 2001 and references therein, Willig *et al.* 2003). Modern interest has therefore focused on the factors responsible for this latitudinal and altitudinal gradient and have furthered understanding of the mechanisms that control spatial species richness patterns (Watkins *et al.* 2006). A large number of explanatory hypotheses have been proposed (Rosenzweig 1995, Heaney 2001,Willig *et al.* 2003) while new ones continue to emerge, an indication of lack of sufficient evidence to reach a consensus on primary predictors of broad-scale species richness patterns (Hawkins *et al.* 2003b). Majority of these hypotheses are interrelated and some are even surrogates for others.

The species area-relationship (MacArthur & MacArthur 1967, Magurran 1988) is one of the major proposed explanations for observed global species richness patterns. This predicts that large areas contain more individuals, habitats, and biomes than do smaller areas (Rosenzweig 1995). As a consequence of all three considerations, it harbours high species richness (see Willig *et al.* 2003). This echoes interpretations of the equilibrium theory of island biogeography (see MacArthur & Wilson 1967). However, studies have shown that area alone is not the only explanatory factor (*e.g.* Anderson 1998, Collins *et al.* 2002, Galbiati *et al.* 2005, Crist & Veech 2006) while the effects of area and habitat diversity have been found to be interrelated (*e.g.* Kohn & Walsh 1994). Habitat diversity is not independent from environmental variables such as rainfall, temperature and elevation which have been documented to influence species richness patterns through their indirect effects on habitat productivity (see van Rensburg *et al.* 2002, Sanders *et al.* 2003, Hawkins *et al.* 2003a&b). The area effect is not a sufficient predictor of species richness patterns because global species distribution is not random. In this study, I try to narrow down to the most plausible predictors of observed species richness patterns (Willig *et al.* 2003). I therefore demonstrate that the water-energy hypothesis primarily predicts broad-scale species diversity gradients. Evidence exists that primary productivity is limited by solar energy and water availability (*i.e.* water-energy dynamics) see Hawkins *et al.* (2003b). I used amphibian diversity as a model because of their abundance and richness, and being one of the integral components of many ecosystems, often being the most diverse vertebrate group (see Dodd & Cade 1998, Taylor & Jones 2002). The study tested this hypothesis using amphibian biodiversity among the Eastern Arc Mountains (EAM) of Kenya and Tanzania, (Lovett 1990) and in particular the Taita Hills of Kenya. The EAM montane forests are highly fragmented and threatened from past anthropogenic forest loss despite their high species richness and endemism (see Newmark 1998). Past studies in the EAM have examined spatial, latitudinal and altitudinal species richness patterns, *e.g.* Lovett (1999) on plants, Poynton (2003) on amphibians, Loader *et al.* (2004) on amphibians and reptiles and Poynton *et al.* (2007) on amphibians without discussing the causal factors. But Burgess *et al.* (2007) and Doggart *et al.* (2006) pointed out that the remaining forest area is a measure of EAM biodiversity conservation importance. This was however, found to be a function of survey effort with highly researched mountain blocks (*e.g.* East Usambara, Uluguru and Udzungwa) having high species richness (see Doggart *et al.* 2006, Poynton *et al.* 2007).

In Taita Hills which is the most fragmented forest block, no comprehensive study has ever been done to understand its amphibian species richness pattern. The problem is that, with this paucity of research work in majority of the blocks and lack of clear identification of the primary predictors of observed species richness pattern, the current biodiversity importance ranking of the EAM may be misleading. In view of this the study tested whether the low amphibian species in Taita Hills is due to area effect. Elsewhere in the EAM, new research work in underexplored and/or poorly surveyed areas, has shown that some blocks are more species rich than previously thought and are important for conservation investment (*e.g.* Doggart *et al.* 2006, M. Menegon pers. com.).

In Taita Hills, it therefore examined the influence of climatic variables (temperature and rainfall) on amphibian biodiversity along anthropogenic habitat disturbance and elevation gradients. The study particularly determined the influence of habitat alteration on amphibian composition given that this is one of the major causes of amphibian population declines. I further examined the basic life history characteristics of a frog species susceptible to decline. This is because some species are good bio-indicators of environmental change and the information gained greatly aid conservation prioritization and planning of the remaining habitats.

2.1 Declining amphibian populations

Declines of many amphibian species have been recorded, and many species are seriously threatened under the IUCN/CI/NatureServe Global Amphibian Assessment, GAA (www.globalamphibians.org). Declines are non-random in terms of species' ecological preferences, geographic ranges, and taxonomic associations and are most prevalent among montane, small range and stream-associated species (see Stuart *et al.* 2004). These declines are often credited to anthropogenic causes, including habitat loss and over-utilization (see Pearman 1997, Guerry & Hunter 2002, Vallan 2002, Daniels 2003, Herrmann *et al.* 2005, Gagné & Fahrig 2007) as well as habitat loss and fragmentation (Wake 1991, Marsh & Pearman 1997, Duellman 1999, Kolozsvary & Swihart 1999, Vallan 2000, Gardner 2001, Funk & Mills 2003, Pineda & Halffter 2004, Lea *et al.* 2005, Cushman 2006, Bell & Donnelly 2006), climate change (Pounds 2001, Blaustein *et al.* 2001, Carey & Alexander 2003), forest management (Renken *et al.* 2003, Vallan 2004); environmental pollution (Reaser & Johnson 1997) and the infectious disease chytridiomycosis, caused by the fungus *Batrachochytrium dendrobatidis* (Berger *et al.* 1998, Collins & Storfer 2003, Retallick 2004, Weldon *et al.* 2004). Besides these aspects, an apparent decline in abundance may be due to natural long-term population fluctuations (Wake 1991, Hedges 1993, Reaser & Johnson 1997, Duellman 1999, Blaustein *et al.* 2001, Gardner 2001, Carey & Alexander 2003, Collins & Storfer 2003, Mazerolle 2004). What can be said precisely is that global decline of amphibian populations is among other factors caused directly or indirectly by human activities (Dodd & Cade 1998). Declines in amphibian populations bear significant implications for the functioning of many terrestrial ecosystems, and may signify important implications for human welfare.

2.2 Habitat alteration and biodiversity loss

Habitat change in the form of forest loss and fragmentation are the two most important factors responsible for loss of biodiversity worldwide (Brooks *et al.* 2002, Fahrig 2002, 2003). Fahrig (2003) pointed out that the negative effects of habitat loss apply not only to direct measures such as species richness, population abundance and distribution but also to indirect ones like population growth rate and breeding.

Patch size, isolation and disturbance have effects on biodiversity. As landscapes become increasingly fragmented, animal populations in the remaining habitat patches are isolated. In particular animals with patchy distribution or those, which utilize a range of microhabitats, are especially vulnerable to losses in mosaics of habitats. Insularisation has both ecological and genetic implications and reduced genetic variability has long been recognized as a feature of small isolated populations due to inbreeding, genetic drift, and bottleneck events (Spellerberg, 1991, Beebee 2005).

Marsh & Pearman (1997) and deMaynadier & Hunter (1998) found that forest fragmentation in general has profound effects on the abundance of amphibians. Reduction in area of natural communities affects population size; fragmentation affects dispersal, leading to extinction.

Amphibian populations may easily become isolated within a fragmented landscape because amphibians have low vagility, high philopatry (strong site fidelity) and often find the matrix environment inhospitable (Wind 2000, Marsh & Pearman 1997, Gardner 2001, Cushman 2006). This isolation may consequently prevent "rescue effect" (Marsh & Pearman 1997).These characteristics in addition to their permeable thin skin, make them good bio-indicators of habitat health, condition and quality (Wake 1991, Wind 2001, Morrison & Hero 2003) and their declines is a sign of deteriorating environmental quality (Stuart *et al.* 2004).

2.3 Effects of anthropogenic habitat disturbance on amphibians

Much of observed habitat loss and fragmentation causing amphibian declines is a result of anthropogenic habitat modification and many studies have focused on its effect on amphibians (*e.g.* Marsh & Pearman 1997, Kolozsvary & Swihart 1999, Wind 2000, Vallan 2000, 2002, Vallan *et al.* 2004, Collins & Storfer 2003, Pineda & Halffter 2004, Bell & Donnelly 2006, Hillers *et al.* 2008).

Pearman (1997) observed that amphibians depending on their biological attributes might respond differently to forest fragmentation and disturbance. Some amphibians are area-sensitive (Vallan 2000, Wake 2001) indicating that they can act as potential indicators of suitable reserve size. However, many studies have found that amphibians' response to anthropogenic habitat fragmentation is influenced by the distribution of habitat features such as breeding sites (Vallan 2000, Guerry & Hunter 2000, Wind 2000). Thus the strong relationship between these habitat features may override area relations (*e.g.* wet areas for aquatic breeding species and proximity to old-growth or primary forest stands for terrestrial breeders). Changes in forest cover through fragmentation affect the local climate and thus species composition and distribution (Vallan 2000, Vallan 2002), population dynamics (Blaustein *et al.* 2001) of a landscape. The main microclimatic changes include an increase in light incidence, a decrease in soil moisture and relative air humidity and even strong winds (Vallan 2000). Physiological constraints coupled with reproductive characteristics may cause many amphibian species to be especially sensitive to local changes in climate and microhabitat (deManynaider & Hunter 1997, Vallan 2000, Neckel-Olivieira 2004).

Many amphibians have specialized aquatic and terrestrial habitat requirements, which are often in conflict with human use (Dykstra 2004). However, it is worth noting that human activity does not always generate only two types of extreme scenarios: well-conserved and highly-impoverished habitats. Rather, the anthropogenic habitats represent a gradient of transformation and these habitats have different effects on species dynamics and biodiversity (Renken *et al.* 2004, Fieldler & Schulze 2004, Pineda & Halffter 2004). For example, forest management and maintenance of biodiversity may be compatible when relatively small amounts of landscape are disturbed (see Renken *et al.* 2004). In addition, Vallan (2000) showed that amphibians are relatively resilient to low-level forest exploitation and they are apparently not affected, at least in the short time.

2.4 Thesis aims and structure

In this thesis I investigated, the amphibian biodiversity in the Taita Hills. The Taita Hills are well suited for addressing this question as their habitats are highly fragmented and exhibit both disturbance and elevation gradients.

This thesis consists of four major chapters (Chapter 3, 4, 5 and 6) that can be read concurrently. All the chapters are organized like a journal publication comprising an abstract (summary), introduction, materials and methods, results and discussion sections. Combined list of references and appendices are placed separately at the end as well as acknowledgements and my curriculum vitae. Tables and figures are inserted within their respective chapters.

In chapter 3, I examined why the low amphibian species richness in the Taita Hills in relation to other EAM against explanatory the role of forest area, rainfall, maximum elevation and distant from the Indian Ocean. I explored the applicability of mid-domain and peninsular effects. The species list data for the other Eastern Arc Mountains apart from Taita Hills was largely obtained and updated from peer reviewed literature.

In chapter 4, I investigated the change in amphibian species composition of the Taita Hills along habitat disturbance and elevation gradient. I specifically determined the influence of climatic variables (temperature and rainfall) on amphibian species richness. Data was gathered through standardized transect and pit fall trapping set up within indigenous forests, plantations and farmlands.

In chapter 5, I provided a species account of the currently known amphibians in the Taita Hills giving their distribution, natural history and provided their global and local conservation status. Data for these were collected through transect walks, pitfall traps, time-limited searches and visual encounter survey methods.

Finally in chapter 6, I provided a detailed natural history (ecological and breeding characteristics) of the brevicipitid frog *Callulina* sp by determining the explanatory role of temperature, rainfall, altitude and forest size on its distribution and abundance in the Taita Hills. I used standardized pitfall trap sampling for quantitative analysis; while data from transect and time-limited search methods was used for qualitative investigation of the species breeding characteristics and other habits.

3 IS THE LOW AMPHIBIAN BIODIVERSITY IN THE EASTERN ARC MOUNTAINS DUE TO FOREST LOSS?

3.1 INTRODUCTION

Geographical patterns in species richness have fascinated biologists for decades. Their causes have been the focus of many different disciplines, such as ecology or historical biogeography. The need to document and understand distribution patterns are important as, at the global scale, threats to biodiversity are dramatically escalating (Myers 2003). One of the fundamental hypotheses on distribution patterns is the species-area relationship (MacArthur & MacArthur, 1967, Magurran 1988, Rahbek 1997, Sanders 2002, Triantis *et al.* 2003, Bell & Donnelly 2006), whereby large areas often support more species than do small ones. This follows the interpretations of the equilibrium theory of island biogeography (*e.g.* MacArthur & Wilson 1967).

Several studies have demonstrated that area in the species-area relationship is not the only explanatory factor for species richness (*e.g.* Anderson 1998, Collins *et al.* 2002, Julião *et al.* 2003, Galbiati *et al.* 2005, Crist & Veech 2006, Öckinger & Smith 2006). The effects of area and habitat diversity have been found to be interrelated (*e.g.* Kohn & Walsh 1994, Recklefs & Lovette 1999, Morand 2000, Davidar *et al.* 2001). In addition, it can be quality not quantity (area) of a habitat that explains species richness (see Cody 1985, Davidar 2001, Schoereder *et al.* 2004, Summerville & Crist 2004, Watson *et al.* 2004, Öckinger & Smith 2006). Similarly, primary productivity exhibit positive linear relationship with and influences species richness (Sanders 2002, Hawkins *et al.* 2003b). Studies on altitudinal species turnover have also shown that the highest species richness occurs in areas of maximum primary productivity and at moderate temperatures above which species richness decreases (Sanders 2002, Sanders *et al.* 2003). Climate, especially rainfall and temperature, influences primary productivity (Hawkins *et al.* 2003a, Sanders *et al.* 2003), and both have been used as indirect measures of habitat productivity and quality (MacArthur & MacArthur 1967, van Rensburg *et al.* 2002 Sanders *et al.* 2003). Latitudinal and altitudinal species richness patterns have also been explained using two theories related to the above variables. One is the peninsular effect which predicts a decline in species richness from base to tip of the peninsula (see Means & Simberloff 1987, Wiggins 1999, Johnson & Ward 2002, Choi 2004). The other is the mid-domain effect (see *e.g.* Colwell & Lees

2000 Colwell *et al.* 2004), which predicts that, regardless of latitude, the richness of terrestrial groups should peak in the middle of a biome as a result of constraints imposed by biome boundaries.

Threats to biodiversity are highest in the tropics (Allen *et al.* 2002). In Africa, among the most threatened areas of highest biodiversity are the Eastern Arc Mountains (EAM) of Kenya and Tanzania, having experienced widespread forest loss (Newmark 1998, Burgess *et al.* 2005). They belong to one of the worldwide 'biodiversity hotspots', calculated on the basis of species endemism relative to threatened area (Myers *et al.* 2000, Myers 2003, Mittermeier *et al.* 2004). These mountains are covered with humid montane forest surrounded by dry savanna and are therefore, geo-ecologically, like 'forest islands' in a 'savanna sea' (Burgess 2005, Newmark 2006). They are old compared to neighbouring mountains and have remained under the constant climatic influence of the Indian Ocean, resulting in a unique flora and fauna. The block faulting responsible for the uplifting of the EAM is thought to have begun during the Karroo period 290-180 myr B.P. (Newmark 2002 and references therein).

While, some previous studies in the EAM have examined species richness patterns, *i.e.* Lovett (1999) on plants, Poynton (2003), Loader *et al.* (2004) and Poynton *et al.* (2006) on herpetofauna, none has focused on explanatory factors. Burgess *et al.* (2007), concurring with Doggart *et al.* (2006), suggested that the area of remaining forest on all EAM is a measure of their biodiversity conservation importance. In these studies the Udzungwa, Uluguru and East Usambara Mountains were consistently recognized as being the most important blocks for conservation. This ranking was closely correlated with the present forest area and intensity of biodiversity research work in the different mountain blocks (see Doggart *et al.* 2006). Burgess *et al.* (2007) also showed that, when corrected for remaining forest area, the Taita Hills rank higher than all other blocks in terms of single-block endemic vertebrate species.

Burgess *et al.* (2007) used combined data on the total number of endemic vertebrates (10 mammal, 19 bird, 29 reptile and 38 amphibian species). However, there is evidence that different vertebrate groups respond differently to habitat characteristics (Wind 2000, Fahrig 2002, Bell & Donnelly 2006), and therefore combined data on vertebrates may not present the most appropriate approach to making ecosystem management decisions. For instance, studies on habitat patch size and fragmentation have revealed that amphibians do not respond to area effects as greatly as other vertebrates especially in tropical forests (Wind 2000). However, they may be vulnerable to fragmentation because they have relatively narrow moisture and temperature tolerances and specific breeding-habitat requirements (Bell & Donnelly, 2006 and references therein). Birds especially are ecologically different to amphibians as their response to forest area may depend on their keystone habitat requirements (Davidar 2001, Tews *et al.* 2004). For birds increasing area may result in spatially increased number of habitat types leading to increased habitat heterogeneity and consequently increased bird species richness (Roth 1976, Tews *et al.* 2004). Mammals and birds have been more intensively studied in the Eastern Arc Mountains and their biodiversity and population dynamics are better known despite the higher diversity of amphibians and reptiles.

Herein, this study attempts to show that the amount of forest cover *per se* may not be the only explanatory variable for certain taxonomic groups, including amphibians. It tests the hypothesis that the poor species richness of amphibians in the Taita Hills is related to remaining forest area following the predictions by Doggart *et al.* (2006) and Burgess *et al.* (2007). Alternatively it is hypothesised that the Taita Hills are uniquely located geographically and climate (rainfall) predicts the observed amphibian species assemblage. Consequently it examines amphibian species richness against original and remaining forest area, mean annual rainfall, maximum elevation, distant from Indian Ocean, isolation and habitat diversity as explanatory variables. In addition, it further explores this hypothesis by estimating the shared Eastern Arc Mountain endemic amphibian species composition among neighbouring mountain blocks. This was to test the hypothesis that neighbouring mountain blocks have similar species composition and the geographical location uniqueness of the Taita Hills. Amphibians were used as the main model group because they are sensitive to rainfall patterns and some researchers have demonstrated that both their abundance (Marsh & Pearman 1997) and richness can be affected by forest area (Vallan 2000, Pineda & Hallfter 2004, Bell & Donnelly 2006). Importantly, amphibians currently make up the most species rich group of vertebrate taxa within the EAM (Burgess *et al.* 2007), and recent observations suggest that worldwide this class is more threatened and declining more rapidly than either mammals or birds due to habitat loss, diseases (*e.g.* amphibian chytridiomycosis) and global warming (Stuart *et al.* 2004, Mendelson e*t al.* 2006). Amphibians may more easily become isolated within a fragmented landscape like the

EAM since some have low vagility, high fidelity and high susceptibility to desiccation (Wake 1991, Marsh & Pearman 1997, Wind 2000, Pineda & Halffter 2004).

3.2 MATERIALS AND METHODS

3.2.1 Study area: Taita Hills, Eastern Arc Mountains

The Eastern Arc Mountains is a chain of 13 ancient, crystalline blocks, arranged as an arc, from Udzungwa Mountains in south-central Tanzania northward to the Taita Hills in south-eastern Kenya, uplifted at least 30 million years ago. They are under the direct climatic influence of the Indian Ocean, a characteristic that differentiate them from the other geologically similar forested mountains in the south (Lovett, 1990, Burgess *et al.* 2007 and references therein). The 13 mountain blocks are from north to south: Taita Hills (in Kenya), North Pare, South Pare, West Usambara, East Usambara, Nguu, Nguru, Ukaguru, Uluguru, Rubeho, Malundwe Hill, Udzungwa and Mahenge (all in Tanzania) (Fig. 3.1). Forest cover in the EAM has changed over time from continuous to fragments and vice versa (Newmark 1998, 2002) see Table 3.1. This resulted in isolated mountain forest blocks, producing what we can term as terrestrial archipelagos. The Taita Hills are the most anthropogenically severely deforested of the EAM with an estimated 98.1 % of the original forest already lost (Newmark 1998, 2002). Following the assumptions of the peninsula effect, Udzungwa Mountains (with large original forest cover and closer to other southern highland areas in Malawi) as species source area, is the peninsula base and the northernmost Taita Hills, its tip while for the mid-domain effect the central mountain forest blocks are those between Uluguru and Usambara Mountains (Fig. 3.1).

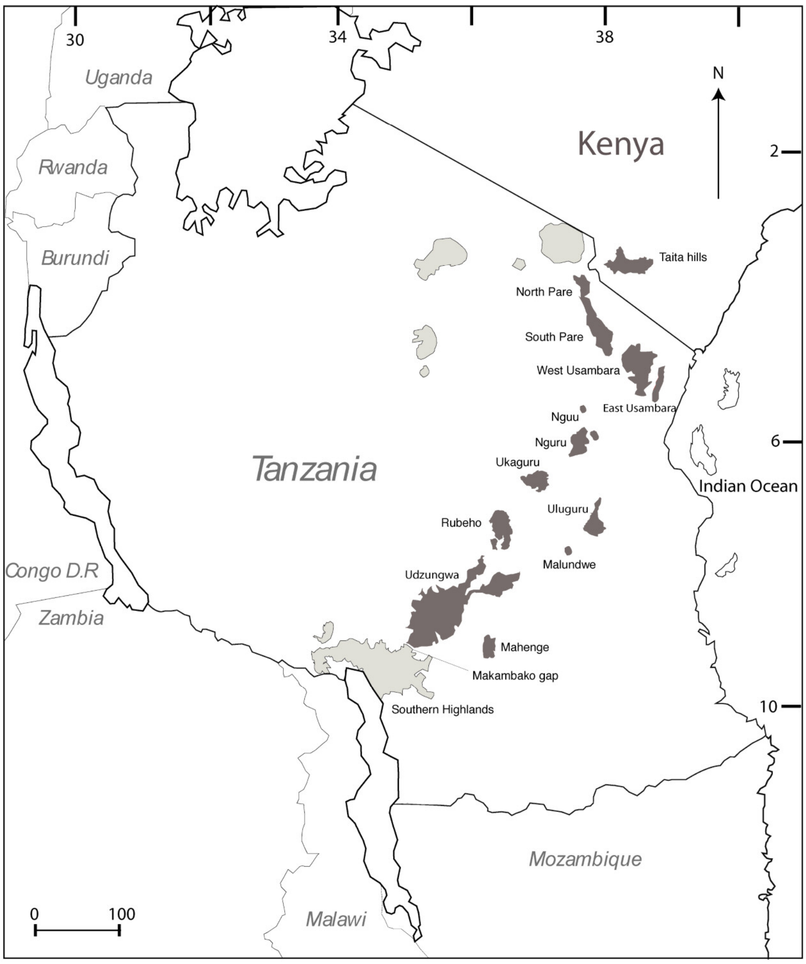


Figure 3.1: Map showing the 13 Eastern Arc Mountains (shaded black) of Tanzania and Kenya. Shaded grey are other neighbouring mountains.

3.2.2 Species data

Methods used for recording amphibians in the Taita Hills are described in detail in Chapter 4. These included opportunistic searching; night transects walks, time-limited searches and pitfall trapping (Karns 1986, Corn 1994, Heyer *et al.* 1994, Sutherland1996, Rödel & Ernst 2004, Veith *et al.* 2004). Additional species records for other EAM were taken from the literature (Howell 1993, Poynton *et al.* 2003, Loader *et al.* 2004, Burgess 2004, Menegon *et al.* 2004, Channing & Howell 2006, Doggart *et al.* 2006, Mariaux & Tilbury 2006, Poynton *et al.* 2007, Loader *et al.* 2006, Burgess *et al.* 2007, Menegon *et al.* 2007, Mariaux *et al.* 2008). Appendix 9.1 lists all known forest associated amphibian species and their known occurrences in the EAM.

Table 3.1: The numbers of EAM endemic amphibian, reptile, bird, mammal species, forest cover remaining, mean annual rainfall, location, maximum altitude, percent forest area loss of original forest and distant from Indian Ocean in the EAM. Data modified after Newmark (1998, 2002), Burgess (2005), Doggart *et al.* (2006), Tilbury *et al.* (2006), Mariaux & Tilbury (2006), Burgess *et al.* (2007) and Mariaux *et al.* (2008).

Mountain block	Longitude	Latitude	Maximum altitude above sea level (m)	Approximate distant from the Indian Ocean (in km)	Annual rainfall mean (mm)	Approximate forest area remaining (km^{2})	Loss of original forest area (%)	Single block endemic amphibians	Shared Eastern Arc Mountain endemic amphibians	Reptiles	Birds	Mammals
Taita Hills	38^{o} 20′ E	3^{o} 35′ S	2228	150	1329	4	98	3	0	2	4	0
North Pare	37^{o} 40′ E	3^{o} 45′ S	2113	170	1400	27	50	0	4	2	2	0
South Pare	37^{o} 50′ E	4^{o} 20′ S	2463	140	-	138	73	0	4	2	4	1
W Usambara	38^{o} 20′ E	4^{o} 40′ S	2200	70	2100	319	84	2	11	4	7	3
E Usambara	38^{o} 50′ E	5^{o} 00′ S	1506	40	1900	263	57	3	11	13	6	4
Nguu	37^{o} 30′ E	5^{o} 32′ S	1550	110	-	188	-	0	5	1	2	1
Nguru	37^{o} 30′ E	6^{o} 10′ S	2087	100	1700	297	82	0	9	9	3	2
Ukaguru	36^{o} 50′ E	6^{o} 28′ S	2250	170	1200	172	90	4	3	3	5	1
Uluguru	37^{o} 40′ E	7^{o} 00′ S	2630	120	3000	278	65	7	13	16	7	4
Rubeho	36^{o} 32′ E	7^{o} 00′ S	2225	220	-	464	37	1	3	4	5	1
Malundwe	37^{o} 18′ E	7^{o} 24′ S	1250	150	-	13	-	0	0	0	0	0
Udzungwa	36^{o} 00′ E	8^{o} 00′ S	2576	280	2000	1353	76	4	10	15	7	6
Mahenge	36^{o} 39′ E	8^{o} 56′ S	1040	250	-	19	89	0	2	2	0	0

3.2.3 Forest area and rainfall

The amount of forest area remaining was determined from various literature sources (see Table 3.1), and calculated original forest area from estimated percentage forest area lost given by Newmark (2002). Data on mean annual rainfall was adopted from Newmark (2002) and Doggart *et al.* (2006).

3.2.4 Species richness ranking

To rank the 13 different blocks of the EAM, richness of strictly endemic amphibians (*i.e.* single block endemics) was used first and then that of EAM endemic amphibian, reptile, bird and mammal species, as listed in Table 3.1. Second, in all statistical analysis, species richness data was corrected for area effects to reduce the potential bias that larger areas contain more species due to the species-area relationship (Rosenzweig 1995). The area effect was corrected using the function:

$$SA = S/A^z$$

where z (a constant, the slope) is the species–area exponent, S is the species richness, *i.e.* the number of species in a given mountain block, A is the remaining forest area (km^2) of the mountain block and SA is the species richness after area correction. I set $z = 0.2$ as this corresponds to empirical results for a wide variety of taxa and terrestrial ecosystems (Rosenzweig 1995).

3.2.5 Amphibian species richness and similarity estimates

Amphibian community composition and turnover was compared among mountain blocks using the Coefficient of Biogeographical Resemblance (CBR) index (Duellman 1990), calculated as:

$$CBR = 2C/(N_1 + N_2)$$

where C is the number of species in common to two areas, and N_1 and N_2 are numbers of species occurring in each area, respectively. Low similarity indicates high turnover as the index provides a range from 0 (no species in common among two areas) to 1 (totally identical set of species among two areas) (Hecnar *et al.* 2002).

This index was then used in a matrix comparison of Eastern Arc Mountain endemic amphibian species among different mountains (Table 3.2).

Community similarity from the matrix table was then grouped using single-linkage cluster analysis (a multivariate exploratory technique) that was then converted into a dendrogram using STATISTICA 6.0 software (StatSoft 2001).

3.2.6 Test and analysis methods

Non-parametric Spearman Rank correlation was used to examine the relationship between species richness and explanatory variables remaining and original forest area, rainfall, elevation and distant from Indian Ocean. This analysis test was chosen over multiple regressions due to presence of missing data on some variables. All correlation analyses were done with $\alpha = 0.05$ and the data were log transformed prior to analysis with STATISTICA 6.0 (StatSoft 2001).

3.3 RESULTS

3.3.1 Species richness response to forest area, rainfall, elevation and distant from Indian Ocean

This study detected 44 (EAM) endemic and/or forest associated species of amphibians (Appendix 9.1). Due to the absence of EAM endemic species at the time of analysis, Malundwe Hill was omitted in all analyses. However, some other mountains blocks were also omitted in some analysis due to absence of data on some variables (see Table 3.1).

Results of Spearman Rank Correlation demonstrated that the logarithm of the number of EAM endemic amphibians was significantly related positively to the logarithm of mean annual rainfall ($R = 0.86$, *d.f.* = 7, $t = 4.50$, $P = 0.0028$, $n = 9$) (Fig.3.2); negatively to distance from the Indian Ocean ($R = -0.61$, *d.f.* = 9, $t = 2.31$, $P = 0.046$, $n = 11$) and not related to maximum elevation ($R = 0.27$, *d.f.* = 9, $t = 0.85$, $P = 0.42$, $n = 11$). Consequently, there are more EAM endemic amphibians in Uluguru, Udzungwa, East Usambara and West Usambara Mountains respectively, which receive relatively high annual rainfall and/or are close to the Indian Ocean. However, EAM endemic and mountain block endemic amphibians cannot be significantly explained by either the remaining forest area (EAM endemics: $R = 0.43$, *d.f.* = 10, $t = 1.52$, $P = 0.159$, $n = 12$; mountain block endemics: $R = 0.74$, *d.f.* = 5, $t = -$

2.45, $P = 0.058$, $n = 7$) or original forest area (EAM endemics: $R = 0.53$, $d.f. = 9$, $t = 1.86$, $P = 0.095$, $n = 11$).

The number of EAM reptiles like amphibians was significantly positively related to the logarithm of mean annual rainfall and not with remaining forest area, original forest area or maximum elevation. Remaining forest area, original forest area, rainfall and maximum elevation have no significant influence on EAM endemic birds and mammals (see Table 3.2).

3.3.2 Amphibian species richness ranking

Single block endemic species richness varies from 0-7 species (Table 3.1). When corrected for remaining forest area, the Taita Hills and Uluguru Mountains exceed all other mountains in terms of single block endemic species per unit area of forest remaining (Fig. 3.3a). Similarly considering original forest Uluguru Mountains followed by Taita Hills tops the list on single block endemics (Fig. 3.3c)

The EAM endemic amphibian species richness varies from 0-20 species (Table 3.1). When corrected for area of forest remaining, Uluguru Mountains exceed the rest, while the East and West Usambara Mountains marginally exceed the Udzungwa Mountains. This also demonstrates a mid-domain effect with high species richness close to the centre of this latitudinal domain from Uluguru northward to Usambara Mountains (Fig. 3.3b).

Considering the total amphibian species richness, Udzungwa Mountains, has the highest with 64 amphibian species. Other relatively species rich blocks are Uluguru and East Usambara Mountains with 48 and 46 species, respectively. Taita Hills has 26 species, and though no complete species lists exist for intervening mountain blocks, there is a discernable peninsular effect northwards from Udzungwa to Taita.

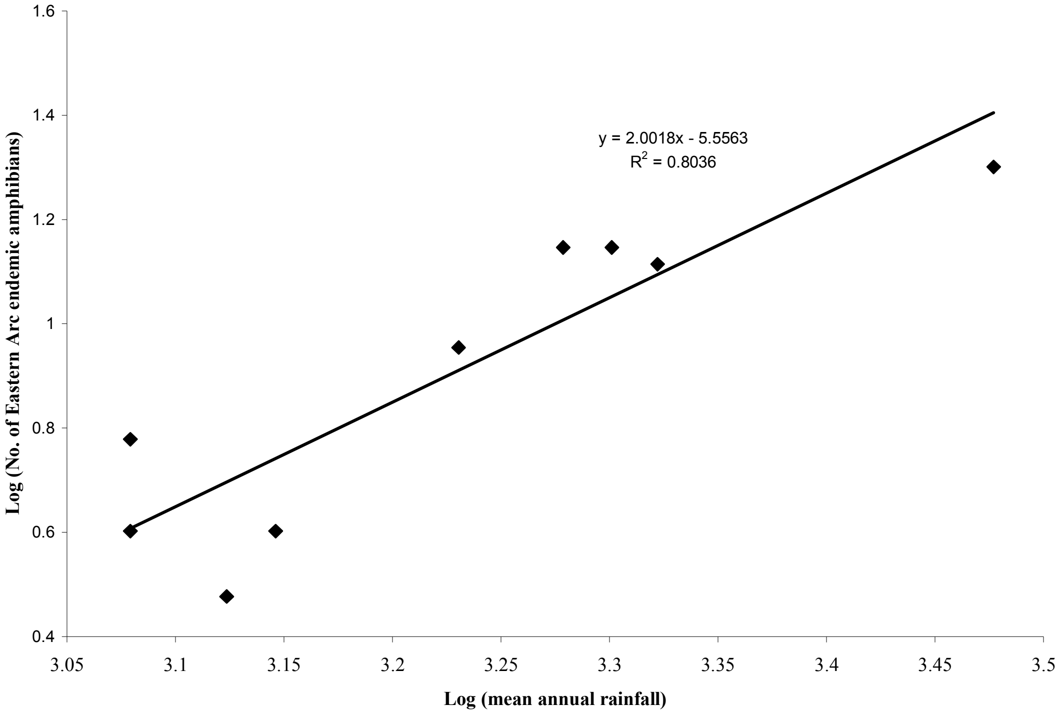


Figure 3.2: Relationship between EAM endemic species richness and annual rainfall in the nine selected Mountain blocks.

Table 3.2: Log EAM endemic species richness-Log explanatory variables correlation values (r_s) for different vertebrates in the EAM.

Variable	Amphibians	Reptiles	Birds	Mammals
Mean annual rainfall	$0.86^{t = 4.50,\ d.f. = 7****}$	$0.69^{t = 2.55,\ d.f. = 7*}$	$0.32^{t = 0.88,\ d.f. = 7ns}$	$0.32^{\mathrm{t} = 0.88,\ d.f. = 7ns}$
Remaining forest area	$0.43^{t = 1.52,\ d.f. = 10ns}$	$0.26^{t = 0.87,\ d.f. = 10ns}$	$-0.09^{t = -0.27,\ d.f. = 9ns}$	$0.70^{t = 2.21,\ d.f. = 5ns}$
Original forest area	$0.53^{t = 1.86,\ d.f. = 9ns}$	$0.28^{t = 0.88,\ d.f. = 9ns}$	$0.05^{t = 0.154,\ d.f. = 8ns}$	$0.095^{t = 2.21,\ d.f. = 6ns}$
Maximum elevation	$0.27^{t = 0.85,\ d.f. = 9ns}$	$0.12^{t = 0.36,\ d.f. = 9ns}$	$0.34^{t = 1.04,\ d.f. = 8ns}$	$0.09^{t = 0.23,\ d.f. = 6ns}$
Distant from Indian Ocean	$-0.61^{t = 2.31,\ d.f. = 9*}$	$-0.34^{t = -1.09,\ d.f. = 9ns}$	$-0.28^{t = -0.84,\ d.f. = 8ns}$	$-0.26^{t = -0.66,\ d.f. = 6ns}$

Note: r_s is the Spearman Rank-correlation coefficient (tested by two sample t-test) with (regression $df = n$-2).

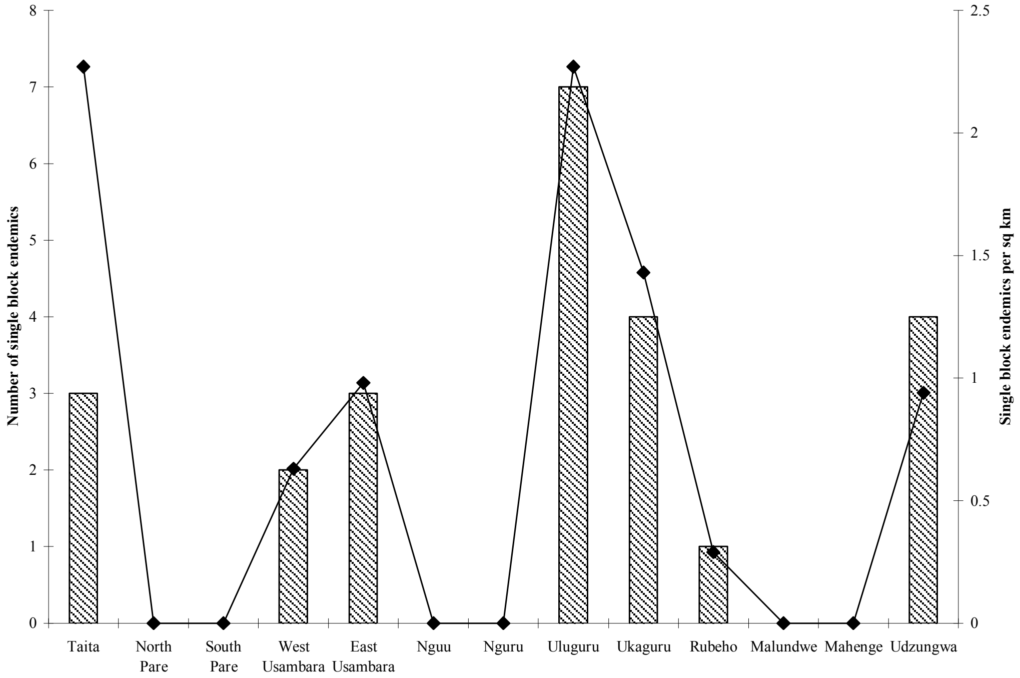
$*P < 0.05$

$**P < 0.02$

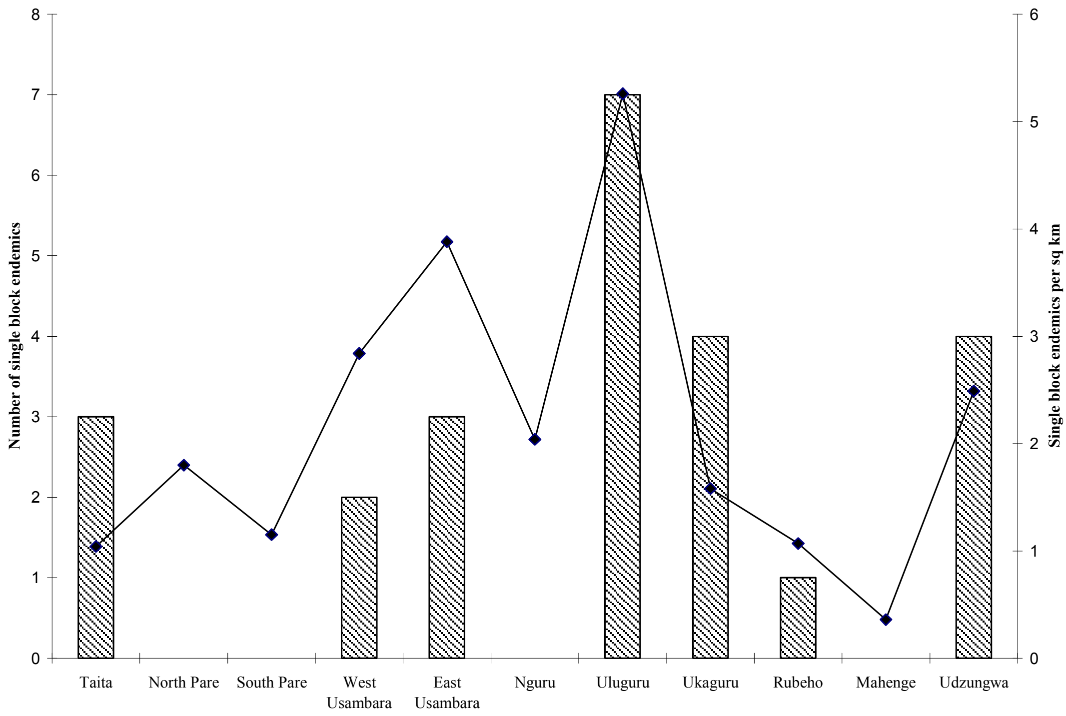
$***P < 0.01$

$****P < 0.005$

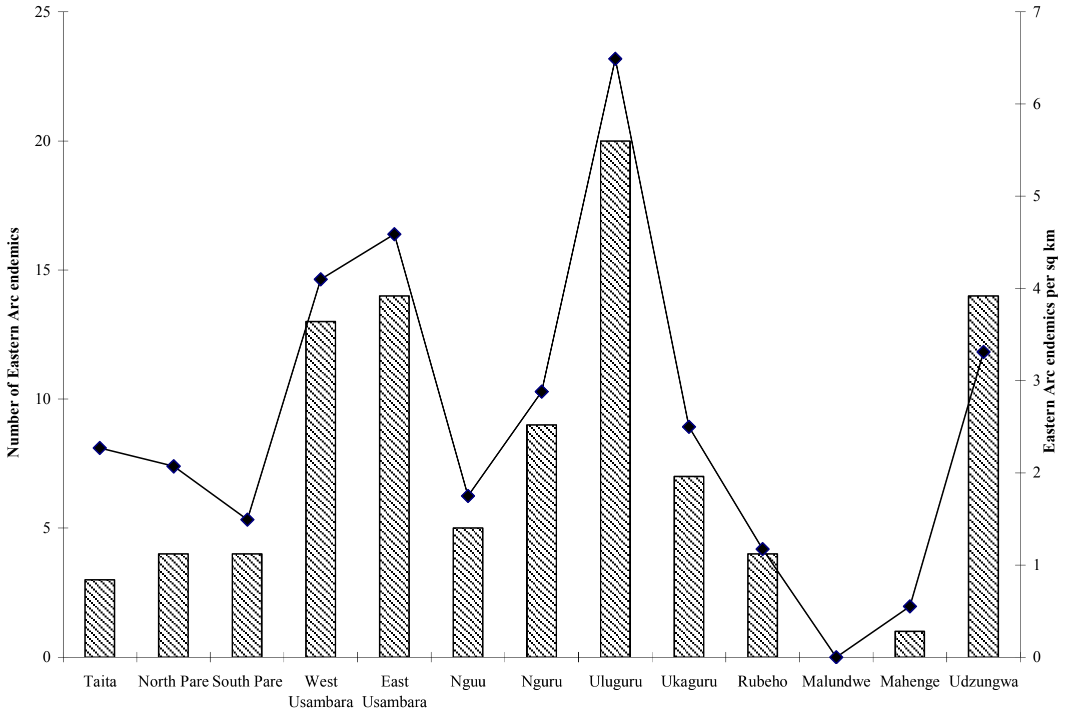
ns - not significant


Number of single block endemics
Single block endemics per sq km
0
1
2
3
4
5
6
7
8
0
0.5
1
1.5
2
2.5
Taita
North Pare
South Pare
West Usambara
East Usambara
Nguu
Nguru
Uluguru
Ukaguru
Rubeho
Malundwe
Mahenge
Udzungwa

a



b



c

Figure 3.3: Amphibian species richness ranking of the 13 mountain blocks of the EAM: (a) Single block endemic species and remaining forest area; (b) single block endemics and

original forest area (Nguu and Malundwe excluded due to absence of data on original forest area); (c) EAM endemic species and remaining forest area. Mountains are arranged (left to right) from north to south. Bars = uncorrected species data; lines with data points = species data corrected for forest area.

3.3.3 Matrix comparison and amphibian community predictability

Cluster analysis of 12 mountain blocks (those having EAM endemics) showed significant correlation between amphibian species composition and geographic distances suggesting that there is a concordance between sites with similar species and geographic proximity. This clearly clustered out Taita Hills from all other blocks (Fig. 3.4). CBR obtained from the matrix comparison are provided in Table 3.3 with Taita Hills having CBR zero with all other mountains while the CBR 0.67 between East and West Usambara Mountains is the highest.

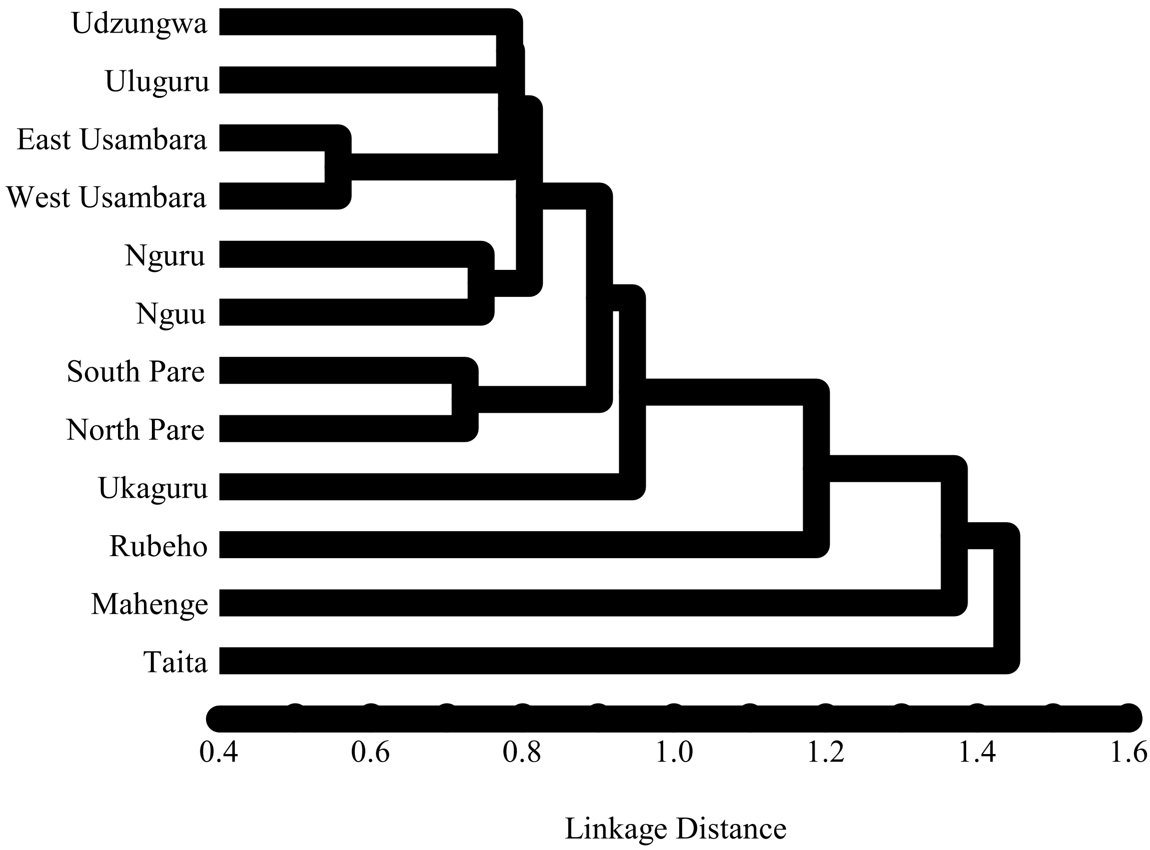


Figure 3.4: Dendrogram of EAM endemic species similarity among twelve selected mountain blocks. It illustrates the results of single-linkage cluster analysis using Coefficient of Biogeographical Resemblance, an index of community similarity calculated from the presence and absence of amphibian species. This shows that the Taita Hills have a special position among the other mountains.

Table 3.3: Coefficient of Biogeographical Resemblance (CBR) matrix obtained from comparing EAM endemic amphibians of twelve selected mountain blocks.

Mountain block	Udzungwa	Mahenge	Rubeho	Uluguru	Ukaguru	Nguru	Nguu	East Usambara	West Usambara	South Pare	North Pare
Mahenge	0.25										
Rubeho	0.11	0									
Uluguru	0.53	0.09	0.25								
Ukaguru	0.09	0	0.18	0.22							
Nguru	0.35	0	0.15	0.48	0.37						
Nguu	0.42	0	0.22	0.4	0.33	0.57					
East Usambara	0.36	0	0.11	0.53	0.28	0.43	0.31				
West Usambara	0.22	0	0.12	0.42	0.2	0.45	0.11	0.67			
South Pare	0.22	0	0.25	0.25	0.36	0.31	0.44	0.33	0.35		
North Pare	0.11	0	0.25	0.25	0.36	0.31	0.44	0.44	0.35	0.5	
Taita	0	0	0	0	0	0	0	0	0	0	0

*Malundwe Hill was excluded due to absence of EAM endemics at the time

3.4 DISCUSSION

Using endemic amphibian species data, the results from the EAM indicate that regional amphibian species richness increases with increasing mean annual rainfall. Endemic EAM vertebrate species seem to respond differently to measured variables, hence the notable variation in species number and composition among the EAM. Amphibian species richness also increased with proximity to Indian Ocean and not necessarily with maximum altitude. Species richness of birds and mammals was insensitive to both rainfall and remaining forest area. Reptile species richness, like amphibians was influenced by rainfall and not remaining forest area. Newmark, (1998) used 1994-1996 satellite imagery to generate land use and cover maps for EAM in Tanzania while in Kenya data was obtained from a personal communication. To estimate the prehistoric (2,000 years BP) forest cover, he assumed that the lowest forest boundary started 400 m higher on the leeward (western) side of each mountain due to rain shadow effect, than the windward (eastern) side. Assumed also was that for all blocks the prehistoric forest cover was unbroken and the upper plateau regions were entirely covered by forest. My results suggest that original forest area had no influence on any of the four vertebrate groups studied. This is a surprising result and may suggest that the areas calculated by Newmark (1998) are not accurate. This seems to be the case in the Taita Hills where nearly a quarter of the area lying above 1500 m has no indigenous forest as it falls in a rain shadow. The disparity in responses of the different faunal groups to the independent variables presumably reflect differences in the biology of these taxa, including dispersal qualities that influence rate of spread through the EAM and local ecological characteristics that influence the persistence of established mountain block populations. This concurs with findings by Ricklefs & Lovette (1999) on the response of faunal groups (bats, birds, butterflies, reptiles and amphibians) of the Lesser Antilles islands to habitats diversity and island area. Eigenbrod *et al.* (2008) also found varying response of anurans in Canada to road traffic and forest cover attributable to their different biological traits.

The Uluguru, East Usambara, Udzungwa and West Usambara Mountains are the most amphibian species rich blocks whereas, and when corrected for remaining forest area, Taita Hills and Uluguru Mountains exceed all others. In the following sections I discuss the various hypotheses put forward to explain the observed amphibian species richness patterns in the EAM and Taita Hills in particular.

3.4.1 The role of rainfall and forest area on amphibian species richness

Endemic amphibians' species richness across the EAM varies with mean annual rainfall and is consequently high in mountains that receive high rainfall. These findings are consistent with many previous studies on a wide range of animal and plant taxa (e.g. Siemann 1998, Heaney 2001, Hawkins *et al.* 2003a&b and references therein, van Rensburg *et al.* 2002, Sanders *et al.* 2003 and references therein, Slik *et al.* 2003, Hill *et al.* 2003, Stefanescu *et al.* 2004, Zhao & Fang 2006, Kerr *et al.* 2006). Elsewhere investigations into the reasons for this autocorrelation are limited. However, in the EAM this is plainly a reflection of the region rainfall pattern which has been shown to increase with elevation and proximity to the Indian Ocean (Lovett & Poćs 1993).

Mean annual precipitation and temperature or energy from solar radiation are indirect measures (surrogates) of net primary productivity and are highly interrelated and greatly influence species richness (see *e.g.* van Rensburg *et al.* (2002) on birds and Sanders *et al.* (2003) on ants. Water (rainfall) drives plants productivity together with energy from solar radiation and both control species richness in warm tropical climates (see Hawkins *et al.* 2003b).

Presumably the strong endemic amphibian richness relationship with rainfall is because they are relatively more aquatic in their habits and moisture dependent than for example reptiles (Hecnar *et al.* 2002). Amphibians need to keep their skin moist to allow gaseous exchange and depend on external heat to regulate their internal temperature (Duellman & Trueb 1994). In addition eggs of direct developing species require humid conditions to avoid desiccation (see Pineda & Halffter 2004). Following predictions of the island biogeography theory by MacArthur & Wilson (1967), more species survive in a larger area because populations in large areas are large enough to make extinctions less likely and that larger areas contain the specialist species of a greater number of habitat types. Therefore, increased area may mean increased habitats for species co-existence (see Kohn & Walsh 1994 and references therein). However, in the EAM both original and remaining forest area did not explain the observed amphibian species richness after area correction. This suggests that original and subsequent forest loss has no significant influence on current amphibian species richness. Therefore for some species the presence of specific micro-habitats is more important than the present area size. This relates to the 'keystone structure' concept which is defined as a distinct spatial structure providing resources, shelter or goods and services crucial for a species as a measure of habitat heterogeneity-species diversity relationship adopted by Tews *et al.* (2004). Habitat specialization as suggested by Ricklefs & Lovette (1999) and as it appears to apply for amphibians in the EAM tend to make species richness more sensitive to habitat diversity and perhaps less sensitive to area *per se*. On faunal groups of the Lesser Antilles island archipelagos, Ricklefs & Lovette (1999) suggested that species vagility may reduce the effects of area on species richness and found that endemism did not parallel the slope of species-area relationship with the less vagile reptiles and amphibians exhibiting very high endemism. This concurs with the EAM extremely high amphibian endemism which also does not show any correlation with mountain block area.

3.4.2 Amphibian species richness ranking

From these results, Uluguru Mountains have both the highest number of single block and EAM endemic amphibians while after correcting for area effects, the Taita Hills matches the Uluguru Mountains with reference to single block endemics richness per unit area. This agrees with findings by Burgess *et al.* (2007) on combined vertebrate species richness. For instance it harbours 45 % of all the EAM endemic amphibians. Complete amphibian species lists for all 13 EAM are still lacking, and identification of cryptic species still ongoing and this may in future change the current ranking. For example, with more field surveys and taxonomic work in unexplored and poorly researched blocks such as Malundwe, Mahenge, Ukaguru, Rubeho, Nguru, Nguu, South and North Pare. Otherwise the current biodiversity importance ranking order of Uluguru, East Usambara, Udzungwa and West Usambara Mountains is strongly correlated with research efforts but not necessarily area (see Doggart *et al.* 2006, Burgess *et al.* 2007). New research has made some mountains (notably Nguru, Ukaguru and Rubeho) increasingly important for conservation investment (see Doggart *et al.* 2006).

The observed support for the mid-domain effect –MDE (Colwell & Lees 2000) on EAM endemics seem to be correlated to their closeness to Indian Ocean and indirectly relate to rainfall. The observed peninsula effect northwards from the species rich Udzungwa

Mountains is due to its link with other southern highlands including those in Malawi. However, both MDE and peninsular effects are not independent from other species richness explanatory variables (habitat diversity and rainfall) and these observed patterns may change with future taxonomic research.

3.4.3 Amphibian community predictability and the uniqueness of Taita Hills

The results of cluster analysis revealed clear pairs and groups of mainly geographically close mountain blocks reflecting amphibian species sharing and clearly separated Taita Hills from the rest. For example the closest pair was that of East and West Usambara Mountains easily explained by their proximity. However there were also high CBR between distant blocks such as East Usambara and Uluguru Mountains suggesting more recent connection and species exchanges *e.g.* via forest corridors. These findings are almost consistent with those of Poynton *et al.* (2007), in their comparison of total forest-associated amphibian species among East Usambara, Uluguru and Udzungwa Mountains. Otherwise studies have shown that two areas may share the same species not because they are similar in area and/or in habitat diversity, but because they are geographically close allowing easy species movement and exchange (see Morand 2000). For example, dispersal of small leaf-litter frogs (*Arthroleptis xenodactyloides*) between neighbouring mountains in the Taita Hills has been shown through a genetic study (Measey *et al.* 2007).

The unique separation of Taita Hills from the rest is not a result of Euclidean geographical isolation since they are not the most distantly isolated from their neighbouring EAM. Elsewhere studies on island archipelagos have found a high degree of species nestedness as a result of area and not isolation (see Hecnar *et al.* 2002). Considering EAM as a terrestrial archipelago, I underscore the high degree of species sharing among them, though it might also be due to incomplete species taxonomy. Similar to formation of typical archipelagos, the forest in the EAM was prehistorically continuous over 2000 years BP (Newmark 1998 and references therein), and were disconnected (shrinking into isolates) at different times. Therefore the current amphibian composition similarity reflects the varying periods when various forest blocks lost their connectivity. Consequently, Taita Hills appear to have been isolated while the others shared connectivity. For instance, some of the EAM might have exchanged species through riverine forest *e.g.* shared drainage systems and/or coastal forest connection (see Hochkirch 2001, Measey *et al.* 2007).

The stable climatic regime of the EAM relative to the surrounding areas promoted allopatric speciation into new species due to isolation in terms of time and not distance following Janzen (1967) hypothesis why mountain passes are higher in the tropics. Therefore, it is likely that the now mountain block endemics represent species that were initially widespread across the EAM while alternatively its likely that some of the now shared EAM endemics are cryptic mountain block endemics. Phylogenetic studies *e.g.* those by Loader *et al.* (2004) on microhylids frogs, Hochkirch (2001) on flightless grasshoppers and Stanley & Olson (2005) on an EAM endemic shrew form good basis for explaining biogeographical patterns. For example Loader *et al.* (2004) on their phylogenetic analysis of microhylids, hypothesised that climatic fluctuations repeatedly isolated (and reconnected) EAM forests over the last 2.8 Myr driving speciation. I suggest that in future phylogeographical reconstruction and evolutionary dating (molecular clock) of for example EAM endemic brevicipitids, which occur across majority of the blocks, may shed some light on the role of physiological isolation.

An alternative hypothesis for the paucity of EAM endemics in the Taita Hills is that natural catastrophes such as the eruption of the recent volcanic Chyulu Hills about 70 km north of the Taita Hills; eruptions thought to have been ongoing for the last 1.4 Myr with the last around 1885 (Haug & Strecker 1995). Mt. Kilimanjaro about 80 km to the north-west is of recent Holecene origin (the exact time of its eruption is unknown; Downie & Wilkinson 1972) and the excessive ash, sparks and heat may have impacted on vegetation and consequently on the number of the EAM endemics. The few species were later colonizers or those few that that survived within small micro-habitats. The poor EAM endemic species richness in Pare Mountains especially the North Pare Mountains may be explained with the assumption that they followed the same trend due to their proximity to volcanic Mts. Kilimanjaro and Meru (which last erupted in 1910, Dawson 1992). With reference to the

Taita Hills, this hypothesis can be tested by examining its species sharing with the nearby Ngulia and Chyulu Hills. If they happen to have high similarity, it may suggest that the shared species were the Taita Hills colonizers after the volcanic disaster. For example the reed frog, *Hyperolius glandicolor* is present in Ngulia Hills as well as in Lake Jipe and Kitobo forest-Taveta both just on the base of the Pare Mountains and its likely that the species is present in Pare Mountains.

3.4.4 Conclusions

Burgess *et al.* (2007) found remaining forest area as the main explanation for observed vertebrate species richness in their biodiversity prioritization of the Eastern Arc Mountains. In the present study their data was reanalysed and updated separately for different vertebrate species groups using a multivariate method and incorporating mean annual rainfall as a surrogate for habitat diversity and/or productivity. The results demonstrated that vertebrate species richness respond differently to the explanatory variables namely forest area, rainfall, maximum elevation and distant from Indian Ocean. Herein, it is shown that rainfall is the major explanation for observed amphibian species richness pattern. The disparity in response among taxa is due to variation in biological attributes related to vagility, habitat specialization, population density and resistance to environmental variation.

It appears that the observed species richness within each mountain block is a function of biological variables such as net primary productivity and habitat diversity.

Generally, this study emphasizes the need to incorporate a measure of habitat diversity or productivity in any appraisal of the species-area relationship. It also stresses the need to include all possible explanatory variables (*e.g.* rainfall, temperature, elevation, geographical distances between pairs (isolation), and area) in one multivariate analysis while searching for patterns in floral and fauna species richness among the geographically related EAM. For example Morand (2000) suggested that geographical distance between areas should be treated in the same manner as phylogenetic distances among species.

Results of this study indicate that climate, and in particular mean annual rainfall, influences regional amphibian species richness in the montane forests of the EAM and that there is no evidence that the low species richness in the Taita Hills is due to forest loss.

3.5 SUMMARY

The Eastern Arc Mountains (EAM) is a well-known global biodiversity hotspot with a rich amphibian fauna, but the Taita Hills (the northern-most block) is comparatively species poor. To better understand the reasons for this, this study tested the hypothesis that the low amphibian species richness in Taita Hills is either due to past forest loss or its unique geographical location by examining the relationship between amphibian communities, forest area, rainfall, elevation and distant from Indian Ocean in all EAM. The amphibian data were compared to other vertebrate species (reptiles, birds and mammals). Vertebrate species lists and the explanatory variables were compiled from published accounts and my own field data. Regression analysis demonstrated that the current observed patterns of amphibian species richness among the EAM significantly increased with mean annual rainfall, a surrogate for habitat productivity. Forest area (original and remaining) was not significantly correlated with amphibian species richness. However, the influence of forest area and rainfall varied in other vertebrates attributable to their different biotic characteristics and habitat requirements. There was also some support of mid-domain and peninsular pattern of species richness largely explained by rainfall. Cluster analysis revealed and supported a unique Taita Hills amphibian species assemblage distinct from that of the other EAM. Therefore there is no evidence that the low Taita Hills amphibian species richness is due to forest loss. These results suggest that in EAM, rainfall and not forest area is the primary predictor of amphibian species richness. However, the inconsistent influence of forest area and other variables across other vertebrates suggests that it is inappropriate to analyse different vertebrate taxa together.

4 AMPHIBIAN SPECIES DIVERSITY ALONG ELEVATIONAL AND HABITAT DISTURBANCE GRADIENTS

4.1 INTRODUCTION

Species diversity is distributed heterogeneously among habitats, landscapes and regions (Crist & Veech 2006). Developing an understanding of this most conspicuous geographical variation has played a central role in community ecology for a century and half (see Heaney, 2001 and references therein). In recent years, the need to document and understand patterns of biological diversity has become more urgent than ever as the current threats have become more widely recognized (Heaney 2001, van Rensburg *et al.* 2002, Cleary *et al.* 2004, Nogueira *et al.* 2005). Determining the factors that influence community diversity remains one of ecology's most persistent and controversial issues (van Rensburg *et al.* 2002).

Habitat loss and fragmentation is one of the major threats to biodiversity (Fahrig, 2003; Ross *et al.* 2002, Kupfer *et al.* 2005, Taberelli & Gascon 2005, Ewers & Didham 2006, Cayuela *et al.* 2006, Bell & Donnelly 2006). Consequently, throughout the world, previously extensive tracts of natural habitat now exist as isolated fragments scattered across inhospitable landscapes (see Benedick *et al.* 2006 and references therein). This is evident in tropical regions, where remnants of forests exist within agricultural or urban landscapes, resulting in the remaining forest patches supporting increasingly isolated populations of forest dependent species (see Raman 2006, Benedick *et al.* 2006 and references therein). In tropical areas, amphibian studies have mainly focussed on species diversity and richness, with some conducted in fragmented environments (*e.g.* Marsh & Pearman 1997, Vallan 2000, Pineda & Halffter 2004, Neckel-Oliveira & Gascon 2006, Bell & Donnelly 2006, Cushman 2006). Habitat loss and fragmentation is usually a result of anthropogenic disturbance, and many studies have focussed on its effect on biodiversity (*e.g.* Marsh & Pearman 1997, Kolozsvary & Swihart 1999, Wind 2000, Vallan 2000, Pineda & Halffter 2004, Ernst & Rödel 2005, Hillers *et al.* 2008). For example, many forest-dependent species have been shown to be detrimentally affected by habitat loss and degradation, and there are cases of species going locally extinct when forest fragments are either too small or too degraded to support viable populations (see Watson *et al.* 2004 and references therein). Habitat loss and fragmentation does not affect all amphibian species equally (Vallan 2002, Pineda & Halffter 2004), and the most affected are rare species, species with low dispersal abilities, large area requirements, low fecundity, low population densities, abundance or high population variability, habitat and food specialists, (Bell & Donnelly 2006 and references therein).

Mid-domain effect (MDE, see Colwell & Lees 2000, Colwell *et al.* 2004), predicts that, regardless of latitude, the richness of terrestrial groups should peak in the middle of large, isolated biomes to which they are endemic, as a result of the constraints imposed by biome boundaries. Recently, attention has been given to variation in species richness in non-fragmented habitats, especially along elevation gradients exploring the applicability of the MDE (*e.g.* Rahbek 1997, Romero-Alcaraz & Ávila 2000, Sanders 2002, Sanders *et al.* 2003, McCain 2004, Krömer *et al.* 2005, Carpenter 2005, Navas 2006).

Numerous hypotheses exist to explain elevational species richness patterns. However, many are neither mutually exclusive nor independent (Heaney 2001). Most diversity hypotheses attempt to explain entire gradients based on factors such as productivity, habitat complexity/ disturbance, habitat and resource diversity, environmental stress, or competition (Heaney 2001, McCain 2004). Also climatic, biological, geographical and historical factors have been suggested as causes of variation in species richness along elevational gradients (Rosenzweig 1995, Sanders *et al.* 2003).

Recent studies on elevational species turnover in some blocks of the EAM (see Chapter 3 for the description of this biodiversity hotspot) examined only species richness without exploring the causal factors (*e.g.* Lovett 1999, Poynton 2003, Loader *et al.* 2004). The Taita Hills has the least amount of remaining forest (about 2% of the original forest) making it the most fragmented block in the EAM (see Newmark 1998). Despite having the smallest remaining forest area it has three endemic amphibians (see Chapter 5). Surprisingly, no study has examined amphibian composition at different disturbance and elevation levels in the EAM. It is essential to ascertain how amphibian communities and individual species are affected by deforestation, habitat fragmentation and modification to derive appropriate ecosystem management options. Therefore, understanding the factors that influence patterns of species richness in fragmented systems may be critical to conserving the remaining habitat (Ross *et al.* 2002).

In this chapter, I aim to asses how spatial anthropogenic habitat disturbance along elevational gradients affect the Taita Hills amphibian community and if this can be explained by environmental variables. I tested the following hypotheses: (1) Sites with similar environmental characteristics (temperature, rainfall and elevation) have similar amphibian species composition, (2) sites in close proximity have similar species composition, and (3) sites with similar disturbance levels (habitat types) are similar with respect to species composition.

Amphibians have been used as bio-indicators as they are easy to quantify and as a group may be especially vulnerable to habitat fragmentation because they have relatively narrow moisture and temperature tolerances (see Duellman & Trueb 1994). Forest habitat loss has been found to cause micro-climate alteration such as higher temperatures, lower soil and atmospheric humidity as well as increasing wind velocity (see Pineda & Halffter 2004, Ernst *et al.* 2006). Previous studies have shown that deforestation and habitat modification affect amphibian communities in the tropical forests (*e.g.* Pearman 1997, Vallan 2000, 2002, Vallan *et al.* 2004, Pineda & Halffter 2004, Bell & Donnelly 2006). In particular, species with direct development reproductive mode (*e.g.* deposit eggs on leaf) are very sensitive to changes in moisture regime, leaf litter thickness and humidity (Marsh & Pearman, 1997 and references therein)

The first aim was to test the hypothesis that amphibian species differed in their use of three distinct habitat types (forests, plantations, and farms). Studies have shown that different species compositions or guilds respond differently to habitat modification (*e.g.* Pineda & Halffter 2004). Consequently it was possible to identify specialist and generalist species and be able to understand if a response to each habitat type were species specific or if certain guilds were more influenced by their habitat modification than others.

The second aim was to test the hypothesis that climatic variables (temperature and rainfall), influence amphibian species richness and abundance. Generally, both annual rainfall and mean temperature change over elevational gradients (see Krebs 2001). Studies have shown that climate could have both direct and indirect (*e.g.* through net primary productivity) effects on species diversity along elevational gradients (Sanders *et al.* 2003). Consequently, net primary productivity should peak at elevations where there is sufficient moisture, but temperatures are not too extreme (Sanders *et al.* 2003).The physiological stress of climatic extremes, as might be found at extremes of elevation, can limit species distributions (Sanders *et al.* 2003 and references therein, Navas 2006). Understanding the climatic requirements of species plays a pivotal role in their conservation.

4.2 MATERIALS AND METHODS

4.2.1 Study area

The Taita Hills is the northern outlier of the EAM, a well known biodiversity hotspot (Myers *et al.* 2000). The Taita Hills complex consists of the main block known as Dawida c. 25km north-west of Voi town and three other blocks; Mt. Mbololo (1779 m), Sagalla Hill (1500 m), and Mt. Kasigau (1645 m) approximately 5, 25 and 50 km respectively from Dawida. Sagalla Hill, directly south of Voi, is separated from Dawida and Mbololo by the Voi River on the Tsavo plains, while Mt. Mbololo is separated from Dawida by the Paranga valley at c. 900 m. Dawida has its highest peak at Vuria (2228 m); other high peaks are Ngangao (2109 m) and Iyale (2149 m) (see Figure 4.1a&b). The three blocks rise from different altitudes depending on their location. Dawida and Mbololo rise from an altitude of about 800 m, while Sagalla and Kasigau are from altitudes of about 700 m and 600 m, respectively. Dry bushland runs up the flanks of the hills, giving way rather abruptly near the top (1000 to 2000 m) to small-holder cultivation and remnant patches of moist forest. As a result of the high human pressure on land, forest remains only as scattered fragments on hilltops and ridges (Peltorinne, 2004). Mt. Kasigau hilltop moist forest is c. 20 ha, Sagalla retains only c. 3 ha of moist forest and Mbololo c. 220 ha along the hill crest, while the main block (Dawida) has a number of tiny remnants that range in size from 1 to 92 ha, including Fururu (12 ha), Mwachora (4 ha), Macha (3 ha), Ndiwenyi (3 ha), Ngerenyi (3 ha), Kichuchenyi (2 ha), Iyale (2 ha) and Vuria (1 ha), and two larger patches: Chawia (c. 50 ha) and Ngangao (c. 92 ha) see Brooks et al. (1998). In the Taita Hills moist forest remnants total about 400 ha. Taita-Taveta County Council has approved the gazettement of all these sites as Forest Reserves for many years. However, while a number of smaller patches (including plantations) such as Macha, Mwachora, Ndiwenyi, Iyale, Kinyesha-mvua, Fururu, Kasigau, Boma and just recently Ngangao have been gazetted, major blocks like Sagalla, Chawia and Mbololo (though managed by the Kenya Forest Service) still have not. Other major non-gazetted exotic forest plantations are Mwambirwa-Rong'e, Irizi, Mwarungu, Sungululu (Shomoto) and Mraru (Kenya Forest Service, Wundanyi). Beentje (1987) estimate the indigenous forest loss since 1960s in the major fragments as 99%, 95%, 85%, 50% and under 50% for Vuria, Sagalla, Chawia, Ngangao and Mbololo, respectively, but recognized Kasigau as relatively undisturbed.

The patterns of human settlements on the Taita Hills are dependent on water availability with the main land use type in the Taita Hills being small scale intensive agriculture and forestry. It has one of the highest and ever increasing rural human population densities in Kenya (Mwagore 2005). The majority of farming activities are either on the valleys and slopes, hill tops or at the base of blocks. It is also in these areas where there are wetlands that are the preferred habitats for many amphibians. While the people on the hilltops depend on high rainfall, those at the base depend mainly on flooding from the highlands. Mean annual temperatures decrease (22 to 16^{o}C) while rainfall increases (600 to1400 mm) with elevation (Jätzold & Schmidt 1983). The remnant moist natural forests are confined to the hilltops mainly from 1300-2200 m. The majority of the hilltops and slopes in the highland areas are now covered by pine and eucalyptus plantations.

Figure 4.1a: Map showing the location of Taita Hills within the EAM. Inset a map of Africa showing the location of the Eastern Arc Mountains.

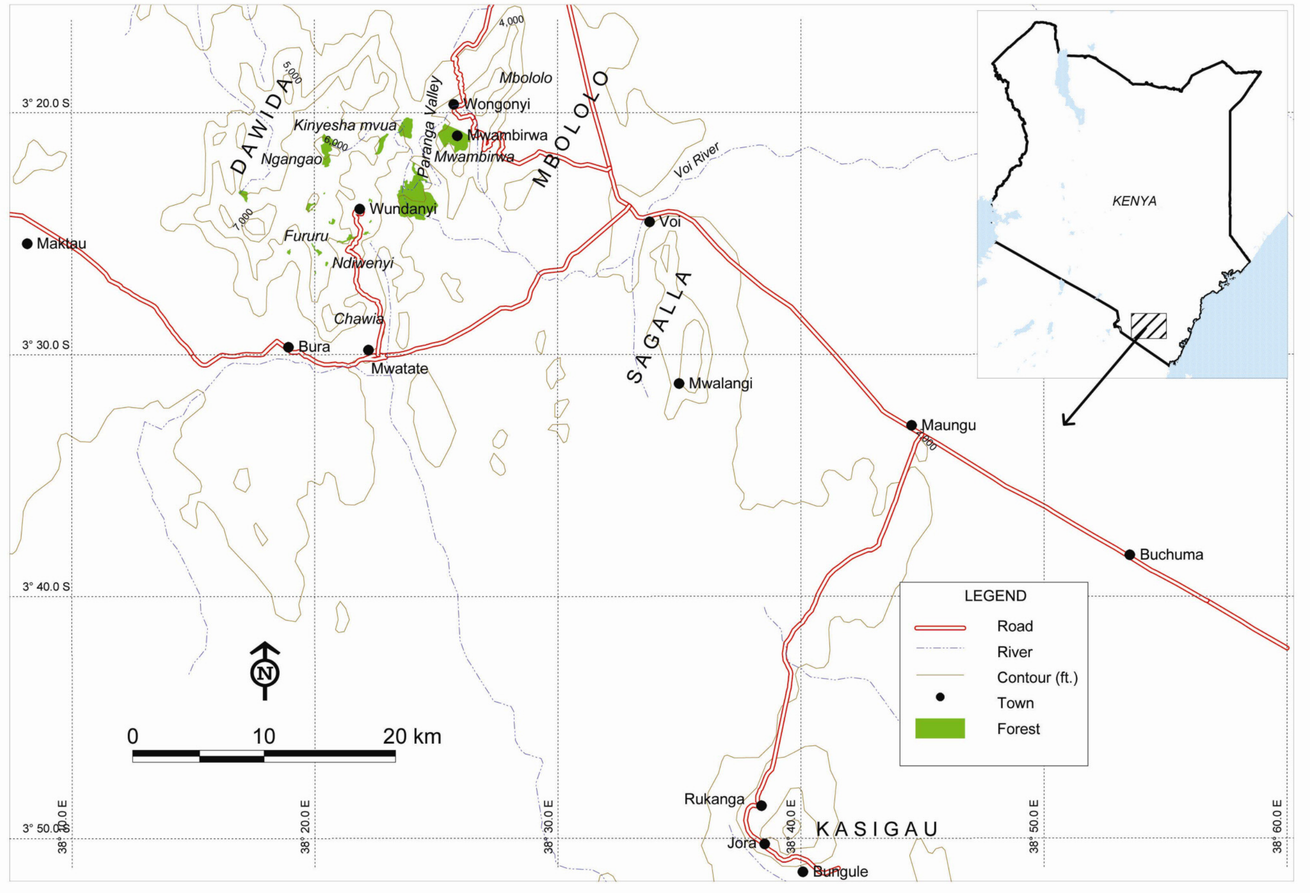


Figure 4.1b: Map of the Taita Hills showing the main block Dawida and the three isolates of Mbololo, Sagalla and Kasigau and inset a map of Kenya showing the location of Taita Hills.

4.2.2 Site description

Three main habitats (farms, forests and plantations) were selected representing different land uses at varying elevations. The forest plantations were originally mainly of exotic pine, but due to mismanagement the pine died and eucalyptus has invaded and/or continue to take-over many places. The farmlands in the highlands are intercropped with bananas, maize, beans, arrow roots, sorghum, pepper, cassava, sugarcane, irish and sweet potatoes; vegetables: cabbages, kales, spinach, onions, tomatoes and fruit plants such as citrus, avocado, mangoes, pawpaw and guava. Those farms on the lowlands are mainly dominated by maize and mango trees except where there is irrigation water like in Mwatate, in which case the crops are similar to those in the highlands.

4.2.3 Site selection

Three habitat types (altitude ranges and moist indigenous forest size in parentheses) were selected; sites below 1000 m were designated as lowland and those above as highland; sites where both transect and trapping sampling was done are asterisked: - 1. *Forests* (n = 8): Ngangao* (1700-1952 m), size 140 ha (92 ha); Chawia* (1600 -1625 m), size 86 ha (50 ha); Mwachora* (1600 -1650 m), size 6.4 ha (3 ha); Macha (1600 -1700 m), size 15 ha (3 ha); Boma, Wundanyi forest (1430 -1460m), size 0.25 ha; Mbololo* (1600 -1779 m), size 273 ha (220 ha); Sagalla* (1400 -1500 m), size 70 ha (5 ha); Mount Kasigau* (1350-1645 m), total gazetted area 202 ha natural forest (20 ha).

2. *Plantations* (n = 4): Kinyesha-mvua* (1500 -1642 m), size 50 ha; Sungululu (1450 -1562 m), size 50 ha; Mwambirwa* (1250 -1500 m), size 340 ha; Sagalla* (1350 -1500 m), size 70 ha.

3. *Farms* (n = 18): Kasigau:- Jora* (560 m), Bafwe dam (577 m) and Hezron dam (563 m); Mbololo:- Chale (1236 m); Mwalenjo, (1292 m) and Mwasange* (1309 m); Sagalla:- Marapu (651 m); Mghange (1273 m); Kauze (1081 m); Lata dam, (1064m); Mtangoni* (1100 m); Dawida:- Piringa* (1187 m); Mndangenyi (1397 m); Mbirwa (1430 m); Mghambonyi* (1546 m); Makandenyi (1647 m); Ngulu dam-Chawia (1600 m); Mwatate*, Mwatate dam (839 m) and Madungunyi-Mwatate (846 m).

4.2.4 Sampling methods

Amphibian sampling was accomplished by use of standardised transect sampling from April 2006 to January 2007 and pitfall trapping with drift fences from November 2005 to January 2007.

4.2.5 Transect design and sampling

One rectangular transect of 600 m standard length (as used by Rödel & Ernst 2004, Veith *et al.* 2004) was selected and laid out in every habitat. Transects were selected and laid in similar habitat characteristics in all sites to control for differences in species composition being masked by differences in habitat type. There were in total 30 transects in the four mountain blocks.

Along each night transect walk all amphibians observed 1 m on either side and above of the transect path were recorded. Visual and/or acoustic surveys were made (Rödel & Ernst 2004, Veith *et al.* 2004). A standard time of 1 hour sampling was spent in each transect and interrupted only when recording data. Sampling of each transect was repeated every one week.

4.2.6 Trapping with pitfall traps along drift fences

Y-shaped drift fence/pitfall trap arrays (Corn 1994) with segments of 5 m length were used. The pitfall traps consisted of 10 litre plastic buckets flush with the ground; in total, every trap had 4 buckets. Three trap sets were set in each site for five days (trapping sessions) after which they were closed and re-opened after five days. In total, there were 15 trapping sites. Checking of the traps was done once every morning not later than 0730h. Quantitatively the data could be expressed as the number of individuals per trap day (Rödel & Ernst 2004).

4.2.7 Timed limited searches (TLS)

Timed limited searches (TLS) or time constrained search-and-seize method as described by Karns (1986), Heyer *et al.* (1994); Sutherland (1996) was used. TLS were done on a habitat for one man hour and the area covered estimated. Here time is standardized and yields the number of species recorded per person-hour. During the searches all possible amphibians' microhabitats such as under leaves debris, decomposing tree stumps and logs, including digging were intensively searched. This method was particularly fruitful in detection of caecilians. It was however not used in the diversity analysis as it was not applicable to all the three study habitats especially farms.

4.2.8 Taxonomy of the specimens

Initial identification of the specimens was made using published taxonomic keys and followed taxonomy by Frost *et al.* (2006) and Frost (2007). As a reference, selected individuals were kept as voucher specimens and deposited in National Museums of Kenya (NMK). Specimens which could not be identified initially were identified by comparing them with those already deposited in NMK.

4.2.9 Species richness and amphibian similarity estimates

Magurran (1988) defines species diversity as the variety and abundance of species in a defined unit of study. In the context of this chapter, I refer to the number of different species or species richness. Three levels here are analysed α (within patch richness), β (spatial turnover among sites) and γ (landscape - among mountain blocks) diversity of amphibians (see Crist & Veech 2006 and references therein).

4.2.10 Environmental variables

To assess the explanatory power of climatic factors on amphibian species richness patterns, I examined the statistical relationship between species richness and two environmental variables (mean annual rainfall and mean annual temperature for each site). Rainfall and temperature data was gathered from daily records of minimum and maximum rainfall and temperature for the majority of the sites and then calculated the mean of minimum and maximum daily values. Where data on rainfall and temperature was unavailable it was gathered from sites as close in elevation and physical proximity as possible to the sampling sites. The polynomial interpolation was used to estimate values for these sites. Taita Hills rise from dry plains and rainfall increases with elevation while temperatures decrease (Jätzold & Schmidt 1983). Geographic location was based on GPS data, Garmin 12XL (Garmin International, Olathe, Kansas, USA).

4.2.11 Statistical methods and analysis

Watkins *et al.* (2006) quoting from other sources pointed out that generally biogeographical data are not spatially independent. Because in my study adjacent sites (*e.g.* transects sites) or those that occur at similar elevations in the Taita Hills are more likely to share species and to have similar climates than sites further apart, neither the species richness nor environmental values among them are statistically independent.

Amphibian species diversity among transect sites was measured with Shannon Index (*H'*) and 1st order Jacknife estimator. I used several procedures to compare amphibian species abundance and species richness among the three habitat types. Non-parametric Kruskal-Wallis H test was used to compare the observed total number of individuals and observed species richness by habitat type and site.

The species richness for every transect site was estimated using EstimateS 7.5.1 program (Colwell 2007). A number of species richness estimators were used – Chao 1, ACE, and Jacknife 1. Species accumulation curves were calculated and generated using the software programme EstimateS using 1000 randomizations. These were compared to the observed species curve (see Sørensen 2004 and references therein). The species richness was plotted as a function of the accumulated number of samples (transect walks). Study sites with only one observed species were excluded from the analysis.

Similarity of amphibian communities between sampling sites were calculated using Sørensen similarity index. This index is based on the probability that two randomly chosen individuals, one from each site, both belong to a species shared by both sites (but not necessarily to the same species) see Watkins *et al.* (2006). It was calculated as: $C_s = 2j/(a+b)$, where j equals the number of species shared between two sites, and a and b are the number of species in each site. The index ranges from 0, when adjacent communities share no species in common, to 1, when adjacent communities are identical.

To investigate the influence of habitat type and environmental (habitat) characteristics (temperature, rainfall and elevation) on the presence of amphibian species, I performed non-metric multidimensional scaling (NMDS) analyses. Using PRIMER 5 software (Plymouth, UK; Clarke & Gorley 2001), NMDS ordinates the resultant triangular distance matrix enabling visual assessment of the amphibian community among the sampling sites. The distance matrix based on Sørensen qualitative similarity (Bray-Curtis) index were used to provide a two dimensional summary of the similarity in amphibian species composition and to establish their ensembles according to their responses to the three habitat types (forests-plantations-farms) in the Taita Hills. NMDS was chosen because it overcomes some major weaknesses in other ordination techniques: it has greater flexibility both in definition and conversion of dissimilarity to distance; its rationale is the preservation of these relationships in low dimensional ordination space, it does not need to meet parametric assumptions of other ordination or multivariate techniques and any similarity measure can be used for ordination (see Watson *et al.* 2004, Cleary *et al.* 2004, Cleary *et al.* 2005, Urbina-Cardona *et al.* 2006). Using STATISTICA 6.0 (StatSoft 2001) the same Sørensen's similarity index matrix generated from transect and trap data was converted into a dendrogram using complete linkage or ranked similarity cluster analysis.

Forward stepwise multiple regressions were used to detect the relationship between measured environmental variables (temperature and rainfall) and elevation as predictors of species richness (the response variable). Data were logarithmically transformed prior to the analysis to improve the normality of the data. Data was analyzed with STATISTICA 6.0 software (StatSoft 2001), with significance levels set at $\alpha = 0.05$.

4.3 RESULTS

4.3.1 Species richness and diversity

In total, 23 and 12 amphibian species were registered from transect and trap sampling, respectively. I recorded 5577 amphibians from transect walks and 1889 from traps (Appendix 9.2). From transect data counts, 5, 3 and 21 species were recorded within forests, plantations and farms, respectively (Table 4.1). Nineteen species (83% of all species recorded through transect count), were found only in farms and 2 were found in indigenous forests. Only 2 (9 %) species were found in all the three habitat types.

Observed species richness and number of individuals per transect count differed significantly among habitat types and sites (Table 4.1, Kruskal-Wallis: richness, H = 19.84, df = 2, n = 28, P < 0.001); abundance, H = 13.64, df = 2, n = 28, P = 0.0011) with higher values in farms than in forests and plantations.

Excluding transects with only one species, the first order Jacknife estimator was significantly higher in farms (Kruskal-Wallis H = 15.67, df = 2, n = 25, P = 0.0004) see Table 4.2. The Shannon diversity index (H') was also significantly higher in farms than in the other habitats (Kruskal-Wallis H = 15.71, df = 2, n = 25, P = 0.0004).

Chao 1 and ACE estimators were in many cases similar to observed species. The Jacknife 1 estimate was in general higher than the others (Table 4.2). In many cases the species accumulation curve did not reach an asymptote (Appendix 9.3), indicating that the sampling was incomplete.

Table 4.1: Number of species and individuals recorded during amphibian transect counts for all sites combined and by habitat type (*i.e.* forests, plantations, farms); standard deviations are in parentheses

Variable	Forests (*n* = 7)	Plantations (*n* = 4)	Farms (*n* = 17)
Species accumulated over transect counts	5	3	21
Species per count	1.86 (0.38)	1.75 (0.95)	6.4 (1.84)
Individuals accumulated over all transect count	455	162	5054
Individuals per count	3.48 (3.91)	2.6 (1.33)	18.87 (15.13)

Note: The sample size is the number of transect counts within each habitat type

Table 4.2: Descriptive data and species richness estimates (ACE, Chao 1, jacknife 1) ±SD and *Sobs* (species observed) for amphibians from 28 transect sampling sites in the Taita Hills.

Transect site	Transect walks	*Sobs*	ACE	Chao 1	Jacknife 1
Ngangao forest	17	2	2±0	2±0.35	2.94±0.94
Chawia forest	16	2	2±0	2±0.35	2.94±0.94
Mwachora forest	16	1	1±0	1±0	1±0
Macha forest	15	2	3.11±0.51	2±0.35	2.93±0.93
Boma forest	18	2	2±0	2±0	2±0
Sungululu plantation	16	1	1±0	1±0	1±0
Kinyesha-mvua plantation	14	3	4±0	4±2.12	4.86±1.26
Mndangenyi farm	16	4	4±0	4±0	4±0
Mbirwa farm	17	5	5±0	5±0	5±0
Mghambonyi farm	13	5	5±0	5±0	5±0
Makandenyi farm	12	6	6±0	6±0	7.83±1.24
Piringa farm	18	5	6.11±0	5±0.45	5.94±0.94
Ngulu dam farm	16	7	9±0	7.33±0.92	7.33±0.92
Mwatate dam farm	19	8	8±0	8±0.47	8.95±0.95
Madungunyi farm	18	7	7±0	7±0	7.94±0.94
Mbololo forest	21	2	2±0	2±0	2±0
Mwambirwa plantation	17	2	2±0	2±0.35	2.94±0.94
Mwasange farm	19	8	8.38±0	8±0.25	11.79±1.73

Mwalenjo farm	19	6	6.72±0	6±0.25	7.89±1.3
Chale farm	16	5	5±0	5±0	5.94±0.94
Sagalla forest	15	2	2±0	2±0.35	2.93±0.93
Sagalla plantation	16	1	1±0	1±0	1.01±0.01
Mghange farm	13	5	5±0	5±0	5±0
Kauze farm	17	6	6.62±0	6±0.46	6.94±0.94
Lata dam farm	18	9	9±0	9±0	9.94±0.94
Marapu farm	16	4	4±0	4±0	4.94±0.94
Hezron dam farm	14	9	9±0	9±0	9.93±0.93
Bafwe dam farm	16	10	10±0	10±0	12.81±1.51

4.3.2 Species response to abiotic parameters, disturbance level and amphibian community predictability

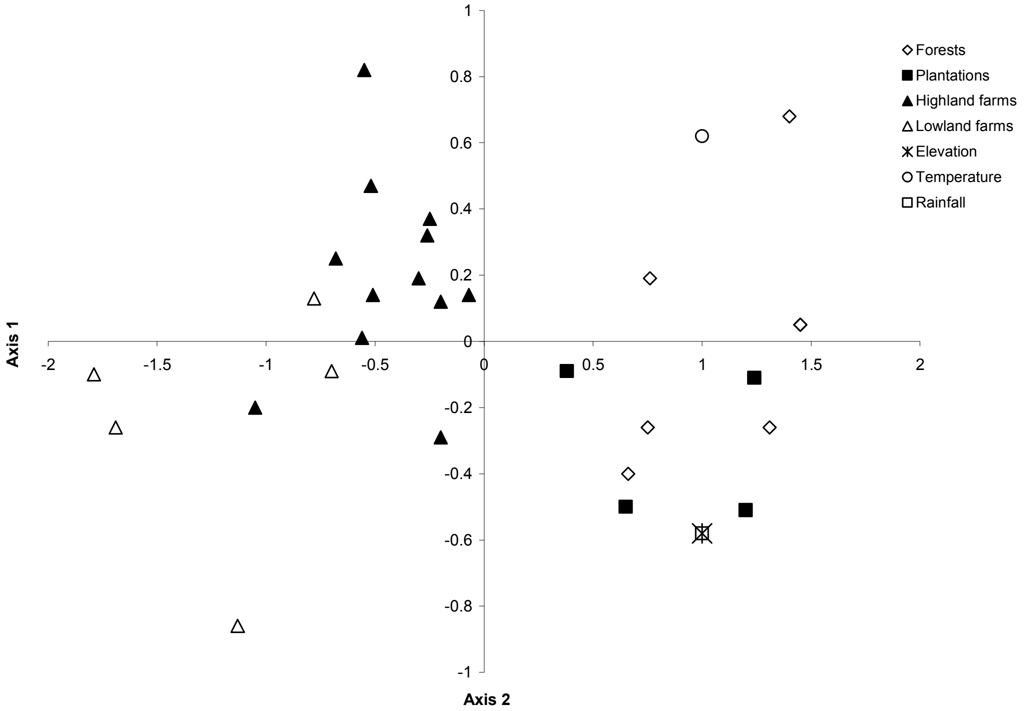
With NMDS, I identified two major species ensembles according to their responses to the forests-plantations-farms habitat types: (a) lowland and highland farm species, and (b) species that use both plantations and forests. The NMDS produced an adequate fit in two dimensions on observed species richness (stress 0.06, Fig 4.2a). Abiotic factors (rainfall, temperature and elevation) explained well most of the placement of the different sites based on their amphibian composition. This ordination clearly showed that there were differences in the amphibian composition among the different habitat types. Predictably, there was greater overlap between forests and plantations than either of them with farm habitats. Forests and plantations shared the leaf litter frog *Arthroleptis xenodactyloides* explaining the entire results.

Some lowland farm transects (Mwatate farms at 840 m unlike the others that are below 700 m) were embedded within highland farms due to their sharing of widespread species such as *Ptychadena mascareniensis, Amietophrynus gutturalis* and *Hyperolius glandicolor* which are absent in other lowland farms (Fig 4.2a). Similar results were obtained from NMDS based on trap species richness data (stress 0.11, Fig 4.2b). Similar to NMDS results, cluster analysis of transect and trap data produced 2 clear clusters (lowland/highland farms and forests/plantations). This clear clustering out of farms from forests and plantations on both axes appears to be explained by temperature and elevation (Fig 4.3a&b). This distinctly classified study sites within similar disturbance regime and/or elevations or in close geographical proximity. Similarly, there were largely two major groups of amphibian guilds, namely generalist species (open water breeders) and specialists or forest associated species (direct developers). With decreasing indigenous forest cover to plantations and farmlands, the species richness of forest associated species (*Arthroleptis xenodactyloides* and *Callulina* sp) decreased while that of generalists increased. However, this did not apply to direct developing caecilians which were found at all sites above 1000 m elevation.

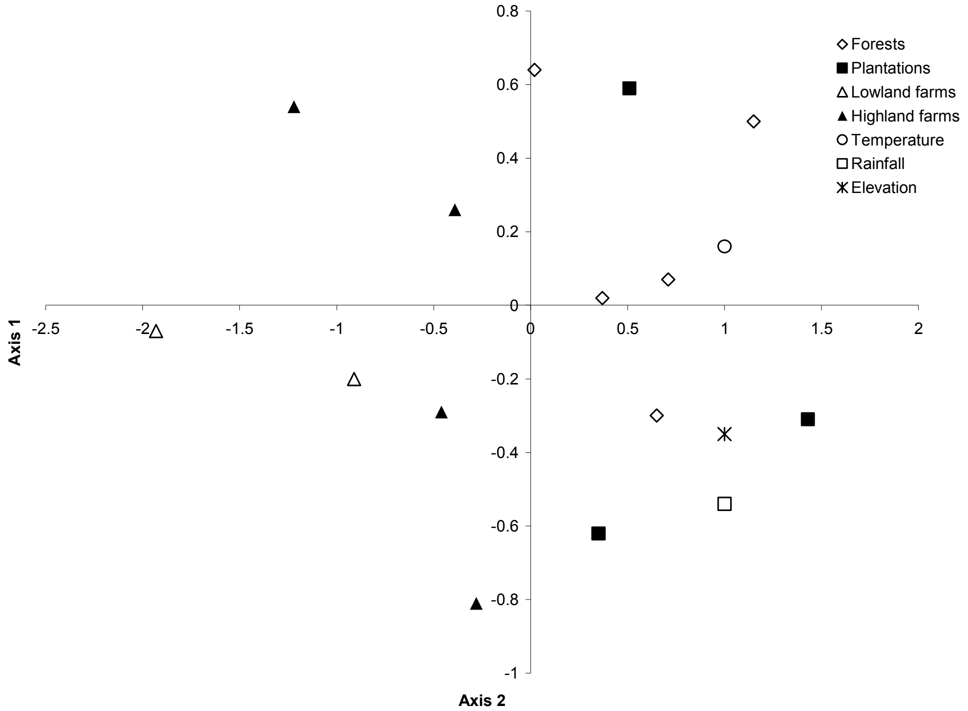
These findings again are supported by pairwise correlations between species richness and environmental parameters (rainfall, elevation and temperature). Results of forward stepwise multiple regression of the 28 transect sites demonstrated that the logarithm of the observed amphibian species richness significantly varies from transect sites ($F_{1,26} = 9.66$, $P = 0.004$, $R = 0.51$, $n = 28$) and is positively related to both the logarithm of mean annual temperature ($F_{1,26} = 16.64$, $P = 0.003$, $R = 0.62$, $n = 26$) and rainfall ($F_{1,26} = 9.52$, $P = 0.005$,

$R = 0.52$, $n = 26$) while it negatively changes with elevation ($F_{1,26} = 9, 13.24$, $P = 0.0012$, $R = 0.58$, $n = 28$). Consequently, there were more amphibian species at low to mid-elevation farm areas such as Mwatate, Sagalla and Kasigau respectively, with high temperatures and are in low to mid altitudes but receive low to moderate rainfall. The elevational range of the various amphibians in the Taita Hills is shown in Figure 4.4.

Predictably therefore, habitat sites with the same disturbance and/or elevation level, in close proximity and similar environmental characteristics have similar amphibian community assemblage.

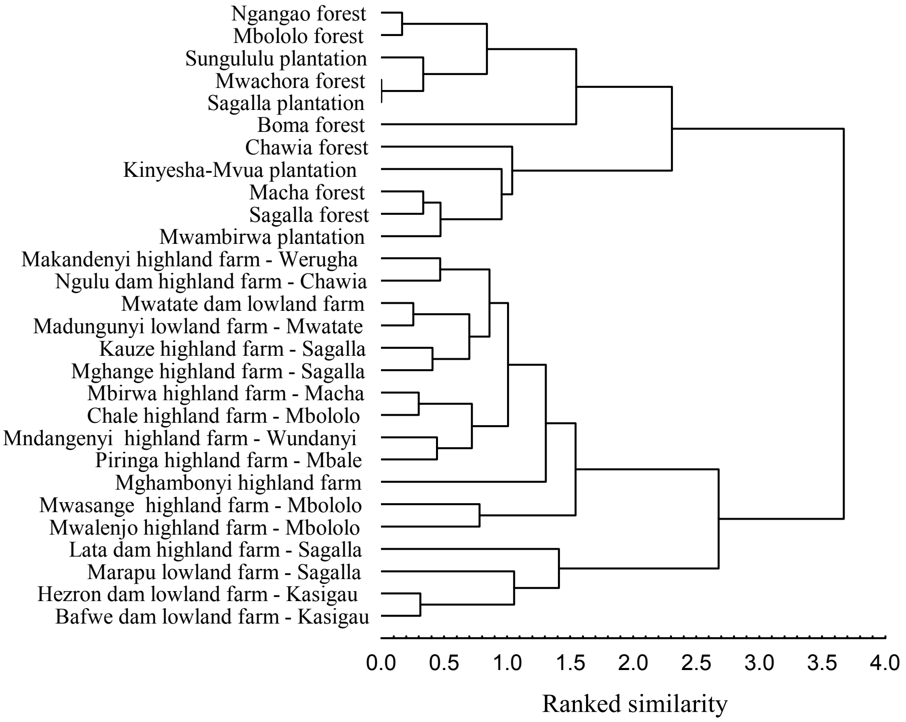


a)

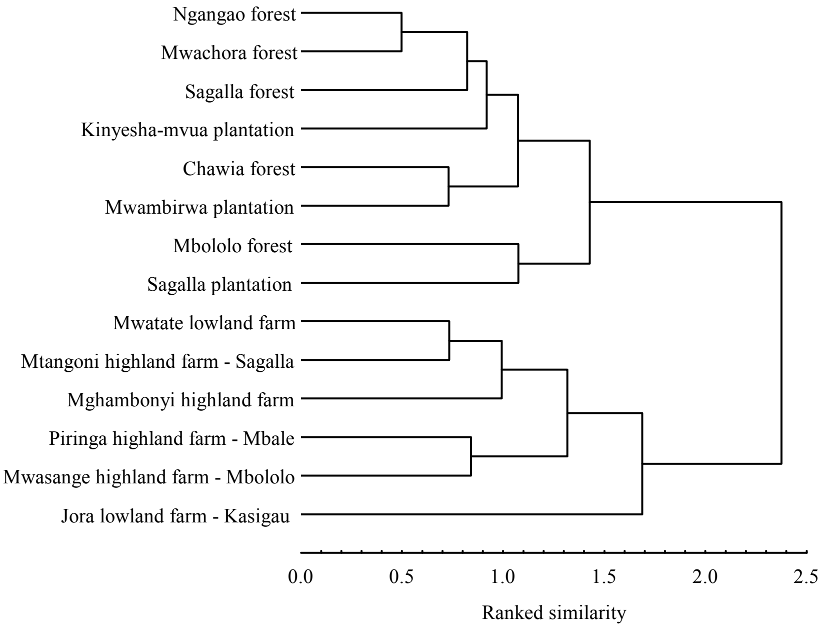


b)

Figure 4.2: Two dimensional non-metric multidimensional-scaling plots, using Sørensen's similarities of amphibian richness; (a) 28 transect sites located in three habitat types (n = 7, 17 and 4 for forests, farms and plantations, respectively) and (b) 14 trapping sites located in three habitat types (n = 5, 6 and 3 for forests, farms and plantations, respectively). Kasigau forest was excluded in the analysis as its traps were unsuccessful. Abiotic parameters (temperature, rainfall and elevation) are included to strengthen the interpretation.



a) Transect sites



b) Trap sites

Figure 4.3: Dendrograms from cluster analysis of (a) 28 transect and (b) 14 trap sites from Taita Hills based on Sørensen's similarity. The dendrogram, in general, clusters transects together that are either spatially close, or at similar elevations.

Altitudinal range **Species**	**< 600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**	**2100**	**2200**
GYMNOPHIONA																	
Ceaciliidae																	
Boulengerula niedeni					▨	▨	▨	▨	▨	▨							
Boulengerula taitana							▨	▨	▨	▨	▨	▨	▨	▨			
ANURA																	
Pipidae																	
Xenopus borealis								▨	▨	▨	▨	▨	▨				
Bufonidae																	
Amietophrynus garmani	▨	▨	▨	▨	▨	▨											
Amietophrynus gutturalis			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Amietophrynus xeros	▨	▨	▨	▨													
Mertensophryne taitana							▨	▨	▨	▨	▨	▨					
Microhylidae																	
Phrynomantis bifasciatus	▨	▨	▨	▨	▨	▨											
Brevicipitidae																	
Callulina sp.									▨	▨	▨	▨	▨	▨	▨	▨	▨
Hemisotidae																	

Hemisus marmoratus	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
Arthroleptidae																	
Arthroleptis xenodactyloides							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Leptopelis concolor	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
Hyperoliidae																	
Hyperolius glandicolor			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
Hyperolius tuberilinguis	▨	▨	▨	▨													
Kassina senegalensis																	
Ptychadenidae																	
Hildebrandtia macrotympanum	▨																
Ptychdena anchietae	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
Ptychadena cf mascareniensis			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
Ptychadena mossambica	▨																
Ptychadena schillukorum	▨																
Phrynobatrachidae																	
Phrynobatrachus scheffleri	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
Pyxicephalidae																	
Amietia angolensis						▨	▨	▨	▨	▨	▨	▨	▨				
Pyxicaphalus adspersus	▨																

Tomopterna cryptotis	▨	▨	▨	▨	▨	▨	▨										
Rhacophoridae																	
Chiromantis kelleri	▨																
Chiromantis petersi	▨	▨	▨	▨	▨	▨											

Figure 4.4: The altitudinal ranges in metres of amphibian species of the Taita Hills.

4.4 DISCUSSION

4.4.1 Response of species to habitat disturbance, elevation, rainfall and temperature

The results on local amphibian species richness in the Taita Hills show that species abundance and richness differs significantly among the three habitat types (forests, plantations, farms). Farms contained significantly more species than forests and plantations. Results from transect data; show that plantations were very depauperate in both species richness (3 species) and number of individuals (162 individuals). Overall species richness and abundance positively increase with disturbance with more species in farmlands except forest associated direct developing species that decreased. Only a small proportion of species were habitat generalists, *i.e.* utilized forests and non-forested environs. These results concur with those of Lea *et al.* (2005) in Nigerian rainforests who observed that, following degradation of rainforests to other human modified habitats, species richness may remain constant or locally increase. However, these results contrast with several similar studies which have shown that species richness decreases from indigenous forests, through plantations to farms (see Vallan 2001, Pineda & Halffter 2004).

Species richness increased positively with increasing temperature and rainfall but negatively with elevation with more species at low to mid elevations and few at high elevations. This pattern agrees with that reported by many previous studies on a wide range of taxonomic groups (see Heaney 2001 and references therein; Smith *et al.* 2007 and references therein). In Taita Hills, rainfall tends to increase with elevation (Jätzold & Schmidt 1983) but its influence on species richness appears to be obscured by that of temperature. Despite the high rainfall at high elevations in the Taita Hills, much of the water as observed elsewhere, settles on the mid-elevations and the rest on the base of the hills therein creating breeding sites for open water breeders and consequently increasing their diversity (see Hofer *et al.* 2000). The occurrence of high species richness at lowlands is associated with high energy and productivity (see Hawkins *et al.* 2003b, Willig *et al.* 2003). This concurs with other studies that have observed energy inform of temperature as an indirect measure of net primary productivity and hence species richness (*e.g.* Sanders *et al.* 2003). However, past studies have repeatedly shown that many taxonomic groups including birds, amphibians, invertebrates, mammals and plants exhibit mid-elevational peak (mid-domain effect-MDE) in species richness (*e.g.* Rhabek 1997, Sanders 2002, Sanders *et al.* 2003, McCain 2004, Smith *et al.* 2007).

In Taita Hills, certain species (with direct developing reproductive mode) are restricted to high altitudes and associated with forests (*e.g. Arthroleptis xenodactyloides, Callulina sp, Boulengerula niedeni* and *Boulengerula taitana*). Similarly on Mount Kupe, Cameroon, Hofer *et al.* (2000) found that the elevational gradient is not generally a descriptor for amphibian assemblage structure as compared to reptiles. They suggested that the dependence of most amphibians on aquatic breeding sites that were not available at all elevations reduced the relative importance of elevational gradient on amphibian species distributions. However, on a finer scale they observed a significant response to amphibian species that do not depend on streams for development (*i.e.* direct developers) to elevational gradient variables. This disparity in the pattern of species richness with elevation may be due, in part, to underlying relationships between climate, elevation over space and more so geographical location.

4.4.2 Matrix comparison and amphibian community predictability

The results of NMDS ordination and cluster analysis produced two major groups (forests/plantations and farmlands) of communities which is a reflection of amphibian ensembles response. Forests and plantations grouped together as they both share the leaf litter frog *Arthroleptis xenodactyloides* which is missing from farms. Farmlands were characterised largely by open water breeders or generalist amphibian species. Similar observations across varying habitat types on amphibians and reptiles have been made in Madagascar (Vallan 2000, 2002), Mexico (Pineda & Halffter 2004), Missouri (Renken *et al.* 2004) and Nigeria (Lea *et al.* 2005). Furthermore, Lea *et al.* (2005) pointed out that as rainforest environments become degraded there is a shift from a predominance of forest specialists to that of generalists that are able to utilize a wide range of habitats (although overall species diversity may remain stable or even locally increase), and the same shift is seen regardless of the type of habitat or taxa. Neckel-Oliveira *et al.* (2000) in the

Brazilian Amazon savanna, found that anuran community consists of generalist frog species (widely distributed) and others restricted to certain habitats (habitat specialists).

Predictably, sites similar in disturbance, elevation, climate (rainfall, temperature) or in close proximity geographically grouped or clustered together reflecting their similarity in amphibian community. In Ivory Coast, Ernst & Rödel (2005) found that amphibian community was positively correlated with disturbance level and/or geographical proximity in different anthropogenically altered forest habitats.

Regrettably, little is known about the exact effects of human habitat disturbance on amphibian species diversity. The available evidence suggests that the response of species to habitat disturbance is not uniform. In general, wide-ranging open-site breeding species seem less vulnerable to human habitat modification than forest-associated species (Vallan 2000, 2002), but there is some consolation in the fact that open-site breeders account for over three quarters of the species currently known in the Taita Hills. However, the uniqueness of the indigenous forest-associated *Callulina* sp, combined with its evident vulnerability to disturbance makes it a subject for conservation concern. Similarly, Glor *et al.* (2001) on lizards in the Caribbean observed that native species were restricted to undisturbed hilltops and were absent in agricultural habitats. They pointed out that these hilltop forests had served as refuges for species that could not tolerate disturbance when the region was being exploited for agriculture.

These results show that there are more direct developing amphibian species in forests (*Callulina* sp., *Arthroleptis xenodactyloides, Boulengerula niedeni, Boulengerula taitana*) than in farms (*Boulengerula niedeni, Boulengerula taitana*) which is a reflection of habitat diversity. This suggests that the loss of forest cover result in the loss of the conditions (microclimate) required for supporting these species by altering the functional diversity (*e.g.* forest associated species). Caecilians occur on farms only within sites with organic manure that are moist and well-sheltered or buffered from extreme micro-climate changes. However, any deterioration or loss of such sites results to their disappearance. Elsewhere, microclimate change has been found to negatively impact leaf litter frogs (see *e.g.* Ernst & Rödel (2005), Ernst *et al.* 2006, Hillers *et al.* 2008). This may be due to physiological or ecological factors. Higher temperatures, lower soil and atmospheric humidity, leaf litter loss, as well as increasing wind velocity are some of the consequences of forest removal (see Marsh & Pearman 1997, Pineda & Halffter 2004). In general, amphibians need to keep their skin moist to allow gaseous exchange and depend on external heat to regulate their internal temperature (Duellman & Trueb 1994). The eggs of such species (direct developers) are exposed to the atmosphere and with reduced humidity would be vulnerable to desiccation. Exceptionally, fossorial caecilians are able to move within the soils (not on the surface) and lay their eggs in under ground chambers (well buffered against desiccation), which make them able to survive in farms (see Malonza & Measey 2005). Therefore, simplification of the vegetation structure could reduce the availability of oviposition sites mainly for species that deposit their eggs on leaf litter (see Vallan 2000, 2002). Consequently, in Taita Hills certain species like *Callulina* sp and *Arthroleptis xenodactyloides* can serve as potential bio-indicators of forest quality. Other studies in the tropics have also identified certain herpetofauna as good indicators of forest quality and fragmentation (*e.g.* Urbina-Cardona 2006, Bell & Donnelly 2006).

On the other hand the proportions of arboreal and/or open water breeding species in Taita Hills increased from forest to farms. Basically, the reduction in forest patch size or area is related to decreasing environmental heterogeneity at ground level, resulting in the loss of microhabitats, breeding sites and territory for several species. Hence, terrestrial or ground living species would be most affected. However, it appears that this group of species is insensitive to reduction or change in forest cover. For arboreal species, one reason is that in spite of dwindling forest cover, their microhabitats' patchiness may not be affected or may even increase since high canopy may not be crucial. For open water breeders small loss of forest cover should be related to a decrease in availability of the microhabitats (ponds and streams) required for oviposition (see Pineda & Halffter 2004), for these species the presence of a body of water (breeding sites) had stronger positive effect than that of the forest loss or reduction in patch size. This concurs with findings by Vallan (2002) in rainforests of Madagascar, Pineda & Halffter (2004) in a montane forest in Mexico and Hillers *et al.* (2008) in Taï National Park and selected forest fragments in Ivory Coast. Fossorial species (caecilians) seem unaffected by forest loss rather by altitude and soil characteristics (see Malonza & Measey 2005, Measey & Barot 2006).

This analysis relates to the habitat heterogeneity hypothesis which assumes that structurally complex habitats (*e.g.* indigenous forests) may provide more niches and diverse ways of exploiting environmental resources and hence increase species diversity (Tews *et al.* 2004). This hypothesis was rejected in the case of the present Taita Hills amphibian diversity study. This study clearly demonstrate that the relationship between animal species diversity and habitat heterogeneity depends on how habitat heterogeneity is perceived by the animal guild or group studied. For instance, structural attributes of the vegetation that constitute habitat heterogeneity for one group may be perceived as habitat fragmentation by another taxonomic group. In this analysis human habitat modification for open water breeders appears to be equivalent to increased habitat heterogeneity, while it is habitat loss for some of the direct developers.

Forest plantations generally had few numbers of species and guilds attributable solely to their habitat structural simplicity. Plantation stands may have such a dense canopy or produce chemicals virtually excluding other plant taxa (see Evans 1982).

Biogeographically the three isolates of the Taita Hills are not clearly separated in terms of amphibian species assemblage due to the high species sharing. However, on a finer scale some notable species are absent in some blocks. For example *Callulina* sp is only present in Dawida and Mbololo. *Arthroleptis xenodactyloides* is absent in Kasigau while *Boulengerula niedeni* is endemic to Sagalla. These differences could be attributable to temporal and physiological isolation during the historical separation of the then one Taita Hills forest block.

4.4.3 Implications for conservation management

Indigenous forest habitats were relatively species poor as compared to the farmlands. These finding lend no support for targeting conservation strategies primarily on species richness or diversity (Ernst *et al.* 2006). This approach has the limitation of not presenting particular taxa and important conservation management my not be drawn. In this approach, for example functional diversity or guild diversity (see Pineda & Halfter 2004, Ernst *et al.* 2006), may not be well represented. The alternative approach of considering functional diversity is that it embraces the understanding of life history traits of concerned species (Murray & Hose 2005). In Taita Hills the indigenous forests supported species restricted to them (*e.g.* direct developers). However, from a conservation perspective, indigenous forest fragments are not sufficient to preserve the amphibian fauna of this landscape. Therefore, the continued maintenance of a set of forest fragments together with the human modified habitats extensively distributed (see Pineda & Halfter 2004) including some form of habitat connectivity *e.g.* corridors (Cushman 2006, Akçakaya *et al.* 2007) appears to be an appropriate strategy for maintaining amphibian diversity of the Taita Hills ecosystem.

4.4.4 Conclusions

This study shows that elevation, temperature and rainfall are highly interdependent variables and all explain the observed amphibian species richness. In high elevation areas, rainfall is high while temperatures and species richness are low. This echoes the observation that mountain passes are physiologically more challenging (Janzen 1967, Ghalambor *et al.* 2005). Therefore the occurrence of few species on high elevation areas may be due to physiological constraints (Navas 2006). Climate (rainfall and temperature) influences primary productivity that in turn affects species diversity (Hawkins *et al.* 2003a, Sanders *et al.* 2003).

Therefore future studies of the causes of variation in species richness along environmental and disturbance gradients should consider the multiple mechanisms that contribute to the pattern. This study indicates that temperature and rainfall influences regional amphibian species richness in the Taita Hills. At local scales, human disturbance influences the abundance of indigenous forest species. However, anthropogenic activity does not generate only two types of extreme scenarios: well-conserved and highly-impoverished habitats. Rather, the habitats created represent a gradient of transformations, and these habitats have different effects on the species dynamics and biodiversity. The small forest fragments though important serve as short to midterm refuges for species diversity and without connectivity to large forests fragments may act as population sinks due high juvenile mortality as amphibians have low rates of movement in amphibians (see Akçakaya *et al.* 2007 and references therein). Therefore, preserving a network of forest patches together with the human disturbed habitats may be of great conservation value to Taita Hills amphibian fauna.

4.5 SUMMARY

To better understand responses of amphibians to habitat alteration, I evaluated the relationship between amphibian composition along anthropogenic habitat disturbance and elevational gradients in the Taita Hills. I tested the hypothesis that sites with similar environmental characteristics (temperature, rainfall and elevation), in close proximity and with similar disturbance levels (habitat types: forests, plantations and farms) harbour similar species composition. Rainfall and temperature were measured at sampling sites. Standardised transects and pitfall traps were used. A non-parametric Kruskal-Wallis test showed that amphibian species richness differed among the three habitat types. Species accumulation curves generated using EstimateS 7.5.1 program showed that 1st order Jacknife species richness estimate was higher than the other estimates and in many cases the curves did not plateau. Non-metric multidimensional scaling (NMDS) and cluster analysis community similarity revealed distinct species assemblages in terms of elevation and habitat type. Amphibian species richness tended to decrease with increasing elevation and disturbance from forests to plantations. Forward stepwise multiple regressions demonstrated that amphibian species richness positively increased linearly with both temperature and rainfall and negatively with elevation. The results show that forest associated species decreased with increased disturbance from forests to farms while generalists or open site breeders increased. The observed amphibian richness patterns show that anthropogenic habitat disturbance not only affects ecosystem descriptors like species richness, abundance and diversity but also alters the landscape dynamics. Nevertheless the relatively high amphibian diversity along elevation and disturbance level indicates that preserving a network of forest fragments with some form of connectivity alongside human modified habitats is of conservation value.

5 TAITA HILLS' AMPHIBIAN SPECIES ACCOUNT

5.1 INTRODUCTION

Amphibians are one of the most threatened animal groups on Earth. At least one third of the approximately 6000 known species is threatened with extinction when applying IUCN Red List criteria to them (*e.g.* Stuart *et al.* 2004, 2008). One demand of the IUCN Amphibian Conservation Action Plan (Gascon *et al.* 2005) is to make available considerably more knowledge to all kinds of stakeholders including governmental conservation management and local NGOs. This includes basic information on systematics, distribution and life history. For many amphibian species, especially in species-rich tropical countries, such data are lacking or are 'hidden' in printed publications (*e.g.* old, rare, taxon-specific) which are distributed over a limited number of libraries in Europe or North America.

Despite increased efforts in recent years, the diverse amphibian fauna of eastern Africa is far from being well understood (Poynton 1999, Lötters *et al.* 2006, Channing & Howell 2006, Poynton *et al.* 2007). One such area is the Taita Hills in south-eastern Kenya which constitute the northernmost portion of the crystalline block faulted Eastern Arc Mountains, EAM (Lovett 1990, Newmark, 2002). All EAM blocks have remnant hilltop moist forest fragments and belong to the 34 worldwide biodiversity hotspots (Myers 2003, Mittermeier *et al.* 2004).

Sampling in the EAM, though currently active, is very uneven. The best studied mountains blocks for the last eighty years (*e.g.* Barbour & Loveridge 1928, Loveridge 1957), are the East Usambara, Uluguru and Udzungwa mountains. These initial studies underscored the importance of biodiversity in the EAM, only uncovered through the most recent and extensive focus on the EAM amphibian fauna (*e.g.* Loader *et al.* 2004, 2006, Menegon *et al.* 2004, 2007, Doggart *et al.* 2006, Burgess *et al.* 2007, Poynton *et al.* 2007). However, as shown by the authors, not all EAM blocks have been well explored including the Taita Hills.

Amphibian studies in the Taita Hills date back to the early colonial era. Since then Mt. Mbololo was the focus for collections which led to the descriptions of the endemic *Boulengerula taitana* Loveridge, 1935 (Gymnophiona) as well as the more widely ranging anurans *Mertensophryne taitana* (Peters, 1878) and *Hyperolius glandicolor* (Peters, 1879). Recently, *Boulengerula niedeni* Müller, Measey, Loader & Malonza 2005 was described from Sagalla Hill, one of the isolates of the Taita Hills.

Preliminary amphibian species lists of the Taita Hills have been published by Beentje (1988), Bytebier (2001) and Burgess *et al.* (2007). Presented here is an updated species account for the Taita Hills (Dawida block, Mt. Mbololo, Sagalla Hill and Mt. Kasigau; Fig. 1), listing 26 species, three of which are endemic to the Taita Hills. Diagnostic features, geographic range, life history and conservation status of each are provided.

5.2 MATERIALS AND METHODS

All data presented here are based on (i) published references as mentioned throughout the text, (ii) collections made by previous workers and housed at National Museums of Kenya, Nairobi (NMK), or (iii) collections (at NMK) and own observations. Fieldwork was conducted from April 2005 to December 2007 in all the four Taita Hills blocks (Dawida, Mbololo, Sagalla and Kasigau; Fig. 1) from the base to the top in selected sites. All material collected was deposited in NMK and that examined is listed in appendix 9.4.

When providing diagnostic features, they apply to specimens from the above mentioned study area in particular and refer to adult specimens only, except where noted. Taxonomy follows Frost *et al.* (2006) and Frost (2008). Measurements of preserved animals were taken with dial calipers or with a string for caecilians, which was subsequently stretched along a ruler. Labial tooth row formulae in anuran larvae were determined in the manner of McDiarmid & Altig (1999). Abbreviations used: LTRF = labial tooth row formula; PA = number of primary annuli in Gymnophiona; SVL = snout-vent-length (frogs and toads). The range (min, max) of SVL, PA and body length of caecilians and mean±SD (standard deviation) are provided for each taxon.

The IUCN Red List status of species was made according to the IUCN (2001) following the IUCN ‘Global Amphibian Assessment’ (www.globalamphibians.org, latest accessed 1st Ocrober 2008, IUCN 2006) and re-assessed the endemics. The categories are: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Extinct (EX) and Data Deficient (DD).

5.3 SPECIES ACCOUNT

Gymnophiona

Caeciliidae

Caecilians are limbless worm-like amphibians that burrow into soil and/or leaf-litter. Two species occur in Taita Hills.

Boulengerula niedeni Müller, Measey, Loader & Malonza, 2005

Diagnosis: A species with male body length range 205.7-287 mm (235.4±29.65), *n* = 10 and female 215-290 mm (251.88±20.10), *n* = 25; PA 140-155 (144.86±3.53), *n* = 35; head longer than wide; snout dorsally rounded; eyes not visible externally; tentacles short and globular; body smooth but annulated. In life, dorsal colour brownish, ventral colour light brown with the dorsal head region pinkish; throat flesh pink. Juveniles show little to no pigmentation.

Boulengerula niedeni is most similar to *B. taitana* but differs in its distinctive brownish colour in contrast to bluish-black colour and the tendency of having more PA.

Distribution and life history: Endemic to Sagalla Hill in small patchy areas within farms and indigenous forests in low density at altitudes between 1000-1504 m. In farmlands, these caecilians can be found mainly in soils rich in organic manure or under organic debris. During the dry seasons they can be found adjacent to permanent water drainage channels and are also presumed to occur elsewhere deeper in the soil profile. In indigenous forest, during the wet season, they can occur close to the surface within or under decomposing logs. Reproduction is expected to be similar to *B. taitana,* see below.

Conservation status: Global: Critically Endangered (CR) B1ab (iii). There is continuing decline on the species area, extent and quality of habitat and it is restricted only to

Sagalla Hill. The species population is declining because its suitable habitat is disappearing due to soil erosion and water draining effects of Eucalyptus trees.

Boulengerula taitana Loveridge, 1935

Diagnosis: A species with males relatively longer than females; male body length range 243-420 mm (299.17±42.72), *n* = 23, and female 235.5-345 mm (283.96±28.47), *n* = 27; PA 125-143 (135.48±3.88), *n* = 50. This concurs with Malonza & Measey (2005) who, using a larger sample size, found males to be significantly longer than females; head longer than wide; snout dorsally rounded; eyes present but covered by a translucent skin; tentacles short and globular; body smooth but annulated. In life, dorsal colour dark gloss bluish black; ventral colour is also variable from blue grey to the extent of having dark blotches or speckling; head region flesh pink; throat flesh pink. Juveniles are pigment-less. These characteristics are similar to those given by Loveridge (1957) and Nussbaum & Hinkel (1994). *Boulengerula taitana* is most similar to *B. niedeni,* see above.

Distribution and life history: Endemic to Taita Hills, this species is locally abundant in forests, plantation forests and farmlands in Mbololo and Dawida at altitudes between 1230 m and 1859 m and much less abundant in Mt. Kasigau forest from around 1200 to around 1635 m. This species was previously recorded only from Mbololo and Dawida, so these new records from Mt. Kasigau represent an important 55 km extension to its extent of occurrence to the south-east. *Boulengerula taitana* prefers moist soils rich in organic manure in farmland and can be found just under decomposing leaves and/or debris, *e.g.* on terraces' debris within banana, avocado and fig plants bases. During dry seasons, it can be found deep in soils or confined to moist sites especially alongside permanent water drainage channels. Adults can be found throughout the year (Malonza & Measey 2005). In forests, they occur in loose soil with dead leaves under and within decomposing logs. On two occasions in the wet seasons, during a night transect walk in Boma forest an individual was found moving within leaf litter while during the day in Ngangao forest another individual was observed moving on the forest grassed floor. Otherwise individuals are only known to leave their subterranean burrows when they get waterlogged or raided by Safari ants (*Dorylus molestus*) (Measey, 2004), after which they can be found in pit-fall traps.

Boulengerula taitana are carnivorous generalists that mainly prey on a variety of invertebrates, including termites; dipteran larvae and earthworms (Hebrard *et al.* 1992, Gaborieau & Measey 2004).

Boulengerula taitana is a direct developing amphibian (Nussbaum & Hinkel 1994). The membranous eggs (mean clutch size is 5 as reported by Malonza & Measey 2005) are laid in an underground chamber. Kupfer *et al.* (2006) collected 21 females with broods of between 2 and 9, an indication of egg clutch size range. The hatchlings are found in January after the short rains. The species offers parental care to its eggs and young. Eggs are guarded and the skin of a brooding female is transformed (pale in colour) to provide a rich supply of nutrients for the developing offspring. The young caecilians posses a specialized dentition, which they use to remove the outer layer of their mother's modified skin (Kupfer *et al.* 2006). Additional characteristics on spermatogenesis in this species are given by Measey *et al.* (2008).

Conservation status: Global: Vulnerable (VU). This species has previously been recorded as Least Concern (LC) as it is abundant in both agriculture and forest and does not appear to suffer detrimental effects from small scale farming. Here it is proposed to change the level of IUCN listing, based on the following reasons: (i) This species has a limited altitudinal range which decreases the moist forest associated area it inhabits in the Taita Hills. (ii) It does not occur in large areas of the Taita Hills which fall in rain shadows, even though they may be of appropriate altitude. (iii) Soil erosion is of considerable concern in the Taita Hills, particularly at higher altitudes. This species is commonly found in dark fertile soil, but was not traceable in areas where soil erosion has occurred. Given the new data concerning the limited distribution of this species and the habitat loss due to susceptibility to ongoing soil erosion I recommend that this species is moved into a threatened category. While it qualifies as a higher threatened status than Vulnerable in terms of area of occurrence, as it is clearly able to adapt to novel habitats (*e.g.* agriculture and plantations) the IUCN listing should reflect this and category VU B2a&b (ii,iii) is recommended here.

Anura

Pipidae

Pipids are tongue-less principally aquatic frogs with heavy hind limbs rather strong and extensively toe-webbing, and so well adapted to swimming. A single species is known from Taita Hills.

Xenopus borealis Parker, 1936

Diagnosis: Male SVL 50.71-61.26 mm (55.21±4.85), n = 6, females 54.96-80.28 mm (69.58±10.69), n = 5; SVL at most four times head width and at least twice tibia length; snout dorsoventrally flattened and rounded; nares visible from above; eyes located on top of head and with small tentacle below them (sub-ocular tentacle half or less than half the eye diameter); lower lid covers half eye; dorsal side smooth; feet with claws on the 1st three inner toes; finger tips pointed; the prehallux is cone shaped and prominent; females have two lobes around the cloaca; in life, dorsally dark brown, often blotched; ventrum pale to orange with dark blotches; posterior parts on thighs and front limbs yellow. This species cannot be confused with any other amphibian in Taita Hills.

Distribution and life history: *Xenopus borealis* is common in the Kenyan highlands as well as parts of Tanzania (Loveridge 1957, Lötters *et al.* 2006). This species was found to be locally abundant in permanent ponds, swamps, streams and/or drainage channels in the Dawida block at altitudes of 1397-1814 m. It seems likely that this species also occurs in the Mbololo block as habitat characteristics are similar but it is absent from Sagalla.

Calling and mating takes place in water. The male produces a slow series of trills or clacks as described by Vigny (1979). In Taita Hills, *X. borealis* has been heard calling and seen in inguinal amplexus in November during when they deposit eggs singly and attached to plants or objects in water pools or ponds. The tadpoles have long, tapering tails and broad, flat heads with two long tentacles projecting from the corners of the snout. The tadpoles collect in shoals like those of *X. laevis* Daudin, 1803, around shallow water at the edge of pond, heads down, tails up and it vibrates constantly (Stewart 1967, Tinsley & Kobel 1996).

Conservation status: Global: LC. Local: LC. The species is locally abundant in permanent water bodies at high altitudes even those within highly disturbed sites.

Bufonidae

Bufonids are toads which encompass a high diversity of life forms in different genera. They commonly have short limbs, thick and warty skins and live on the ground. Four species in two genera are known from Taita Hills.

Amietophrynus garmani (Meek, 1897)

Diagnosis: Male SVL 62.33-75.21 mm (68.03±4.37), *n* = 7, females 50.13-84.0 mm (64.53±9.74), *n* = 9; tibia length less than half SVL; horizontal eye diameter almost twice the distance from nostril to anterior corner of eye; dorsal snout rounded; tympanum distinct, its horizontal diameter slightly less than half eye diameter; parotid glands conspicuous; dorsal skin warty; only traces of foot webbing; subarticular tubercles present on toes and fingers; in life, dorsally with three pairs of brown or tan blotches down the mid-body on an olive or yellowish background, top of snout and head unmarked; ventrally white except for the black throat in males.

In Taita Hills, *A. garmani* can be confused with *A. xeros* (sympatric in Kasigau) and *A. gutturalis* (sympatric in Sagalla) but the absence of markings on the top of the head or snout and the presence of regular dorsal markings differentiate it from these species. Juveniles are similar to *Mertensophryne taitana* and those of the other toads.

Distribution and life history: A nocturnal, terrestrial toad with a large geographical range in southern and eastern Africa (*e.g.* Channing & Howell 2006). In Taita Hills, *A. garmani* occurs in savanna and grassland, occasionally next to or in ponds, dams and temporary water points in Sagalla Hill and Mt. Kasigau at altitudes of 563-1081 m.

The species was observed in axillary amplexus to lay black eggs in strings mainly during the onset of short rains of November. In Lata Dam area, Sagalla Hill, males were found calling from the water edge of rock pools and even under rock slabs. In such places when disturbed they rush and hide under them. These toads were also heard calling during the day under cover. The call is a loud ‘kwaak’ with some pulses (described by Channing & Howell 2006). Tadpoles have LTRF 2(2)/3 and metamorphs were collected in November from rock puddles at Rukanga, Kasigau block.

Conservation status: Global: LC. Local: LC. Within Taita Hills, especially at low altitudes, the species is locally abundant in suitable sites including human habitation.

Amietophrynus gutturalis (Power, 1927)

Diagnosis: Male SVL 62.70-77.44 mm (69.88±5.72), *n* = 7, females 59.55-94.42 mm (73.53±10.84), *n* = 17; tibia length less than half SVL; horizontal eye diameter more than the distance from nostril to anterior corner of eye; dorsal snout rounded; tympanum distinct, its horizontal diameter less than the eye diameter; parotid glands conspicuous but smooth; dorsal skin warty; only traces of foot webbing; subarticular tubercles present on toes and fingers; in life, dorsally with a pale cross pattern on top of head between eyes, occasionally a thin vertebral line and dark dorsal markings in pairs on a pale background; ventrally white except for the dark throat in breeding males.

Among the toads from Taita Hills, this species is similar to *A. garmani* (see above) and *A. xeros* (see below). The latter can be distinguished from *A. gutturalis* by its lighter dorsal colour and heavy spinules on the dorsal warts. Juveniles are similar to *Mertensophryne taitana* see below.

Distribution and life history: *Amietophrynus gutturalis* is a widespread nocturnal, terrestrial toad in eastern, central and southern Africa. In Taita Hills (especially in the highlands), it is the most familiar toad for local people and abundant in wetlands within farmlands even within homesteads as compared to any other sympatric toad. In forest, it is found mainly on forest glades and/or edges. Altitudinal range in the study area is 845-2200 m. The toad was most abundant in Mwatate Dam, Lata Dam (Sagalla Hill) farmlands and virtually everywhere in Mbololo and Dawida blocks.

In Taita Hills, this toad breeds in both temporary and permanent water bodies throughout the year with highest reproductive activity during the rainy seasons between late October until the end of December. Males call and mate while floating in shallow water near the edge of pools and were observed in axillary amplexus in November. Although nocturnal, males were also heard calling during the day mainly under cover. The call is a slow pulsed and audible snore, as described by Channing & Howell (2006). *Amietophrynus gutturalis* produces small black eggs in strings which are often wound in and around vegetation within the wetland. The newly hatched small black tadpoles occur in aggregations and have LTRF 2(2)/3, *e.g.* NMK A/4610.

Conservation status: Global: LC. Local: LC. In Taita Hills, this species is locally abundant in suitable habitats and it's quite adaptable to human disturbance.

Amietophrynus xeros (Tandy, Keith & Duff-Mackay, 1976)

Diagnosis: Male SVL 57.52-68.7 mm (64.32±4.33), *n* = 5, females 45.19-79 mm (52.55±7.63), *n* = 6; tibia length less than half SVL; horizontal eye diameter slightly less than twice the distance from nostril to anterior corner of eye; dorsal snout rounded; tympanum distinct, its horizontal diameter less than half the eye diameter; parotid glands conspicuous; dorsal skin warty; only traces of foot webbing; subarticular tubercles present on toes and fingers; in life, dorsally cream with dark blotches in pairs, heavy dark spinules and bright red markings or vermiculation on thigh that extend to the groin; ventrally white except for the dark throat in breeding males.

Among the toads from Taita Hills, this species can be confused with *A. garmani* and *A. gutturalis,* as indicated above (Tandy *et al.* 1976). Juveniles are similar to *Mertensophryne taitana* and those of the other sympatric toads (*A. garmani* and *A. gutturalis*).

Distribution and life history: A nocturnal, terrestrial species that is widespread in arid lowland regions from northern Africa into sub-Saharan Africa up to Tanzania. In Taita Hills, it occurs in seasonal rivers and dams at elevations of 563-846 m and often next to human settlements. *Amietophrynus xeros* was mainly found at artificial water bodies in Mwatate Dam, Sagalla nyika (Marapu) and Kasigau lowlands.

In the study area, male calls can be heard from the water edge of larger water bodies or from shallow water. The male call is like a hoot as described by Channing & Howell (2006). Breeding mainly takes place during the short rainy season around November (observed at Mwatate Dam) when pairs can be observed in axillary amplexus and black eggs are deposited in strings. The tadpole is large reaching 34 mm long.

Conservation status: LC. Local: LC. This species is locally abundant where present in Taita Hills even within human habitation.

Mertensophryne taitana (Peters, 1878)

Diagnosis: Male SVL 24-33 mm (28.11±2.66), *n* = 5, females 31.63-36 mm (33.8±156), *n* = 5; tibia length and head width less than half SVL; horizontal eye diameter more than the distance from nostril to anterior corner of eye; dorsal snout rounded with nares visible from above; tympanum absent; small and flattened parotid glands; dorsal skin covered by small sand-paper like warts; only traces of foot webbing; double subarticular tubercles present on pointed toes and fingers; in life, dorsally light brown to grey with darker markings, more common and prominent in males; ventrally pale or whitish in colour and granular, with males having a conspicuous dark grey or black trident mark on their chest.

Mertensophryne taitana are similar to juveniles of the other sympatric toads found in Taita Hills but differ in having flattened parotid glands and absence of tympanum.

Distribution and life history: A both nocturnal and diurnal, terrestrial toad known from drylands and savannas in eastern Africa. In Taita Hills, *M. taitana* is mainly known from the Mbololo block plus two individuals singly collected in traps in Macha and Mwachora forests in 1998 and 2007 respectively in Dawida block. It occurs at elevations around 1236-1644 m in farmlands and forests plantations.

In the Mbololo block, breeding specimens in axillary amplexus, black eggs in strings and tadpoles have mainly been encountered during the November rains in farmlands, *e.g.* within road puddles in Macha, Mwasange, Mchanga, Irindiyi and Kilumaluma villages. Aggregations of about 50 individuals were found breeding at around late morning. This species does not have an advertisement call *per se* as hearing apparatuses (tympanum, middle ear and vocal sac) are absent. The tadpole has been described by Müller *et al.* (2005) and is conspicuous by having a 'crown'. According to these authors, metamorphosis is short and completed after only 13 days. The species tadpole LTRF not reported elsewhere is 2(2)/3(1) from NMK A/4526.

Conservation status: Gobal: LC. Within its known global range, *Mertensophryne taitana* is presumably quite common with no observable population decline. Local: Endangered (EN) B2a&b(i,ii,iv). Locally the range of this species is small and fragmented in only two sub-populations within the Taita Hills (only one has breeding sites recorded). (i) It is not yet recorded in Sagalla or Kasigau. (ii) It occurs within a small range of altitude. (iii) It breeds on temporary road puddles that are quite vulnerable to drying or being run over by vehicles. With this available information about the limited distribution of this species it may locally deserve EN status.

Microhylidae

The narrow-mouthed and headed frogs comprise a group divided into numerous genera. Most have moderately built legs as they have a walking gait. One species with a narrow and flat head is known to occur in Taita Hills.

Phrynomantis bifasciatus (Smith, 1847)

Diagnosis: Male SVL 37.79-50.91 mm (45.13±3.98), *n* = 8), female SVL 38.2-50.15 mm, 44.8±4.03), *n* = 7); tibia and foot length less than half SVL; horizontal eye diameter less than distance from nostril to anterior corner of eye; dorsal snout truncated; tympanum distinct, its horizontal diameter less than the eye diameter; dorsal skin smooth; little webbing; toes and fingers bearing small and truncated discs with the last segment of the fingers and toes not in line with the rest; only the inner metatarsal tubercle is present; in life, the dorsum grey with orange to red patches on the rump and broad dorsolateral bands of the same colour running from the snout over the eyes to the legs; ventrally grey with white spots and blotches; the male gular flap is strap-like and dark.

Phrynomantis bifasciatus is quite conspicuous and distinguished from all other frogs known from the Taita Hills. Only the sympatric *Kassina senegalensis* slightly resembles this species but lacks any reddish colour and has no toe discs.

Distribution and life history: A nocturnal amphibian which walks rather than hops on the ground. It is widespread in savanna habitats of sub-Saharan Africa. In Taita Hills, *P. bifasciatus* occupies dry savannas at elevations of 563-1081 m. It has been recorded from the Mwatate, Sagalla and Kasigau sites in man-made dams as well as within water drainage channels in swamps. Males call from concealed sites, *e.g.* thick bushes, or from the water edge. The call is long melodious or musical high-pitched trill or purr (described by Channing & Howell 2006). In Taita Hills, this happens during the start of the rainy seasons in March/April and November. According to Channing & Howell (2006), amplexus is inguinal and darkly pigmented eggs (1.3 mm diameter within a 4 mm capsule) are deposited in 75-mm mass on vegetation or sunk in a clutch 300-1500. The tadpole has a wide or broad head and its body is transparent, with dark pigmentation and many shiny pigment cells along the midline. The spiracle is located at the centre of the throat.

Conservation status: Global: LC. Local: LC. The species is locally abundant in suitable habitats when present.

Brevicipitidae

These are small-mouthed and narrow headed groups of short rounded bodied frogs. Most of them are burrowing but few are climbers. There are numerous genera with only one species known to occur in Taita Hills.

Callulina sp. (cf. *kreffti*)

Diagnosis: This is an undescribed species similar to the East Usambara Mountains' endemic *Callulina kreffti* Nieden, 1911 (Barbour & Loveridge, 1928); but differs morphologically in being relatively small. In *Callulina* sp. the distance from the eye to the tympanum and the tympanum diameter are not equal. Male SVL 26.36-33.3 mm (30.36±2.26), *n* = 8, females 39.55-44.97 mm (42.48±1.99), *n* = 8; tibia and foot length less than half SVL; horizontal eye diameter greater than distance from nostril to anterior corner of eye; dorsal snout truncated or blunt; tympanum distinct, its horizontal diameter less than eye diameter; dorsal skin warty and gummy; webbing present in traces; toes and fingers bear small and truncated discs; toes arranged in two opposable groups, with the fourth and fifth toes together, pointing posteriorly when the frog walks on the ground; subarticular tubercles distinct; in life the warty dorsal colour of this frog is quite variable with shades of light yellow through orange, brown to dark brown. In majority of brown individuals, the eyebrows, flanks, hind and fore quarters are normally lighter; ventrum pale but occasionally spotted while the throat of males is slightly mottled.

In my study area, this species can be confused with small toads which lack the flattened toe discs and have parotid glands.

Distribution and life history: This is a high elevation (1397-2200 m) forest species endemic to Taita Hills. It is only known from forests in Mbololo and Dawida blocks (Ngangao, Chawia, Fururu, Vuria, Ndiwenyi, Mwachora, Boma-Wundanyi). *Callulina* sp. is mainly nocturnal and primarily burrows under decomposing logs or debris. However, it may also be found walking on leaf litter and perched at some distant off the ground during both day and night. When disturbed, the frog inflates and arches its body, with the head tucked in and when handled it produces a sticky gum.

The phonetic call is a 'kru … kru … kru', repeatedly made during day or night mainly from concealed sites, from June to September. In September 2007, a female was found sitting on ca. 30-40 eggs in a tight clutch (egg diameter ca. 2 mm), with incubation taking about 3 months *i.e.* end of November. It is likely, as in similar species (brevicipitids), that *Callulina* sp. guards its eggs which develop directly. Majority of the juveniles were found mainly between January and May (see chapter 6).

Conservation status: Global: Currently not listed but it is suggested that *Callulina* sp. should be ranked CR B1a&b (ii,iii,iv) due to the following reasons. (i) Geographically it occurs in only two sub-populations (Mbololo and Dawida) that are severely fragmented; (ii) restricted to indigenous forests and only within certain altitudinal range and (iii) its habitat quality is declining due to continuing forest disturbance and degradation.

Hemisotidae

Pig-nosed frogs have robust spherical bodies with a bloated appearance, short limbs and sharp hardened snout, which protrudes beyond the small mouth and conspicuous transverse skin fold (groove) behind the eyes. The small beady black eyes are bulging. A single species of this primarily burrowing amphibian occurs in Taita Hills.

Hemisus marmoratus (Peters, 1854)

Diagnosis: Male SVL 25.43-32.63 mm (28.26±2.45), *n* = 9, in females 27.06-39.3 mm (34.93±3.78), *n* = 10; tibia and foot length less than half SVL; tympanum not distinct; trace of web; inner metatarsal tubercle remarkably large and scraper-like; dorsal life colour is variable with brown or grey marbling and spots on a paler brown background; ventrally white with males having a black throat. This species cannot be confused with any other amphibian from Taita Hills.

Distribution and life history: An abundant species in grassland and woodland of sub-Saharan Africa. In Taita Hills, it has been found at Mwatate, Mbololo, Sagalla, Kasigau and Dawida blocks, Here, *H. marmoratus* occurs in soft soil associated to farmlands at an altitude of 563 to 1647 m and where present it is the most dominant species in traps. It has also been recorded in Chawia forest.

Breeding takes place within the onset of the rainy seasons both around March and November. Then males call from concealed sites at the edge of pools, usually on wet mud. The call is a long buzz, repeated frequently as described by Channing & Howell 2006). Inguinal amplexus has been observed in mid November at Wundanyi in temporary puddles. According to Channing & Howell (2006), 150-200 eggs are laid in a compact mass and larvae hatch after the nest floods. Tadpoles that vary from light to dark grey have LTRF 5(2-5)/4(1). In Taita Hills, they have been observed in March, April, May and November in pools, ponds and slow moving stream water.

Conservation status: Global: LC. Local: LC. Within the Taita Hills the species is quite abundant in suitable habitats with no observable threats.

Arthroleptidae

A diverse group consisting mostly of terrestrial small to medium-sized forests-dwelling frogs usually associated with leaf litter. Its members often have a more or less distinct hourglass-shaped mark on the back. Breeding males of many species have an elongated third finger and these are predominantly terrestrial species living in leaf litter. Included in this family, are some tree frogs (Leptopelinae) that have broad heads with large digital discs and extensive webbing. Two species are known to occur in the Taita Hills.

Arthroleptis xenodactyloides Hewitt, 1933

Diagnosis: Male SVL 12.14-21.23 mm (17.75±1.84), *n* = 28 female SVL 17.25-23.83 mm (20.65±1.77), *n* = 22; tibia about half SVL; horizontal eye diameter twice distance from nostril to anterior corner of eye; dorsal snout rounded; tympanum not distinct; dorsal skin smooth; webbing present in traces on toes and fingers; toe and finger tips slightly enlarged; subarticular tubercles distinct; the third finger of males is elongated and less than two-thirds of the head width; in life, dorsally brownish to pinkish, sometimes with a darker diamond or hour glass pattern in the centre, a pattern of dorsolateral stripes is common; some specimens back of thighs and flanks reddish or pink; ventrally white except for the grayish speckled throat in males.

In Taita Hills, *A. xenodactyloides* resembles *Phrynobatrachus scheffleri.* The two can be distinguished on the basis of smooth versus warty dorsal skin texture and occasional presence of darker pattern in *A. xenodactyloides.*

Distribution and life history: An eastern Africa leaf litter anuran known from Mozambiaque, Malawi, Tanzania and Kenya. It is equally found during both night and day among dead leaves as well as in grassed forest glades at an altitudinal range from 1293 to 2200 m (Mbololo, Dawida and Sagalla blocks). It occurs in both indigenous and exotic forest plantations even those patches within farmlands. A study on gene flow among the Taita Hills sub-populations has found gene exchanges through shared water drainage systems, even between the mountain blocks of Dawida and Mbololo (Measey *et al.* 2007).

Breeding may take place throughout the year but with peaks during heavy rains (March, November). The call is a brief cricket-like chirp, as described by Channing & Howell (2006) and can be heard during day and night normally under cover of dead leaves on the forest floor. Amplexus is axillary during both day and night. Clutches of 13-30 white eggs each within a 4 mm diameter capsule have been found under and/or on leaf litter. My observations suggest that eggs take about 30 days to hatch directly into miniature frogs. The size at hatching is about 3.1 mm.

Conservation status: Global: LC. Local: VU B2a&b (i,iii,iv). In Taita Hills, this species can be categorized as VU. This is because it is associated only with indigenous forests and forest plantations at high altitudes (limited range) and which is severely fragmented. In general the species extent of occurrence, area of occupancy (within the three sub-populations) and quality of habitat continue to decline.

Leptopelis concolor Ahl, 1929

Diagnosis: Male SVL 32.51-40 mm (36.60±1.77), *n* = 27, live male SVL about 40 mm; tibia length less than half SVL; horizontal eye diameter almost twice the distance from nostril to the anterior corner of the eye; pupil vertical; dorsal snout rounded; tympanum distinct, its horizontal diameter slightly less than half eye diameter; dorsal skin smooth; foot webbing moderately expressed; inner metatarsal tubercle spade-like; subarticular tubercles well-developed; semicircular terminal discs present in all toes and fingers; in life, dorsum light to dark brown with a darker triangle between the eyes pointing posteriorly (sometimes a Y-shape), occasionally with dark brownish stippling only; dark brownish canthal stripe from nostril 'through' to the eye; ventrally pale or whitish with males lacking pectoral glands (see Schiøtz 1999); juvenile coloration is dorsally cream or green.

In Taita Hills, *L. concolor* may be confused with *Hyperolius* species which differ in being smaller, having a smaller inner metatarsal tubercle and horizontal pupil in contrast to vertical in *Leptopelis.* See also under *Chiromantis* below.

Distribution and life history: A nocturnal tree frog common along the coastal strip in Kenya and Tanzania (Schiøtz 1999). On Kasigau, Mwatate, Mbololo, Dawida and Sagalla, this species can be found perched on bushes, a few meters above ground, and locally abundant within farms and forest edges (altitudinal range 563-1604 m), especially in proximity to water. It appears to be more abundant in low to mid altitudes (up to around 1300 m) than higher altitudes.

This species breeds just after the onset of the rainy seasons in March and November in stream and/or rock pools as well as in dams. During these periods, males have been heard and observed calling while perched on widely-spaced short shrubs, reeds, tall grass or even various farm crops and fruit plants. As described by Schiøtz (1999), the call consists of a croak followed by two whines. Amplexus is axillary. Egg deposition sites are unknown, but presumably on the ground in areas which are flooded after rain, as known in other members of the genus (Schiøtz 1999). In early December and late April, tadpoles and metamorphs were found on seasonal rock pools and perched on short grass adjacent to a flowing stream, respectively. The general *Leptopelis* tadpoles have elongated tails with LTRF of 4(2-4)/3 for many species (see Channing & Howell 2006). Cream and green backed metamorphs were found on Mt. Kasigau in late April.

Conservation status: Global: LC. Local: LC. In Taita Hills, this species, though it shows seasonal variation in abundance it is quite abundant with no observable decline when present.

Ptychadenidae

Ptychadenids are a group of frogs commonly called ridged frogs because of the presence of six or more ridges (skin folds) down the back overlain by black spots. These grass frogs are specialized jumpers due to their proportionally long muscular legs. Included also are ornate frogs which are stockily built and possess large scraper-like inner metatarsal tubercle that aid in digging. Characteristically frogs in this family have paired lateral vocal sacs inside slits (on the side of the throat). Four species occur in Taita Hills.

Hildebrandtia macrotympanum (Boulenger, 1912)

Diagnosis: Male SVL 41.9-49.7 mm (46.24±2.65), *n* = 7, single female SVL 45.13 mm; head width and tibia length less than half SVL; horizontal eye diameter almost twice the distance from nostril to anterior corner of eye; dorsal snout rounded; nostril is nearer to eye than the snout tip; distinct tympanum, its horizontal diameter slightly less than that of eye; dorsal skin smooth; toes with traces of foot webbing; inner metatarsal tubercle large, strongly compressed and flange-like; each finger has a simple basal subarticular tubercle; tooth-like projections (cusps) present on lower jaw; in life, dorsally brown to olive green, dark mottling on the sides; ventrally white; throat in males spotted or mottled; males have paired lateral vocal sacs (Balletto *et al.* 1980); juveniles found on Kasigau lowlands in late April are brown and cream.

This species is similar to young *Pyxicephalus adspersus* and adult *Tomopterna cryptotis* but differs in having smooth dorsal skin while that of *Pyxicephalus adspersus* is warty with skin folds and *Tomopterna cryptotis* has warts.

Distribution and life history: A nocturnal, fossorial, savanna species known from altitudes below 800 m from southern Ethiopia and Somalia south to Kenya. In Taita Hills, it was only recorded from Bafwe dam at the base of Mt. Kasigau (577 m).

As pointed out by Channing & Howell (2006), males call from the water edge of flooded pools or dams. The call is a brief hoot and eggs are deposited possibly singly in water. The characteristically similar *Hildebrandtia ornata* (Peters, 1878) eggs are scattered singly in shallow water (see Stewart, 1967). Although breeding of this anuran in Taita Hills was not observed, it is expected to reproduce within the onset of the March (and probably even November) rainfall peaks, since juveniles were found on the water edge in Bafwe dam, Kasigau lowland farms in late April. The tadpole is large, up to 95 mm long and heavily built, dark in colour with LTRF of 1/2 (Channing & Howell, 2006).

Conservation status: Global: LC. Local: Data Deficient (DD). In Taita Hills, the full extent of distribution of this typical lowland species is unknown. Timing of the breeding period for this species seems to be crucial in understanding its natural history. Otherwise it appears to be a sporadic breeder that lasts for a very short period.

Ptychadena anchietae (Bocage, 1867)

Diagnosis: Male SVL 30.41-41.53 mm (36.94±3.39), *n* = 28, female SVL 36.50-54.61 (48.09±5.03), *n* = 17; legs long with tibia greater than half SVL; eyes relatively large with eye diameter slightly greater than the distance from nostril to anterior corner of eye; tympanum distinct with horizontal diameter slightly greater than half the eye diameter; one phalange of the 4th toe free of web. The back has 6-7 ridges, snout pointed and with a characteristic pale triangle on top, dorsum variably brown, to grey with dark marks, some males uniform dark brown, flanks spotted in some individuals, ventral surface white; fingertips not enlarged, paired lateral vocal sacs in males, back of thighs with two irregular strips separated by dark bands or blotches (Stewart, 1967).

In Taita Hills, *P. anchietae* can be confused with *Ptychadena* sp. (cf. *mascareniensis*), *P. mossambica* and *P. schillukorum* (see below). But *P. anchietae* has a characteristic pale or light triangle on top of snout, different back of thigh pattern and more extensive webbing between the toes. Juveniles of all occurring *Ptychadena* species can be confused.

Distribution and life history: Both nocturnal and diurnal widespread savanna species in eastern, central and southern Africa. In Taita Hills, it is locally abundant in farmlands and grassed forest glades and the most widespread (altitudinal range 563-1750 m) but common at altitudes below 1000 m. The species was recorded from sites in all the study blocks (Kasigau, Dawida, Sagalla and Mbololo). When disturbed on pond edge the species jumps away from water.

The species calls from open ground near water edge. The call is a high-pitched ‘waak-waak-waak’ at one second intervals, either night or morning following heavy rain. In Taita Hills, they breed in both seasons with concentration in the short rain season of November. In the high altitude areas few calls are occasionally heard any time of the year. Tadpoles were found during both long and short rain season in April and November. Juveniles have been found in April. Mating and egg laying takes place in shallow temporary ponds. The white eggs with a grey top half float in a layer on the water surface in clusters. The greyish tadpole has LTRF 2(2)/2.

Conservation status: Global: LC. Local: LC. This is the most widespread ridged frog in Taita Hills from the lowlands to the highlands. Otherwise apart from altitudinal variation *Ptychadena anchietae* is locally abundant within suitable and even human modified habitats with no evidence of population decline.

Ptychadena sp. (cf. *mascareniensis*)

Diagnosis: Male SVL 36.06-52.13 mm (43.35±4.70), *n* = 10, female SVL 41.66-58.12 mm (52.15±4.47), *n* = 18; legs long with tibia greater than half SVL; eyes relatively large with eye diameter greater than the distance from nostril to anterior corner of eye; tympanum distinct with horizontal diameter slightly less than the eye diameter; two phalanges of the 4th toe free of web; the back has 6-7 ridges, snout pointed with nostril equidistant between snout tip and eye. Dorsal surface is dark grey and spotted, majority of females with a cream (olive) or green vertebral stripe or band, tibial line present in some specimens, ventrum white; fingertips not enlarged. Males with paired lateral vocal sacs, back of thighs with regular longitudinal stripes or bands, cream dorsolateral skin folds usually present. The species *Ptychadena mascareniensis* (Duméril & Bibron, 1841) has been recognized as a species complex (see Lamotte, 1967) consisting of many cryptic species (*e.g.* Vences *et al.,* 2004).

In Taita Hills, this species can be confused with *P. anchietae* (see above) and as juveniles from all other co-occuring *Ptychadena* species and *Amietia angolensis* (see below).

Distribution and life history: *Ptychadena mascareniensis* is a widespread pan-African species. In Taita Hills, *Ptychadena* sp. (cf. *mascareniensis*) occur within grassed streams, ponds, and dams in low to high altitude (839 -1750m) mainly in farms. It is mainly abundant in sites at altitudes above 1000 m. In forests only confined to forest glades and/or on forest edge *e.g.* Chawia forest. Abundant in farmlands in ponds, drainage channels swamps and dams in Mwatate, Mbololo, Sagalla and Dawida but absent in Kasigau. Unlike *P. anchietae* when disturbed on pond edge, this species jumps into water.

In Taita Hills, this species breeds throughout much of the year. Males call and mate while floating in water and/or its edge, sometimes from emergent vegetation or grass in November. The call is a wah-wah-wah like that of some duck species or a series of clucking sounds repeated at infrequent intervals, day or night. The eggs are small and white with a black upper half deposited on the water surface in clusters in both temporary and permanent waters.

Conservation status: Global: LC for the similar *Ptychadena mascareniensis*. Local: LC. Despite having altitudinal variation it is locally abundant in suitable habitats including human modified habitats with no observable population decline.

Ptychadena mossambica (Peters, 1854)

Diagnosis: Male SVL 29.43-34.80 mm (33.13±1.88), *n* = 7, female SVL 33.77-44.19 mm (38.21±5.38), *n* = 3; legs short and fat with tibia slightly greater than half SVL; eyes relatively large with eye diameter greater than the distance from nostril to anterior corner of eye; tympanum distinct with horizontal diameter less than the eye diameter; two to three phalanges of the 4th toe free of web; snout pointed; fingertips not enlarged; prominent tubercles on the fourth metatarsal; back of thigh is dark mottled or marbled; tibial line often present; a definite outer metatarsal tubercle present on the foot; dorsum variably olive green to brown with dark marks, and a light mid-dorsal (vertebral) stripe or band; about 9 ridges (skin folds) on the back; the male black-lined gular sacs (pouch) slits end level with the edge of the arm insertion or origin; ventrally white.

In Taita Hills, *P. mossambica* closely resembles the sympatric *P. schillukorum* from which it can be distinguished on the basis of a different thigh pattern and continuous versus discontinuous dorsal skin folds (Stewart 1967). As juveniles all occurring *Ptychadena* species can be confused especially with those of sympatric *P. schillukorum* and *P. anchietae*.

Distribution and life history: This is a widespread species in grassed habitats in dry and moist lowland mainland of Eastern African coast from Somalia to South Africa. In Taita Hills, it is restricted to the lowlands at an altitude of about 600m. A single female was collected in November in Jora, Kasigau lowland farms. There are earlier collections of this species within Tsavo plains around Voi on the base of Sagalla Hill.

The breeding behaviour of this species is largely unknown. Channing & Howell (2006) describes the male call as a repeated quacking mainly made from well concealed sites. The single collection was made in November while earlier collections of males, females and juveniles were done in April. This suggests that this species breeds in both long and short rains in the Taita Hills.

Conservation status: Global: LC. Local: DD. In Taita Hills, the full extent of this uncommon lowland species is unknown. However, it seems to be active within a short period during the rain season.

Ptychadena schillukorum (Werner, 1907)

Diagnosis: A single male SVL was 46.09; female SVL 37.41-44.74 mm (41.51±3.74), *n* = 3); legs short and fat with tibia slightly greater than half SVL; eyes relatively large with eye diameter greater than the distance from nostril to anterior corner of eye; tympanum distinct with horizontal diameter less than the eye diameter; webbing reduced with two phalanges of the 4th toe free of web; snout pointed with light and unspotted; a major distinctive feature is the longitudinal skin folds that are broken into a series of long wart-like structures and the lateral fold broken into 2-5 elongate sections; back of thigh is heavily or finely flecked, vermiculated or mottled; fingertips are not enlarged. Dorsum variably brown with dark marks and occasionally with a thin vertebral stripe or band, with 6-8 dorsal skin ridges (see Stewart 1967, Perret 1987). Males have a paired lateral vocal sac or gular pouch slits that end at the middle of the arm insertion.

Among the Taita Hills amphibians, *P. schillukorum* is similar to *P. mossambica* (see above) and as juveniles from all other co-occurring *Ptychadena* species.

Distribution and life history: This species occur in dry and moist savanna areas from Senegal, Sudan, Egypt, and Ethiopia to Tanzania and south to Malawi and Mozambique (Stewart 1967).

In Taita Hills, recorded on the lowlands (nyika) surrounding Kasigau and Sagalla blocks. Nearby there are earlier collections near Voi within the Tsavo plains. Breeding habits of this species are unknown. Channing & Howell (2006) describes the male call as a series of clicks made while floating in a spread-eagled manner from dense vegetation at the edge of shallow pools. Specimens were collected in November while there are earlier collections from the same plains near Voi in April. This suggests that the species breeds in both long (March-May) and short (November-December) rain seasons.

Conservation status: Global: LC. Local: DD. Data on the distribution and abundance of this species is largely unknown. However, it appears that this species is active only within a short period during the rain season.

Phrynobatrachidae

These are a diverse and complex group of small brown terrestrial frogs. They have low, rounded warts of various sizes scattered over the back. A distinctive feature of this group is the presence of a tarsal tubercle in addition to two metatarsal tubercles.

Phrynobatrachus scheffleri (Nieden, 1911)

Diagnosis: Male SVL 14-21.09 mm (17.85±1.73), $n = 25$, female SVL 17.14-21.19 mm (19.67±1.61), $n = 25$; tibia almost half SVL; horizontal eye diameter slightly greater than the distance from nostril to anterior corner of eye; dorsal snout rounded; tympanum indistinct; dorsal skin warty; toe webbing present in traces; toe and finger tips slightly enlarged but no well-marked digital discs; two metatarsal and one tarsal tubercle present on each foot; in life, dorsally light brown to dark brown with a dark brown chevron mark on the anterior part of the back; a cream vertebral stripe or band may occur; ventrally white; throat of males dark marbled.

Phrynobatrachus scheffleri can be confused with *Arthroleptis xenodactyloides* (see above) but differs in having warts on the back.

Distribution and life history: Both diurnal and nocturnal terrestrial species. In Taita Hills, it occurs in all blocks, commonly on the edge of grassed streams in farmlands or in forest glades at altitudes 563-1750 m.

Males call from vegetation in shallow water and the call as described by Channing & Howell (2006) is a long trill. Amplexus is axillary and the black eggs within a capsule are laid in a single layer that floats on water surface. Except tadpoles, individuals of different developmental stages were recorded in both short and long rains suggesting that the species breeds in both periods.

Conservation status: Global: Un-assessed. Local: LC. *Phrynobatrachus scheffleri* is locally abundant in suitable habitats with no observable decline.

Pyxicephalidae

An extremely large and diverse group of frogs spread over several genera. In Taita Hills, included here are genera like *Tomopterna* and *Pyxicephalus* that have broad, rounded heads and thick bodies with roughened skin that has low rounded warts or short ridges. On the toes is a large, flange-like inner metatarsal tubercle. The other genus is *Amietia*, which has strong and muscular long legs with webbed feet and proportionally large bulging eyes.

Amietia angolensis (Bocage, 1866)

Diagnosis: Male SVL 35.04-41.01 mm (38.77±2.01), *n* = 17, females 42.38-44.85 mm (43.43±1.07), *n* = 4; a large species and in Taita Hills only second to *Pyxicephalus adspersus* (see below); tibia length more than half SVL; dorsal snout pointed; eyes bulging out, with horizontal diameter greater than the distance from nostril to anterior corner of eye; tympanum distinct with horizontal diameter less than eye diameter; dorsally and dorsolaterally with skin folds; toes extensively webbed; single subarticular tubercles; toes and fingertips slightly to not enlarged; in life, dorsally from light brown to tan with dark brown spots, blotches or mottling; sometimes a broad light brownish vertebral stripe; ventrally white with marbled throat in some specimens.

In Taita Hills, juvenile *A. angolensis* is similar to the *Ptychadena* species from which its can be distinguished by lacking lateral gular sac openings in males.

Distribution and life history: A widespread riparian species in sub-Saharan Africa. It is present in Dawida (Wundanyi, Piringa, Chawia, Iyale, Mghambonyi, Ngangao) and Mbololo (Mwambirwa, Wongonyi, Chale) blocks at altitudes of 1187 to 1750 m. Here it is present in permanent streams. It seems quite adaptable to human habitation (*e.g.* it occurs in Wundanyi town stream).

In Taita Hills, males call from the water, often floating near emergent vegetation. The call is biphasic, consisting of a series of clicks and a number of croaks, as described by Channing & Howell (2006). Axillary amplexus occurs and eggs are laid singly in shallow water. Tadpoles were found in shallow almost stagnant water on the edge of streams as well as on manmade dammed ponds for community water schemes. Tadpoles can be up to 60 mm in total length and are light brown and display LTRF 4(2-4)/3(1), but also LTRF 5(2-5)/3(1) and 6(2-6)/3(1) was found (Mwambirwa forest in Mbololo block, *e.g.* NMK A/4470). The larva of this species was described by Channing (2001), reporting LTRF 4(2-4)/3(1-2).

Conservation status: Global: LC. Local: NT. The species is restricted only at high altitudes and its habitat quality is declining because it is dependent on permanent streams many of which are turning to be seasonal due widespread erosion and water siphoning habits of eucalyptus trees in the Taita Hills. However, it is still present even within human habitation.

Pyxicephalus adspersus Tschudi, 1838

Diagnosis: Maximum SVL 230 mm with males being larger than females; tibia less than body length; dorsal snout rounded with three tooth-like projections on the lower jaw; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; tympanum distinct with distance between the eye and the tympanum greater than tympanum width; dorsal skin smooth to warty with a series of glandular elevated ridges (skin folds), sometimes continuous; toes and fingers are short and blunt; fingers free of web; inner metatarsal tubercle large and spade-like; in life, dorsally dark to olive green; ventrally white with the gular or throat being yellow (see also Parry 1982). Data was taken from references from adjacent localities since no material was found during the present study period. Adult *P. adspersus* are unlike any other species from Taita Hills while juveniles may be confused with *Hildebrandtia macrotympanum* (see above).

Distribution and life history: A widespread nocturnal savanna anuran of sub-Saharan Africa that is fossorial. It was previously recorded in Jora farms on the base of Mt. Kasigau at an altitude of 560 m.

According to Channing & Howell (2006), males call from shallow waters in dams and breeding takes place after heavy downpour. The call is low-pitched whoop that resembles the bellowing of cattle. Amplexus is axillary. The eggs are deposited on the edge of the pond or wetland. This species exhibits an elaborate parental or brood care. The male is often found near the eggs and/or near a school of tadpoles. Studies have shown that the male digs long channels to rescue tadpoles trapped within a drying pond to main pond (see Channing & Howell, 2006 and references therein). The tadpole is large, up to 71 mm and robust and assume grey colour at about 60 mm with LTRF 4(3-4)/3. The tadpoles are gregarious and always remain in shallow water. Metamorphosis in warm shallow pools may take as little as 18-33 days or up to 47 days in captivity (see Channing, 2001; Channing & Howell, 2006).

Conservation status: LC. Local: DD. The full extent of this lowland species is unknown. It appears to exhibit seasonal fluctuation in abundance since its breeding and activity seem to be dependent on heavy rains that are becoming rare and unreliable in the study area. This makes its breeding period to be opportunistic and restricted to a short period mainly following initial heavy downpour and whose timing is crucial.

Tomopterna cryptotis (Boulenger, 1907)

Diagnosis: SVL males 36.76-40.78 mm (*n* = 17), females 42.36-44.50 mm (*n* = 4); tibia length less than half SVL; horizontal eye diameter about twice the distance from nostril to anterior corner of eye; dorsal snout blunt and has three tooth-like projections on the lower jaw of both sexes; tympanum distinct with horizontal diameter slightly more than half the eye diameter; elongated white glandular ridge below tympanum; dorsal surface is slightly warty; only traces of foot webbing; inner metatarsal tubercle large and prominent, outer is absent; in life, dorsally pale brownish with various lighter and darker markings or with greyish to light brown blotches, often with a light brown blotch on the head and occasionally a light brown vertebral stripe; ventrally white except for the dark or black throats in males.

In the study area, this species can be confused with *Hildebrandtia macrotympanum* (see above). Again superficially these frogs resemble toads; however they lack the large parotid glands and the intensive warts present in toads (Stewart 1967).

Distribution and life history: A nocturnal fossorial species encompassing a large geographical range in eastern, central and southern Africa. It was found in loose sandy soil within farmlands in Dawida, Kasigau and Sagalla blocks (altitudinal range 563-1200 m).

Calling males were observed from the water edge in flooded pools and dams, sometimes in choruses, mainly after the onset of the rains in March and November. The call is a series of high-pitched notes (see Channing & Howell 2006). Amplexus is axillary and eggs are laid singly in shallow water. Tadpoles of this species were collected in Mt. Kasigau bushland in rock pools in April. The tadpoles are large bodied, reaching 39 mm long and brown and sometimes with darker markings with LTRF of 3(2-3)/3 (see NMK A/4604 & A/4605). In the study area, metamophs and juveniles were found in late April to late May.

Conservation status: LC. Local: LC. In Taita Hills, this species is abundant in suitable sites in farms especially at low altitudes. However, it appears to be active only within a short period after the onset of the rains and adults are quite rare afterwards.

Hyperoliidae

This consists of a large group of mostly tree frogs, many of which are brightly coloured. To aid in climbing the frogs have adhesive digital discs. Several genera exist with two; *Hyperolius* (arboreal) and *Kassina* (terrestrial) represented in Taita Hills.

Hyperolius glandicolor (Peters, 1879)

Diagnosis: Male SVL 28.99-34.61 mm (31.61±1.57), n = 27, that of females 29.34-34.87 mm (31.35±1.60), n = 23; tibia length almost half SVL; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; pupil horizontal; dorsal snout rounded; tympanum hidden; dorsal skin with scattered warts; foot webbing moderately expressed; subarticular tubercles well-developed, inner metatarsal tubercle small; semicircular terminal discs present in all toes and fingers; in life, females and some of the males, dorsum greatly variable pale grayish to brownish with brown marbling, yellow spots or annuli around warts, majority of males pale brownish or yellowish golden with grey blotches on lateral sides and groin; back of thighs and digits reddish or flesh pink; ventrally white except for the bright yellow gular flap in males.

In Taita Hills, this species can be confused with *Leptopelis concolor* (see above) and *Hyperolius tuberilinguis* which is smaller and in life has yellowish golden and green colours. See also under *Chiromantis* below.

Distribution and life history: A nocturnal tree frog known from Taita Hills and its environs (Schiøtz 1999). In the study area it is quite abundant in reed swamps and densely vegetated dams, water lily covered ponds as well as grassy water pools associated to farms, forests and forest plantations. It is the most popular tree frog with the local inhabitants and has been recorded in all sites, except Mt. Kasigau, at altitudes from 839 to 1750 m.

Hyperolius glandicolor is a prolonged breeder which in Taita Hills may reproduce throughout the year but with peaks during the March and November rains. Males call from a variety of sites including on the ground, rocks, tree logs, water edge, vegetation growing in or adjacent to water (reeds, sedges, weeds, grasses), on water lily leaves, rocky outcrops and various crops such as maize, sugar cane, arrow roots, bananas and cassava. The call is a brief xylophone-like click but males sometimes also produce a creaking aggressive call (for call description see Channing & Howell, 2006). Amplexus is axillary and the egg masses are deposited directly into water or on leaves of vegetation above water and then washed into water. The free swimming grey to dark brown tadpoles attain up to 30 mm total length and have the general *Hyperolius* LTRF of 1/3 (see NMK A/4352).

Conservation status: Global: LC. Local: LC. This species is locally abundant in suitable habitats on farms and forest edges and quite adaptable to human modified habitats.

Hyperolius tuberilinguis Smith, 1849

Diagnosis: Male SVL 26.48-32.93 mm (30.02±1.79), *n* = 16; female SVL up to 40 mm; tibia length almost half SVL; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; pupil horizontal; dorsal snout rounded; tympanum not distinct; dorsal skin is smooth; foot webbing moderately expressed; subarticular tubercles well-developed, inner metatarsal tubercle small; semicircular terminal discs present in all toes and fingers; in life, in females and part of the males, dorsum uniform green or yellow, majority of males yellowish golden and green with an indistinct hour glass pattern; ventrally yellowish and/or white with a yellow gular flap in males; hidden parts of legs and digits golden yellow.

In the study area, *H. tuberilinguis* can be confused with the sympatric *H. glandicolor*, *Leptopelis concolor* and *Chiromantis petersi* (see above and below, respectively).

Distribution and life history: This nocturnal savanna tree frog inhabits the East African coast from Kenya south to southern Africa. In Taita Hills (Mwatate area), it can be found in reed and sedge fringed Mwatate dam and swamp including those with water-lilies at an altitude of about 840 m.

In the study area this species breeds during the rain seasons of March-May and October-December. Males were found calling (mainly concealed) from reeds and other low vegetation. The call is a sharp click or tap as described by Schiøtz (1999). Axillary amplexus occurs. The 236-400 whitish eggs are deposited in a mass shortly above the water surface on vegetation. According to Schiøtz (1999), the LTRF is 1/3.

Conservation status: LC. Local: NT. The species restriction to only a small area in Mwatate swamp makes it to qualify for near threatened category. It also exhibits seasonal population fluctuation by being virtually absent at certain times.

Kassina senegalensis (Duméril & Bibron, 1841)

Diagnosis: Male and female SVL 32.4-42.05 mm (37.76±2.44), $n = 24$; tibia less than half SVL; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; dorsal snout rounded; males with strap-like gular flap; tympanum distinct, its horizontal diameter almost half the eye diameter; toes with trace of webbing only; toes and fingers with small swelling at tip; dorsal skin smooth; in life, dorsally grey to bronze with black spots and sometimes with an anterior vertebral stripe that ends at about the mid of back or a dark vertebral band; ventrally whitish except the greyish gular flap in males. *Kassina senegalensis* cannot be confused with any other species in Taita Hills. However, on the ground *Kassina senegalensis* walks rather than hops just like *Phrynomantis bifasciatus* but *Kassina senegalensis* lacks any reddish marks.

Distribution and life history: A widespread terrestrial and sometimes climbing nocturnal anuran, commonly associated with dry and moist savanna of sub-Saharan Africa (see Schiøtz 1999). It was found near reed swamps and man-made dams in farmlands of Sagalla, Mwatate and Kasigau areas at altitudes between 563 and 1081 m.

It was observed breeding during the two rainy seasons, *i.e.* around March and November, when males called from shallow water often concealed under vegetation cover. The call is a rising note that sounds like a bursting water bubble (described by Channing & Howell 2006). Amplexus is axillary and eggs are deposited in small masses into the water. The tadpoles are large up to 80 mm long with a high fin and dark with red or orange markings on the fin. The LTRF is 1/2(1) (see Channing & Howell 2006).

Conservation status: LC. Local: LC. In Taita Hills, this species is locally abundant in suitable sites when present though with seasonal variation in abundance.

Rhacophoridae

A group of tree frogs with a specialized mode of reproduction in which eggs are laid in nests made of foam produced by secretions from the female. Characteristically the fingers of each hand are arranged in opposing pairs, which help in grasping thin branches. They have large adhesive discs on the tips of digits that also assist in climbing. Two species occur in Taita Hills.

Chiromantis kelleri Boettger, 1893

Diagnosis: Male SVL 37.06-55.70 mm (44.76±7.28), *n* = 12, female SVL 61.45-79.43 mm (71.70±6.93), *n* = 8; tibia length almost half SVL; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; pupil horizontal; dorsal snout rounded; tympanum distinct, its horizontal diameter slightly more than half eye diameter; dorsal skin rough and warty; foot webbing moderately expressed; subarticular tubercles well-developed, inner metatarsal tubercle small; semicircular terminal discs present in all toes and fingers; dorsal life colour is grey-white with dark speckling or blotches/spots; ventrally white except for the greyish throat in males.

Chiromantis kelleri is similar to *C. petersi,* co-occuring in Taita Hills (Poynton 2000). But the former has larger discs on toes and more extensive webbing between the outer fingers. *Hyperolius* species and *Leptopelis concolor* have rather smooth dorsal skin. Again *Leptopelis concolor* has vertical pupil and proportionally bulgy eyes.

Distribution and life history: An East African lowland savanna to arid bushland tree frog ranging from Tanzania northward to Somalia and adjacent Ethiopia (*e.g.* Loveridge 1957, Schiøtz 1999, Largen 2001). This species is present at the base of the Mt. Kasigau and the surrounding environs at an altitude of about 600 m. It was found on vegetation at dams and in temporary wetlands where it breeds. Males were found calling during the rains in November and December but reproduction may take place during both rainy seasons. The call is a slow croaking, with isolated clicks (Channing & Howell 2006). Axillary amplexus occurs. Foam nest were found on grass tussocks and short bushes overhanging the water. Tadpoles develop within the foam nest before they drop into water below were development continues.

Conservation status: LC. Local: DD. In Taita Hills, the full extent of this species is unknown. This species seem to show seasonal fluctuation in abundance.

Chiromantis petersi Boulenger, 1882

Diagnosis: Male SVL 36-41.67 mm (39.23±1.94), *n* = 12, female SVL 49.72-53.25 mm (51.71±1.49), *n* = 5; tibia length almost half SVL; horizontal eye diameter greater than the distance from nostril to anterior corner of eye; pupil horizontal; dorsal snout rounded; tympanum distinct, its horizontal diameter slightly more than half eye diameter; dorsal skin is rough with small warts; foot webbing moderately expressed; subarticular tubercles well-developed, inner metatarsal tubercle small; semicircular terminal discs present in all toes and fingers; dorsal life colour is greyish to brownish; ventrally white except for the greyish throat in males.

Chiromantis petersi is most similar to *Chiromantis kelleri* (see above) see Poynton (2000). *Hyperolius* and *Leptopelis concolor* have relatively smooth dorsal skin.

Distribution and life history: An East African lowland tree frog from bushland in Tanzania and Kenya (see Loveridge 1957, Schiøtz 1999). In Taita Hills, it was recorded in Kasigau and Sagalla blocks with an early record from Mwatate. There it can be found at and near dams or temporary swamps in farmland within an altitudinal range of 563-1081 m but quite abundant mainly below 1000 m.

The species breeds in dams, temporary water pools during both March and November rains. Males call either while sitting on the ground near the water edge or on short bushes and grass up to about 2 m high. The call is a series of quiet creaks with pulses as described by Channing & Howell (2006). Axillary amplexus is exhibited. Foam nest were found on grass tussocks and short bushes overhanging the water. In general tadpoles of

Chiromantis develop from eggs while within the foam nest before dropping into water where they swim freely (see Schiøtz 1999).

Conservation status: LC. Local: LC. This species is abundant in suitable sites within Taita Hills including human modified habitats with no observable decline.

5.4 DISCUSSION

The amphibian species account presented here shows that Taita Hills is far more diverse than has previously been realised (*e.g.* Loveridge 1957, Beentje 1988, Bytebier 2001). The previous studies provided species (less than 10) only found on the high altitude areas, whereas the current one covered the entire elevational gradient from the base of the hills and recorded 26 hence presenting a better coverage of the ecosystem.

There were new species, records and range extensions of now more than 10 additional amphibian species. The caecilian *Boulengerula niedeni* is a newly described species endemic to Sagalla Hill. *Boulengerula taitana* was previously known only from the Dawida and Mt. Mbololo but its range is now extended to Mt. Kasigau, while the brevicipitid (*Callulina* sp.) in addition to Dawida, it is present in Mt. Mbololo. The East African lowland tree frogs, (*Hyperolius tuberlinguis* and *Leptopelis concolor*) are new range extensions for Kenya.

Species identifications offered here have removed anomalous records, for example *Arthroleptis adolfifriederici* Nieden, 1911 by Loveridge (1957) is actually the widespread East African lowland *Arthroleptis xenodactyloides*. The species *Hyperolius glandicolor* previously thought to be restricted to the Taita Hills and its environs is now recognized by some authors (*e.g.* Channing & Howell, 2006) as a widespread species complex in East African highlands. It includes the former subspecies of the *Hyperolius viridiflavus* (Duméril & Bibron, 1841) complex *e.g. H. v. ferniquei, H. v. pantherinus, H. v. goetzei, H. v. ngorogoroensis, H. v. pitmani* and *H. v. ommatostictus* (Schiøtz, 1999; Channing & Howell, 2006). The Taita Hills *Callulina* previously thought to be *Callulina kreffti* is an un-described endemic species.

Many of the Taita Hills' species represent widespread taxa, however the few forest endemic, high altitude and/or forest associated species are of conservation importance. The continued survival of these species appears to hinge on the protection of indigenous forest fragments. We stress the importance of protection of forests communally or privately owned including planting of more indigenous over exotic trees.

5.5 SUMMARY

Amphibian populations continue to decline due to the imminent threats they are facing. Accumulation of basic knowledge on systematics, distribution and life history of species is pivotal in formulation of conservation action. For many species, especially in species-rich tropical countries, such data are lacking, and in some areas like the Taita Hills (one of the Eastern Arc Mountains) they are poorly known. Such results for the Taita Hills (*i.e.* Dawida block, Mt. Mbololo, Sagalla Hill, Mt. Kasigau) are presented here based on field surveys undertaken mainly during the period from 2005 to 2007 covering a cross-section of habitat types (farms, forests, plantations) from the base of these hills to the top. Accompanied by information compiled from scientific collections and literature 26 species in two orders and 12 families are listed. Three of these species are endemic to the Taita Hills. For each species diagnostic characters, distribution, life history information is provided, completed by an assessment of its conservation status. Broadly, the amphibian species comprise three ecological/biogeographical assemblages: (i) widespread, (ii) forest associated and/or high altitude, (iii) lowland. One caecilian species, *Boulengerula niedeni,* is categorized as Critically Endangered (CR) under IUCN Red List criteria, and I propose that another species, an undescribed frog in the genus *Callulina*, should fall in the same category. The new survey data significantly elevate the biological importance of the Taita Hills within the Eastern Arc Mountain chain. The surveys recorded high levels of disturbance within most of the forest reserves and attention is drawn to the need for additional conservation investment to the forest habitats. Future conservation efforts should encourage all local activities that are likely to preserve village indigenous forests (sacred groves) including replanting of indigenous trees in the Taita Hills. Additionally, all remaining indigenous forest fragments should be given highest conservation priority and efforts should be considered to either connect or buffer smaller and/or all remaining forest fragments through indigenous tree reforestation programs.

6 LIFE HISTORY OF A BREVICIPITID FROG, *CALLULINA* SP.: (AMPHIBIA, ANURA, BREVICIPITIDAE)

6.1 INTRODUCTION

Amphibians are experiencing more population declines than any other vertebrate group (Stuart *et al.* 2004, Roelants *et al.* 2007) due to habitat loss and fragmentation, diseases and pathogens, invasive species, global warming, over-exploitation and pet trade, UV-radiation, and environmental pollution (Taylor & Jones 2002, Stuart *et al.* 2004, Cushman 2006, Roelants *et al.* 2007). Habitat loss and fragmentation (see Fahrig 2002, 2003) is the major cause of the observed global amphibian population declines (see Funk *et al.* 2005, Bell & Donnelly 2006, Cushman 2006) and is highest in the species rich tropical regions (Jha *et al.* 2005). One of the highly fragmented areas is the East African montane forests of the Eastern Arc Mountains (EAM); with Taita Hills forests being the most fragmented and threatened (see Newmark 1998, Burgess *et al.* 2007). Animal populations within such isolated small fragments are ecologically and genetically vulnerable to loss due to inbreeding, genetic drift, 'bottleneck' and 'founder effects' (see Spellerberg 1991, Beebee 2005, Cushman 2006).

The rate at which amphibian species are declining as a result of human activities is of significant concern to ecologists and conservation biologists (Dodd & Cade 1998). Surprisingly, amphibian extinction risks and population declines are taxonomically non-random (see Stuart *et al.* 2004, Bielby *et al.* 2008), indicating that species biological attributes influence susceptibility to decline: large size, low fecundity, rainforest endemic specialists, breeding in streams; narrow habitat tolerances, restricted range, living at high altitude and low vagility (Murray & Hose 2005, Cushman 2006 and references therein; Bielby *et al.* 2008 and references therein). Determining these particular biological traits is important in species conservation management and planning (see Budischak *et al.* 2006, Bielby *et al.* 2008).

Despite the exceptionally high amphibian diversity and abundance in many ecosystems they are occasionally misrepresented in biodiversity estimates due to their secretive nature, nocturnal habits, and small ranges or because of a general lack of understanding of their life histories (Taylor & Jones 2002). Knowledge on the life history of many amphibians is limited while some; even the most basic biological data is lacking (Donnelly & Guyer 1994). The Brevicipitids (*Breviceps, Balebreviceps, Probreviceps, Callulina* and *Spelaeophryne*) range from South Africa through East Africa to the Bale Mountains of Ethiopia (Frost 2007). Brevicipitids are typically cryptic and spend much of their time in soil and/or leaf litter (*e.g.* Barbour & Loveridge 1928), a behaviour that partly accounts, for the paucity of life history information. A number of brevicipitids exhibit some form of parental care. There are reports of females found with a clutch of eggs in *Probreviceps* (Barbour & Loveridge 1928, Poynton & Broadley 1967); but these are mainly in burrows while that for *Callulina* is on a ground nest-like structure. This close similarity is expected as *Probreviceps* is the sister genus to *Callulina* (see Frost *et al.* 2006). The genus *Callulina* is endemic to the EAM forests of Tanzania and Kenya with currently two species known: *Callulina kisiwamsitu* and *Callulina kreffti* (De Sa *et al.* 2004), but several more are in the process of description (M. Menegon pers. comm.). Species in this genus are mainly forest dwellers, good climbers and lay eggs that are presumed to develop directly into young frogs (Barbour & Loveridge 1928).

Callulina sp. is endemic to Taita Hills and its distribution, abundance and density among the forest fragments is expected to vary following the species-area relationship (MacArthur & Wilson 1967). Studies have also shown that both intrinsic (body size or egg size) and extrinsic factors (environmental) affect the biology of amphibians and hence their abundance (Duellman & Trueb 1994). Extrinsic factors such as temperature, rainfall and altitude are interrelated (see Morrison & Hero 2003, Lai *et al.* 2003, Navas 2006, Summers *et al.* 2007). Understanding the species required habitat characteristics will form a basis for identification of important forest fragments which should be targeted for conservation investment.

In this study, I evaluated data from 30 months capture and mark-recapture study of the Taita warty frog in the Taita Hills. I examined the species ecological and breeding characteristics. I tested the following hypotheses: 1) All remnant moist indigenous forest fragments have Taita warty frog irrespective of forest size, 2) the distribution and abundance of this frog is independent of mean monthly temperature, rainfall and elevation, 3) Taita warty frog eggs are terrestrially deposited anywhere in the forest. In addition to testing these hypotheses, this study documents other general life-history traits of this brevicipitid frog.

6.2 MATERIALS AND METHODS

6.2.1 Taxonomy

Callulina sp. is characteristically very similar to *Callulina kreffti* Nieden, 1911 to which it has earlier been referred (Beentje 1988). However, phylogenetic analysis has shown that it is a different species (Loader, Malonza & Measey in prep). Morphologically, the size that male *Callulina kreffti* reach 25mm is below that recorded for *Callulina* sp but the female size (about 47 mm) is within the range of Taita material see (Barbour & Loveridge 1928, Channing & Howell 2006). In addition, in *Callulina kreffti* the distance between the eye and the tympanum is equal to tympanum diameter whereas in Taita *Callulina* sp they are not equal. From the ongoing analysis of species in the genus *Callulina,* it appears that the present species are mountain block endemics (De Sa et al., 2004) and hence the now EAM widespread *Callulina kreffti* is endemic to East Usambara Mountains (M. Menegon pers. com.).

6.2.2 Study area

I studied *Callulina* sp. within the Taita Hills (Dawida, Mbololo, Sagalla and Kasigau blocks) in selected sites within forests, plantations and farms at varying altitude and habitat disturbance gradients (see Chapter 4 for more details).

6.2.2 Methods

This study relates to a 30 months (between December 2004 and March 2008) data collection on *Callulina* sp. Sampling was accomplished by use of standardized night transect walks and trapping for quantitative data while day time-limited-searches generated qualitative data (see Chapter 4 for details on these methods).

6.2.2.1 Capture-mark-recapture

From September 2006 in Ngangao, Chawia and Mwachora and later in Fururu, Ndiwenyi and Vuria, captured frogs were marked by inserting a numbered alpha-numeric tag (VIAlpha, North-West Marine, USA) subcutaneously on the ventral surface of the thigh and released for later identity after recapture. A Pesola spring balance (Max. 60g) was used to take body mass (to the nearest 1 g) while snout-vent-length (SVL) was measured using a ruler (to the nearest 1 mm). Age classes were defined using SVL size ranges. Voucher specimens were processed like other amphibians (see Chapter 5) and for *Callulina* sp are provided in appendix 9.5).

6.2.2.2 Statistical analyses

All quantitative analyses used data from traps as transect data was not quite productive in terms of number of individuals recorded. One sample t-test was used to test the variation in abundance among the forest fragments. Non-parametric Spearman Rank Correlation was used to test the influence of forests size, temperature and rainfall on abundance. Chi-square was used to test monthly age group variation in abundance and to test whether abundance was associated with altitude. Data were analyzed with STATISTICA 6.0 (StatSoft 2001).

6.3 RESULTS

6.3.1 Species diagnosis

Callulina sp is a medium sized frog with females reaching 55 mm and males 35 mm. The toes of the hind feet are arranged in two opposable groups, with the fourth and fifth together, pointing posteriorly when walking on the forest floor. The skin is warty and dorsal adult colour is variable from light brown, grey, dark brown, orange to yellowish. In terms of colouration there is no well-marked sexual dimorphism. Using SVL, the frog population was grouped into four age groups: juveniles (< 20 mm), sub-adults (20-30 mm) and adults > 30 mm).

6.3.2 Population and habitat characteristics

From December 2004 until March 2008, 101 *Callulina* were recorded. Twenty one frogs were recorded in traps and seven in transects (Table 6.1). The majority of the rest were from time-limited-searches or opportunistic visual encounter surveys and leaf-litter sampling (Appendix 9.1). Thirty three individuals were marked with three recaptures (see Appendix 1). The SVL of the largest live adult and the smallest juvenile recorded in this study were 55 mm and 9 mm, respectively. Characteristically frogs were found in micro-habitats such as on or under leaf litter, debris and within decomposing logs.

Callulina sp was only found in indigenous forest fragments of varying sizes above an altitude of 1400 m. No individuals were found in typical farmland or plantation habitats, and none were found to be present in Sagalla or Kasigau (see Table 6.1).

6.3.3 Distribution and forest size

There was a highly significant discernable monthly age group variation in distribution and abundance ($\chi^2 = 20.31$, *d.f.* = 2, $n = 12$, $P = 0.00004$). While adults could be caught in most months of the year; most of the juveniles were only trapped in January and February (see Table 6.2). There is a significant difference in the mean number of individuals trapped in the four forest fragments (one sample-test; $t = 4.17$, *d.f.* = 3, $n = 4$, $P = 0.025$). Consequently a high number of individuals were recorded in Ngangao relative to any other forest fragment. However, there is a negative and insignificant (Spearman Rank Correlation; $R = -0.316$, *d.f.*= 2, $t = -0.47$, $P = 0.68$, $n = 4$) relationship between the logarithm of the forest size and abundance. Consequently the highest number of individuals was recorded in Ngangao and the least in Mbololo, which is the largest forest fragment (Table 6.2).

6.3.4 Influence of rainfall, temperature and altitude

Spearman Rank Correlation showed that *Callulina* abundance was positively and significantly influenced by mean monthly temperature ($t = 2.39$, $P = 0.037$, $R = 0.60$, $n = 12$) and there was no effect of rainfall with this data set. Consequently individuals are commonly recorded during the warm months of January to March and August to October and less during the cold months of June and July. They are also few to none during the peaks of rain seasons in April and November/December (Table 6.2). Results also demonstrate a significant ($\chi^2 = 8.0$, $d.f. = 2$, $n = 4$, $P < 0.018$) association between altitude and abundance. Hence the species is most abundant in the high altitude Ngangao forest fragment (see Table 6.1).

Table 6.1. The number of *Callulina* sp. individuals recorded in different study sites from trapping and transect methods. The number of trapping sessions (3 arrays), transect walks are given in parentheses. Some characteristics of the sites (size in ha and approximate maximum elevation in m) are given.

Site	**Size**	**Elevation**	**Traps**	**Transects**
Indigenous forests				
Ngangao	192	1952	11 (141)	1 (18)
Chawia	50	1625	4 (146)	0 (17)
Mwachora	3	1650	4 (131)	0 (17)
Macha	3	1700	-	0 (15)
Boma	0.25	1460	-	0 (18)
Mbololo	220	1779	2 (123)	6 (21)
Sagalla	3	1500	0 (132)	0 (15)
Kasigau	20	1645	0 (32)	0 (19)
Plantations				
Kinyesha-mvua	50	1642	0 (98)	0 (14)
Sungululu	50	1450	-	0 (17)
Mwambirwa	340	1500	0 (134)	0 (17)
Sagalla	70	1500	0 (20)	0 (17)
Farms				
Ngulu dam	-	1600	-	0 (14)
Chale	-	1236	-	0 (16)
Mwalenjo	-	1292	-	0 (19)
Mwasange	-	1309	0 (26)	0 (19)
Mghange	-	1273	-	0 (12)
Kauze	-	1081	-	0 (17)
Lata dam	-	1064	-	0 (19)
Mtangoni	-	1100	0 (297)	-
Piringa	-	1187	0 (142)	0 (17)

Mndangenyi	-	1397	-	0 (16)
Mbirwa	-	1430	-	0 (17)
Mghambonyi	-	1546	0 (70)	0 (13)
Makandenyi	-	1647	-	0 (13)

Table 6.2 Monthly abundance records of juvenile and adult *Callulina* sp. in traps.

Month	**Juveniles**	**Adults**
January	5	0
February	4	1
March	1	2
April	0	1
May	0	2
June	0	0
July	0	0
August	0	1
September	0	2
October	0	2
November	0	0
December	0	1

6.3.3 Breeding and other behavioural characteristics

Results from time-limited searches showed that *Callulina* sp breeds during the long dry season which runs from June to October. In August a three note strong trilling call was heard from a male in Mwachora and Chawia forests, and the same call had been heard earlier in July. On 12th September, 2007 in Fururu forest a female (45 mm, 7.5 g, Appendix 9.5) was found on leaf litter sitting on a clutch of 30-40 eggs (2-mm diameter egg capsule) bound together. When displaced she returned to sit on the eggs. The female was then visited on 21st November, 2007 and found on the same state until 29th November when only 6 eggs remained with the female still sitting on them. The smallest juvenile (9 mm) recorded was found on 6th December, 2005 perched on grass within a safari ants (*Dorylus molestus*) infested forest site in Fururu.

Callulina sp is normally solitary except on two occasions in Mbololo forest where during night transect walks two adult individuals were found less than a meter apart and two juveniles only a meter apart. One of the adults which had been found perched on a sloping dry thin branch about 30 cm off the ground, was subsequently found on the same site and position the following night. On the forest floor the frog mainly walks but can also make short hops. When disturbed, while walking it tends to stay immobile, inflates itself or freezes before proceeding. Information gathered from three marked and recaptured individuals indicates that the species movement is limited; (a) An individual of 20 mm had moved about 25 m after 8 months with a new SVL of 42 mm. (b) An adult of 35 mm was recaptured about 7 m away having increased in SVL to 48 mm after 7 months. (c) An adult of 48 mm was recaptured about 30 m away after 7 months with no change in body length.

6.4 DISCUSSION

The results presented here provide evidence that *Callulina* sp occur in all indigenous forest fragments within Dawida and Mbololo blocks of Taita Hills at an altitude above 1400 m. These fragments range from < 1 ha to 220 ha (see Brooks *et al.* (1998) It is absent in typical farmland and plantation habitats as well as the isolated indigenous forest fragments in Mt. Kasigau and Sagalla Hill. Its absence in these two blocks is presumably due to their physiological isolation from Dawida and Mbololo (see details on EAM isolation in Chapter 3). Results on monthly distribution showed age group variation in abundance and for juveniles it reflects the time of their recruitment.

The results of trapping showed that the number of individuals recorded was independent of forest fragment size. This means that this species can survive in tiny forest patches though continued population viability within such small isolated patches is questionable due to associated ecological and genetic problems (see Spelleberg 1991, Beebee 2005, Cushman 2006).

Ngangao forest had the highest number of individuals captured. This suggests that it has a combination of the best habitat characteristics for the occurrence of this species. The results showed that abundance of the *Callulina* sp is influenced by temperature with more individuals recorded during the warm months of the year in Taita Hills (see Jätzold & Schmidt 1983). This coincides with the periods of moderate to high temperatures and humidity. No individuals were recorded in July which is the coldest month in Taita Hills (see Measey *et al.* 2008). These observations concur with other studies that have shown that temperature affects amphibian populations through its effects on growth and development (see Morrison & Hero 2003). It was also found that more individuals were recorded in high altitude forest of Ngangao. Elsewhere studies have found that altitude and its relation with temperature has negative effects on amphibian population (*e.g.* Navas 2006). However, *Callulina* sp. is a high altitude species and with increased altitude it appears to thrive more possibly due to reduced competition from other species. Rainfall was however, not found to influence species abundance with this data set. It may be that with a better data set this effect is found as many previous studies have generally found that rainfall and temperature directly affect food availability which in turn affects amphibian population through growth and development (Morrison & Hero 2003, Summers *et al.* 2007). Other studies have found rainfall to be the most important abiotic factor influencing tropical anuran reproduction by affecting/regulating the timing and length of breeding season in open (water) site breeders (see Donnelly & Guyer 1994).

The results suggest that, *Callulina* sp start breeding with calls mainly during the long dry season from around July. Then from the single clutch observation, eggs are deposited on leaf litter in September and the mother broods them for three months until November, a relatively long egg hatching duration expected in high altitudes (see Morrison & Hero 2003). While a clutch of 30-

40 capsulated eggs was found, it was only 6 that were found towards the end of the incubation. Similarly on another brevicipitid (*Probreviceps macrodactylus macrodactylus*), Müller *et al.* (2007) found a clutch of 32 eggs including 21 infertile jelly-filled capsulated eggs laid during the dry season. They predicated that infertile jelly-filled egg capsules prevent the fertile eggs from desiccation during this dry period. This form of parental care is not new as it has been recorded in other brevicipitids *e.g. Probreviceps uluguruensis* and *Probreviceps macrodactylus loveridgei* (see Barbour & Loveridge 1928) and *Probreviceps rhodesianus* (Poynton & Broadley 1967). These results also show that *Callulina* sp. similar to some other brevicipitids, lay relatively small clutch of large yolk-rich eggs that are buffered by infertile jelly-filled egg capsules. This finding concur with others that have shown that direct developing high altitude species (montane) produce relatively small clutches of large yolk-rich eggs and exhibit increased parental care (*e.g.* Summers *et al.* 2006, Summers *et al.* 2007).

The results also suggest that growth and development in *Callulina* sp is fast attaining sexual maturity within 8 months. This rapid attainment of a reproductive size is expected in tropical areas where temperatures are high and many anurans grow throughout the year (see Duellman & Trueb, 1994; Morrison & Hero 2003).

6.4.1 Conservation and management strategy

The species is restricted to severely fragmented indigenous forests. Again the extent of occurrence, area of occupancy and habitat quality is inferred to continue declining. A combination of these factors makes the species to qualify for listing in the critically endangered (CR) category (B1a&b (i,ii,iii,iv). To ensure a comprehensive protection of *Callulina* sp, all currently known indigenous forest fragments should be accorded some form of protection. However, this may not be wholly feasible due to differing land tenure and use rights (communal/trust/private). I suggest a step-up of the current protection status of most of the forest fragments that are now trust lands to national forest reserve. In addition I recommend promotion of local initiatives that encourage preservation of private or community sacred forest groves including potential habitat corridors (*e.g.* riverine forests) that connect forest fragments. Local people education and awareness campaign involving reforestation programmes to plant more indigenous trees over exotics should be promoted.

6.5 SUMMARY

Frog populations are rapidly disappearing throughout the world and an important issue to resolve is why some species are more susceptible to decline than others. Evidence exist that susceptible species possess particular biological attributes. Understanding species life histories and environmental factors responsible would greatly aid conservation prioritization and planning. Herein I examined the life history and habitat characteristics of *Callulina* sp, a frog endemic to the Taita Hills. This brevicipitid is a medium sized (adult males body length 35 mm and females 55 mm) brownish terrestrial and arboreal frog. Sampling was accomplished mainly by use of standardized trapping. The results show that this species likely occur in all indigenous forest fragments only in Dawida and Mbololo blocks at an altitude above 1400 m and is abundance is independent of forest size. It is absent in typical farmlands and plantations as well as in indigenous forests of Kasigau and Sagalla blocks. Mean monthly temperature, altitude but not mean monthly rainfall significantly influence the species distribution and abundance. It is rare or absent during the cold season and vice versa. Its abundance appears to increase with altitude, a factor that explains the species high abundance in Ngangao forest. Temperature, rainfall and altitude are factors known to act in synergy and influence amphibian distribution patterns. This species breeds during the long dry season (June to October) with juveniles being abundant between January and March. There is evidence that this species deposits a cluster of large yolk-rich eggs on forest floor and exhibits parental care. Growth and development to sexual maturity is rapid and attained in a less than a year. Its occurrence only within highly fragmented indigenous forests makes the species worth listing as critically endangered (CR) B1a&b (i,ii,iii,iv). To continually conserve this species, the conservation status of the remaining indigenous forest fragments should be stepped up. In addition efforts should be made to promote and create community awareness to continue preserving communal and private forest patches including potential habitat corridors and to plant more indigenous trees over exotics.

7 GENERAL DISCUSSION AND CONCLUSIONS

This study supports the hypothesis that global biodiversity is not evenly distributed across regions (see *e.g.* Crist & Veech 2006) and that the un-even threats to biodiversity are increasing and vary among taxonomic groups (Burgess *et al.* 2006). In an effort to understand the patterns of amphibian biodiversity among the EAM, this study found that rainfall was the major explanatory factor and not that of remaining forest area as found by Doggart *et al.* (2006) and Burgess *et al.* (2007).

My findings are in support of previous studies on a variety of taxonomic groups that water (rainfall) together with energy (temperature) from solar radiation drives plant productivity and both contribute to species richness in warm tropical climates (see Hawkins *et al.* 2003b). This study does not support the species-area relationship hypothesis in identifying important areas for conservation (Magurran 1988, Rosenzweig 1995). It also discredits the use of a single taxon distribution data (see Burgess *et al.* 2006) as well as use of combined taxonomic classes' data in prioritization of conservation sites. The former approach has the limitation of leaving-out areas of importance to other biological groups while the latter would mask the contribution of certain taxa. There is therefore support that species distribution patterns and their response to habitat change are governed by individual species' biological traits (see *e.g.* Ewers & Didham 2006, Bell & Donnelly 2006).

Within Taita Hills, the study shows that amphibian distribution and abundance along anthropogenic and altitudinal gradients is influenced by rainfall and temperature, well known surrogates for habitat productivity (see van Rensburg *et al.* 2002, Sanders *et al.* 2003). The study supported the hypothesis that sites with similar environmental variable (rainfall, temperature, and altitude), disturbance level and in close proximity geographically (Ernst & Rödel 2005) harbour similar amphibian species assemblages. It was also found that overall amphibian species richness increased with increasing human habitat disturbance from indigenous forests to farmlands as observed elsewhere (*e.g.* Lea *et al.* 2005) but contrasts other previous findings (*e.g.* Vallan 2002, Pineda & Halffter 2004). However, species richness of reproductively direct developing species decreased suggesting loss of the conditions crucial to survival of this group of species. The importance of considering specific species biological attributes in diversity patterns analysis was evident from results of *Callulina* sp. It was found that the distribution and abundance of this high altitude forest-associated frog was influenced by mean monthly temperature and altitude but not by mean monthly rainfall contrasting many previous studies on a broad range of taxonomic groups (see Hawkins *et al.* 2003b).

7.1 Conservation and management implications

Prioritization of conservation areas has never been comprehensive in protecting all components of biodiversity (ecosystems, species and genes). Many have targeted areas of either high species richness and/or endemism alongside other ecosystem goods and services. The challenge has been that rarely you find sites with a combination of these factors. The results of this study show that even the largest forest fragment (Mbololo) is not sufficient to preserve the amphibians of Taita Hills. Despite hosting all the species susceptible to forest loss *i.e.* direct developers, most of the amphibian species occur in human modified habitats. Therefore conservation strategies for Taita Hills' amphibians could benefit from taking multi-scale; landscape-level approaches that integrate knowledge of species biology. Hence, maintenance of a set of forest fragments extensively distributed (attitudinally and spatially) together with the human modified habitats appears to be an appropriate conservation strategy. In particular the results show that the *Callulina* sp should be listed as critically endangered (CR) B1a&b (ii,iii). This species meets these criteria because geographically its populations are severely fragmented while its extent of occurrence, area of occupancy, quality of habitat and number of locations are inferred to continue declining (see IUCN 2001).

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9 APPENDICES

Appendix 9.1: Distribution of endemic and non-endemic amphibian species across the EAM of Tanzania and Kenya.

Species	Udz	Mah	Mal	Rub	Ulu	Uka	Ngur	Ngu	EU	WU	SP	NP	Tai
ANURA													
Amietophrynus brauni (Nieden,1911)	x				x		x		x	x			
**Amietophrynus uzungwensis* (Loveridge,1932)	x												
Nectophrynoides asperginis Poynton *et al.* 1999	x												
Nectophrynoides cryptus Perret, 1971					x								
Nectophrynoides frontieri Menegon *et al.* 2004									x				
Nectophrynoides laevis Menegon *et al.* 2004					x								
***Nectophrynoides laticeps* Channing *et al.*						x							

2005								
Nectophrynoides minutus Perret, 1972			x	x				
***Nectophrynoides paulae* Menegon *et al.* 2007					x			
Nectophrynoides poyntoni Menegon *et al.,* 2004	x		x	x				
Nectophrynoides pseudotornieri Menegon *et al.* 2004				x				
**Nectophrynoides tornieri* (Roux,1906)	x	x			x	x	x	x
Nectophrynoides vestergaardi Menegon *et al.* 2004								x
**Nectophrynoides viviparus* (Tornier, 1905)	x		x	x				
Nectophrynoides wendyae Clarke, 1989	x							
Stephopaedes usambarae Poynton & Clarke, 1999							x	
Churamiti maridadi Channing & Stanley, 2002					x			

Callulina kreffti Nieden, 1911	x				x	x	x	x	x		x	x	
Callulina kisiwamsitu De Sa *et al.* 2004										x	x		
***Callulina* sp.													x
Hoplophryne rogersi Barbour & Loveridge, 1928	x				x			x	x				
Hoplophryne uluguruensis Barbour & Loveridge, 1928	x				x		x	x					
Parhoplophryne usambarica Barbour & Loveridge, 1928									x				
***Probreviceps durirostris Loader et al.* 2006						x							
Probreviceps m. macrodactylus (Nieden,1926)							x		x	x		x	
***Probreviceps m. Loveridgei* Parker, 1934	x				x								
**Probreviceps rungwensis* Loveridge, 1932	x												
Probreviceps uluguruensis Loveridge, 1925					x								
**Spelaeophryne methneri* Ahl, 1924	x	x			x								
**Amietia angolensis* (Bocage, 1866)	x	x	x	x	x	x	x	x	x	x	x	x	x

Arthroleptides martiensseni Nieden, 1910				x		x		x	x			
Arthroleptides yakusini Channing *et al.* 2002	x	x		x								
Phrynobatrachus krefftii Boulenger, 1909								x	x		x	
**Phrynobatrachus rungwensis* (Loveridge, 1932)	x											
**Phrynobatrachus parvulus* (Boulenger, 1905)	x											
Phrynobatrachus uzungwensis Grandison & Howell, 1983	x			x		x	x					
**Arthroleptis affinis* Ahl, 1939	x		x	x		x	x	x		x	x	
**Arthroleptis reichei* Nieden, 1911	x			x								
Arthroleptis nikeae Poynton, 2003			x									
Arthroleptis tanneri Grandison, 1983				x	x	x		x	x			
**Arthroleptis xenodactyla* Boulenger, 1909	x			x				x	x			
**Arthroleptis xenodactyloides* Hewitt, 1933	x			x				x	x	x		x
**Leptopelis barbouri* Ahl, 1929	x				x	x		x	x			

Leptopelis parkeri Barbour & Loveridge, 1928	x				x				x	x	x	
Leptopelis uluguruensis Barbour & Loveridge, 1928	x				x				x	x		
**Leptopelis vermiculatus* Boulenger, 1909	x	x			x	x	x	x	x	x		
Phlyctimantis keithae Schiøtz, 1975	x											
Afrixalus morerei Dubois, 1985	x	x										
**Afrixalus uluguruensis* Barbour & Loveridge, 1928	x	x			x		x	x	x			
Hyperolius kihangensis Schiøtz & Westgaard, 1999	x											
**Hyperolius minutissimus* Schiøtz, 1975	x											
**Hyperolius mitchelli* Loveridge, 1953	x	x		x	x	x			x	x	x	x
**Hyperolius pictus* Ahl, 1931	x								x			
**Hyperolius pseudargus* Schiøtz & Westgaard, 1999	x											
**Hyperolius puncticulatus* Pfeffer, 1893	x	x		x	x	x	x	x	x	x	x	

**Hyperolius spinigularis* Stevens, 1971	x				x		x		x	x			
Hyperolius tannerorum Schiøtz,1982										x			
Hyperolius tornieri Ahl, 1931					x								
GYMNOPHIONA													
Boulengerula boulengeri Tornier, 1897									x	x			
Boulengerula niedeni Müller *et al.* 2005													x
Boulengerula taitana Loveridge, 1935													x
Boulengerula uluguruensis Barbour & Loveridge,1928					x		x						
***Boulengerula* sp							x			x			
**Scolecomorphus kirkii* Boulenger, 1883	x	x		x	x		x					x	
Scolecomorphus uluguruensis Barbour & Loveridge,1928					x								
Scolecomorphus vittatus Boulenger, 1895				x	x	x	x	x	x	x	x	x	
Shared EAM endemics	10	2	0	3	13	3	10	5	11	11	4	4	0

Mountain block endemic	4	0	0	1	7	4	0	0	3	2	0	0	3
Grand total	37	10	0	10	34	13	19	10	26	22	9	8	5

Non-endemic species are single asterisked, while double asterisked are those not listed by Burgess *et al.* (2007); Udz = Udzungwa, Mah = Mahenge, Mal = Malundwe, Rub = Rubeho, Ulu = Uluguru, Uka = Ukaguru, Ngur = Nguru, Ngu = Nguu, EU = East Usambara, WU = West Usambara, SPa = South Pare, NPa = North Pare (all in Tanzania), Tai = Taita Hills (Kenya)

Appendix 9.2: Species and their abundance recorded through different methods (transect, trap, time-limited-search TLS) in different study sites in Taita Hills (Dawida, Mbololo, Sagalla, Kasigau).

Site	S	E	Altitude (m)	Period	Method	Sampling sessions	Species	Number
1) DAWIDA								
Ngangao forest				20-23/IV/2005	Trap	141	Callulina sp	11
				7/XI/2005-18/I/2007			Arthroleptis xenodactyloides	48
							Ameitophrynus gutturalis	1
								60
				17/IV-18/I/2007	TLS	23	Arthroleptis xenodactyloides	47
				20/IV/2005			Callulina sp	5
							Boulengerula taitana	3
	9627510	426665	1854	7/IV/2006-18/I/2007	Transect	18	Arthroleptis xenodactyloides	40
							Callulina sp	1
Makandenyi farm-Werugha	9626648	426561	1647	8/IV/2006-18/I/2007	Transect	13	Hyperolius glandicolor	261
							Xenopus borealis	103
							Ptychadena mascareniensis	87
							Ameitophrynus gutturalis	9
							Ptychadena anchietae	5
							Hemisus marmoratus	2
								467
Chawia forest				25-23/IV/2005	Trap	146	Arthroleptis xenodactyloides	99
				16/XI/2005-18/I/2007			Boulengerula taitana	4
							Ameitophrynus gutturalis	8
							Callulina sp	4
							Hemisus marmoratus	1
								116
				22/IV-18/I/2007	TLS	27	Arthroleptis xenodactyloides	180
				25/IV/2005			Callulina sp	1
							Boulengerula taitana	3
							Hyperolius glandicolor	1

	426690	9615280	1600	21/IV/2006-18/I/2007	Transect	17	Arthroleptis xenodactyloides	32
							Hyperolius glandicolor	3
Ngulu dam farm-Chawia	427384	9615734	1562	22/IV/2006-18/I/2007	Transect	14	Hyperolius glandicolor	725
							Ptychadena mascareniensis	71
							Ameitophrynus gutturalis	29
							Xenopus borealis	2
							Leptopelis concolor	1
							Hemisus marmoratus	1
							Ptychadena anchietae	2
Kinyesha-Mvua plantation				10-13/V/2005	Trap	98	Arthroleptis xenodactyloides	148
				7/XI/2005-18/I/2007			Ameitophrynus gutturalis	25
				17/IV/2006-18/I/2007	TLS	20	Arthroleptis xenodactyloides	51
				10/V/2005			Ameitophrynus gutturalis	2
							Boulengerula taitanus	5
	430766	9628982	1612	10/IV/2006-18/I/2007	Transect	14	Arthroleptis xenodactyloides	57
							Hyperolius glandicolor	1
							Bufo gutturalis	1
Mghambonyi farm	429199	9629466	1546	9/IV/2006-18/I/2007	Transect	13	Hyperolius glandicolor	109
							Ptychadena mascareniensis	69
							Xenopus borealis	91
							Phrynobatrachus mababiensis	8
							Ptychadena anchietae	4
								281
				15-18/V/2005	Trap	70	Hemisus marmoratus	3
				17/IV/2006-18/I/2007			Phrynobatrachus mababiensis	10
							Bufo gutturalis	5
							Arthroleptis xenodactyloides	2
Sungululu plantation				3/VI/2005	TLS	19	Arthroleptis xenodactyloides	7
				13/IV/2006-17/I/2007			Boulengerula taitanus	19

	428943	9625202	1483	13/IV/2006-17/I/2007	Transect	17	Arthroleptis xenodactyloides	17
Mwachora forest	429839	9622390	1644	17/IV/2006-18/I/2007	Transect	17	Arthroleptis xenodactyloides	18
							Amietophrynus gutturalis	1
	429839	9622390	1644	17/IV/2006-18/I/2007	TLS	17	Boulengerula taitana	10
							Arthroleptis xenodactyloides	17
				16/XI/2005-18/I/2007	Trap	131	Arthroleptis xenodactyloides	19
							Amietophrynus gutturalis	4
							Callulina sp	4
							Boulengerula taitana	1
Macha forest	428765	9622214	1650	18/IV/2006-18/I/2007	TLS	13	Arthroleptis xenodactyloides	18
							Boulengerula taitana	1
	428765	9622214	1650	18/IV/2006-18/I/2007	Transect	15	Arthroleptis xenodactyloides	6
							Amietophrynus gutturalis	1
Mbirwa farm-Macha	429260	9622624	1430	19/IV/2006-18/I/2007	Transect	17	Hyperolius glandicolor	105
							Ptychadena mascareniensis	4
							Amietia angolensis	3
							Amietophrynus gutturalis	10
							Leptopelis concolor	2
Mndangenyi farm -Wundanyi	429753	9624046	1397	12/IV/2006-17/I/2007	Transect	16	Hyperolius glandicolor	201
							Ptychadena mascareniensis	56
							Ptychadena anchietae	39
							Amietophrynus gutturalis	85
								381
Boma forest-Wundanyi	428847	9624462	1439	12/IV/2006-17/I/2007	TLS	19	Arthroleptis xenodactyloides	35
							Boulengerula taitana	63
							Callulina sp	3

	428847	9624462	1439	12/IV/2006-17/I/2007	Transect	18	Arthroleptis xenodactyloides	51
							Boulengerula taitana	2
Piringa farm-Mbale			1200	15/XI/2005-17/I/2007	Ttrap	142	Hemisus marmoratus	2
							Amietophrynus gutturalis	57
	430237	9626134	1187	14/IV/2006--17/I/2007	Transect	17	Amietia angolensis	8
							Amietophrynus gutturalis	40
							Hyperolius glandicolor	37
							Ptychadena mascareniensis	1
							Ptychadena anchietae	6
								92
Mwatate farms			850	15/XI/2005-17/I/2007	Trap	130	Hemisus marmoratus	433
							Amietophrynus gutturalis	212
							Amietophrynus xeros	37
							Phrynobatrachus scheffleri	8
				29/IV/2006-13/VII/2006	TLS	4	Phrynobatrachus scheffleri	1
Mwatate dam farm	431351	9612026	839	15/IV/2006-17/I/2007	Transect	19	Hyperolius glandicolor	205
							Hyperolius tuberilinguis	50
							Ptychadena mascareniensis	45
							Phrynobatrachus scheffleri	1
							Amietophrynus xeros	61
							Ptychadena anchietae	32
							Amietophrynus gutturalis	64
							Leptopelis concolor	36
Madungunyi farm-Mwatate	431363	9613328	846	16/IV/2006-17/I/2007	Transect	18	Hyperolius glandicolor	110
							Ptychadena anchietae	12
							Amietophrynus xeros	32
							Hyperolius tuberilinguis	16
							Amietophrynus gutturalis	32
							Ptychadena mascareniensis	6
							Leptopelis concolor	5

2) SAGALLA

Sagalla farms			1100	16/XI/2005- 18/I/2007	Ttrap	279	Hemisus marmoratus	491
							Ameitophrynus gutturalis	34
							Ameitophrynus garmani	30
							Phrynobatrachus mababiensis	3
							Ptychadena anchietae	2
							Hyperolius glandicolor	1
Lata dam farm	452646	9613184	1064	27/3/2006- 18/I/2007	Transect	19	Leptopelis concolor	33
							Kassina senegalensis	34
							Phrynomantis bifasciatus	2
							Chiromantis petersi	14
							Ptychadena anchietae	28
							Hyperolius glandicolor	374
							Ameitophrynus gutturalis	6
							Ameitophrynus garmani	23
							Hemisus marmoratus	5
Kauze farm	453142	9613032	1081	27/3/2006- 18/I/2007	Transect	17	Leptopelis concolor	30
							Hyperolius glandicolor	156
							Ptychadena anchietae	35
							Ameitophrynus gutturalis	3
							Ptychadena mascareniensis	1
							Ameitophrynus garmani	5
Mghange farm	454848	9614526	1273	29/3/2006-18/I/2007	Transect	12	Ptychadena anchietae	28
							Ptychadena mascareniensis	10
							Leptopelis concolor	10
							Hyperolius glandicolor	5
							Amietophrynus gutturalis	3
Marapu farm	451276	9612358	651	30/3/2006-18/I/2007	Transect	15	Leptopelis concolor	11
							Amietophrynus xeros	4
							Ptychadena anchietae	43
							Ptychadena mossambica	2
							Hemisus marmoratus	tadpoles

Sagalla plantation	454282	9612844	1384	28/3/2006-18/I/2007	Transect	17	Arthroleptis xenodactyloides	43
				28/3/2006- 18/I/2007	TLS	13	Arthroleptis xenodactyloides	38
				22-31/V/2006-18/I/2007	Trap	61	Arthroleptis xenodactyloides	1
Sagalla forest	454858	9612866	1504	29/3/2006-18/I/2007	Transect	15	Arthroleptis xenodactyloides	47
							Amietophrynus gutturalis	1
				29/3/2006-18/I/2007	TLS	20	Arthroleptis xenodactyloides	79
							Boulengerula niedeni	5
				16/XI/2005- 18/I/2007	Trap	132	Arthroleptis xenodactyloides	59
							Amietophrynus gutturalis	5

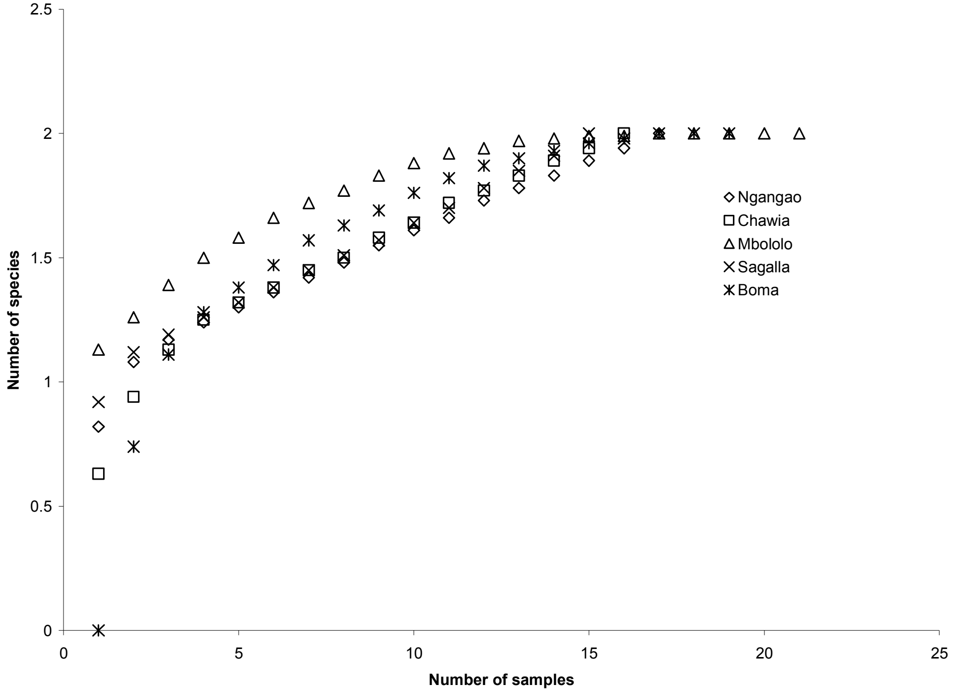
3) MBOLOLO

Mwasange farm	437290	9630988	1309	1/4/2006-18/I/2007	Transect	19	Hyperolius glandicolor	58
							Amietophrynus gutturalis	16
							Amietia angolensis	4
							Phrynobatrachus scheffleri	3
							Leptopelis concolor	21
							Amietophrynus taitanus	1
							Arthroleptis xenodactyloides	4
							Ptychadena anchietae	2
								109
				10-31/V/2006-18/I/2007	Trap	79	Amietophrynus gutturalis	8
Mwalenjo farm	436567	9631482	1292	1/4/2006-18/I/2007	Transect	19	Hyperolius glandicolor	20
							Amietia angolensis	4
							Amietophrynus gutturalis	4
							Ptychadena mascareniensis	1
							Ptychadena anchietae	2
							Arthroleptis xenodactyloides	10
Chale farm	435541	9631190	1236	5/4/2006-18/I/2007	Transect	16	Hyperolius glandicolor	67

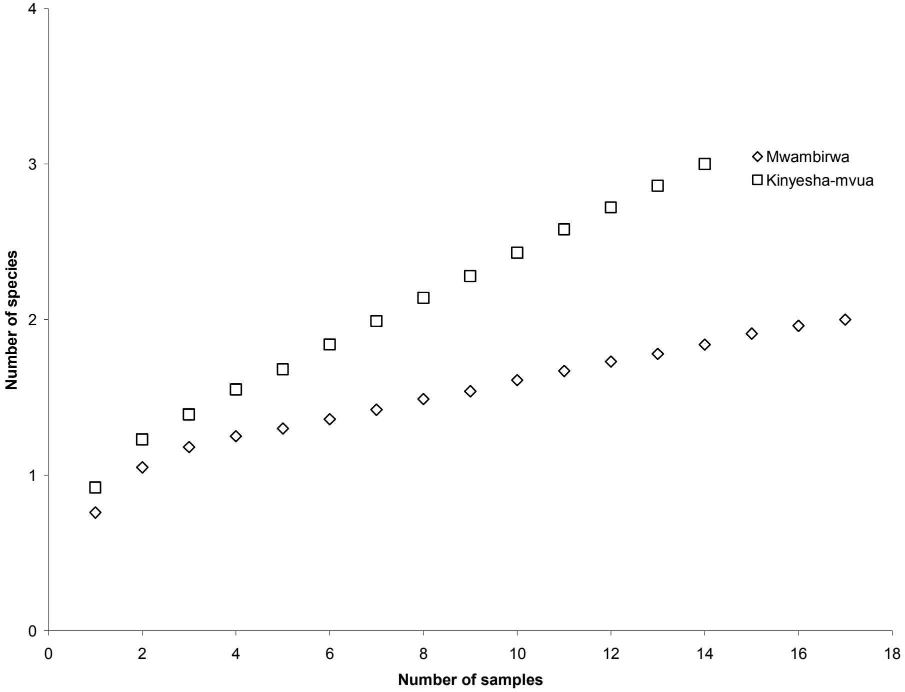
							Amietia angolensis	2
							Ptychadena mascareniensis	5
							Amietophrynus gutturalis	14
							Leptopelis concolor	5
Mwambirwa plantation	436415	9630144	1300	2/4/2006-18/I/2007	Transect	17	Arthroleptis xenodactyloides	43
							Amietophrynus gutturalis	1
				2/4/2006-18/I/2007	TLS	18	Boulengerula taitana	15
							Arthroleptis xenodactyloides	47
				19/XI/2005- 18/I/2007	Trap	134	Arthroleptis xenodactyloides	25
							Amietophrynus guturalis	25
							Boulengerula taitana	2
							Mertensophryne taitana	1
Mbololo forest	438781	9632602	1600	3/4/2006-18/I/2007	Transect	21	Arthroleptis xenodactyloides	233
							Callulina sp	6
								239
				3/4/2006-18/I/2007	TLS	26	Boulengerula taitana	57
							Arthroleptis xenodactyloides	221
							Callulina sp	4
				20/XI/2005-18/I/2007	Trap	123	Arthroleptis xenodactyloides	9
							Callulina sp	2
							Boulengerula taitana	1
4) KASIGAU								
Bungule-Jora			600	4/XI/2005-18/I/2006	Trap	172	Ptychadena anchietae	2
							Phrynobatrachus mababiensis	10
							Hemisus marmoratus	15
							Ameitophrynus xeros	11
							Ameitophrynus garmani	5
							Kassina senegalensis	1
Hezron dam farm-Jora	458077	9575856	563	24/IV/2006-18/I/2006	Transect	14	Chiromantis petersi	106

							Hemisus marmoratus	11
							Tomopterna cryptotis	17
							Ptychadena anchietae	136
							Ameitophrynus xeros	3
							Ameitophrynus garmani	9
							Kassina senegalensis	20
							Phrynomantis bifasciatus	83
							Leptopelis concolor	77
Bafwe dam farm-Jora	457742	9577674	577	23/IV/2006-18/I/2006	Transect	16	Ptychadena anchietae	213
							Hildebrandtia macrotympanum	15
							Tomopterna cryptotis	28
							Ameitophrynus xeros	20
							Chiromantis petersi	99
							Kassina senegalensis	22
							Ameitophrynus garmani	5
							Chiromantis kelleri	6
							Leptopelis concolor	54
							Phrynomantis bifasciatus	57
							Hemisus marmoratus	3
Kasigau forest			1600	25/IV/2006-18/I/2007	Transect	19	Nil	
				23/XI/2005-18/I/2007	Trap	32	Nil	
				26/IV/2006-18/I/2007	TLS	24	Boulengerula taitana	6
							Ptychadena anchietae	3
							Phrynobatrachus scheffleri	2

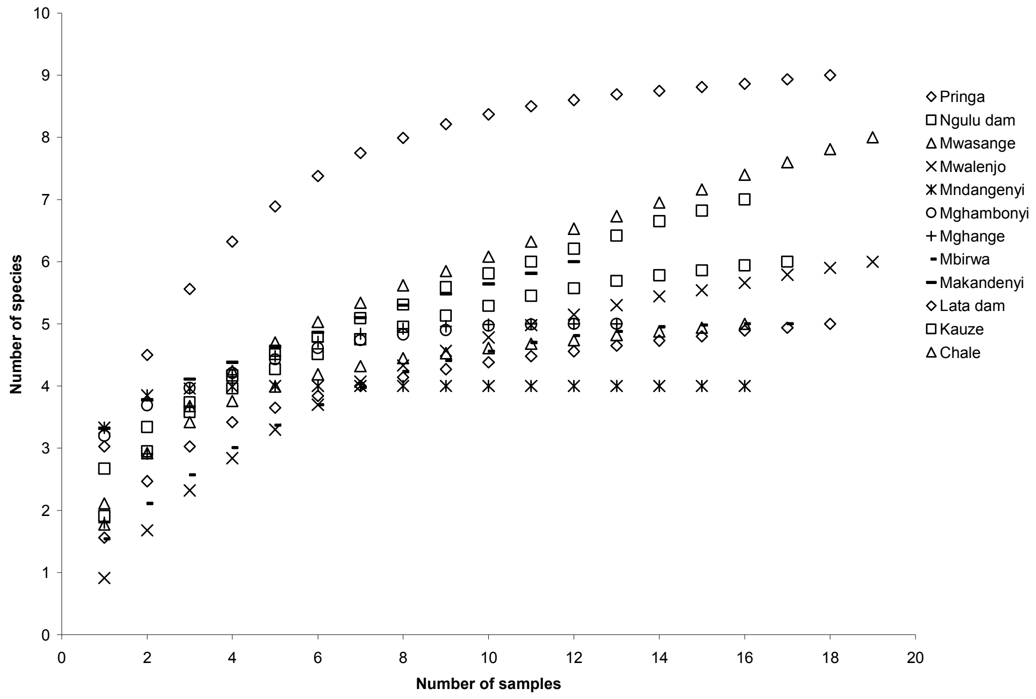
Appendix 9.3: Species accumulation curves of the 25 transect samples (sites) with more than one observed species. a) forests, b) plantations, c) Highland farms (above 1000 m), d) Lowlands farms (below 1000 m).



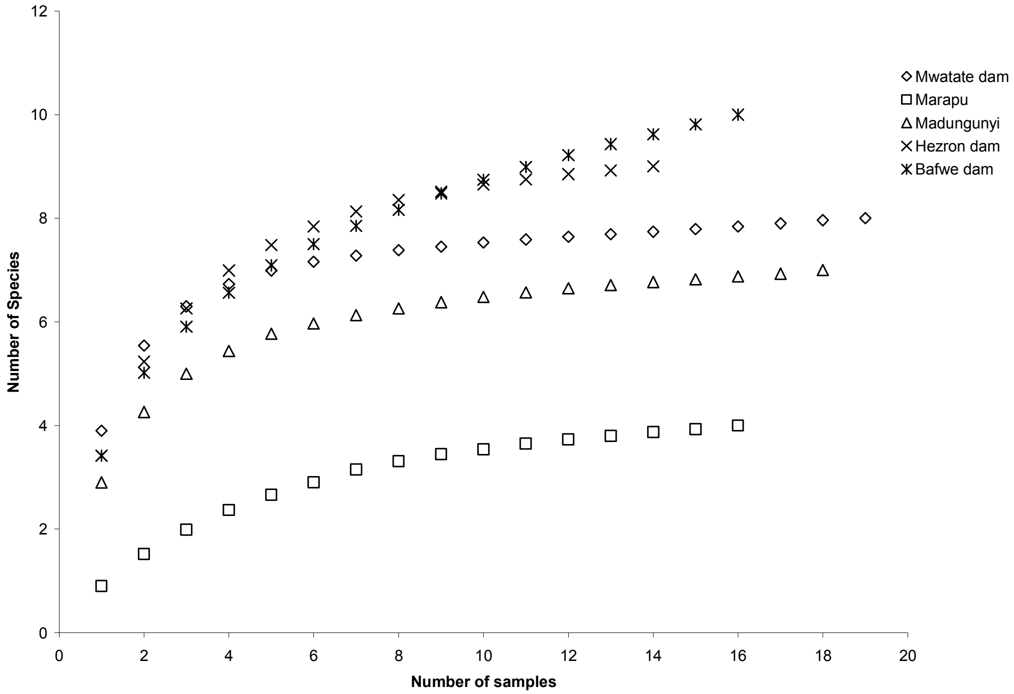
a. Forests



b. Plantations



c. Highland farms



d. Lowland farms

Appendix 9.4: Amphibian materials examined

Abbreviations: F, female; M, male; A, catalogue prefix letter for class Amphibia at NMK.

Boulengerula niedeni (all from Sagalla): A/4294 (F) Holotype; A/4298/7(F), A/4298/6, A/4298/1(M) and A/4298/3(M) paratypes; A/4262/2 (M), A/4262/4 (F), A/4262/3(F) - Mwalangi; A/4761(F)-Sagalla forest (UTM: S454858, E9612866, 1504 m); A/4672 (M), A/4265/2(F) - Mghange (UTM: S454848, E9614526, 1273 m); A/4261/2 (F), A/4664/12 (F), A/4265/2 (M), A/4262/1(M) - Sagalla; A/4759 (F) - Sagalla valley; A/4802/2 (M), A/4802/1 (M) - Mtangoni (UTM: S453275, E9612860, 1101 m); A/4264/14(F), A/4264/6 (F), A/4264/11(F), A/4264/9 (F) A/4264/15 (F), A/4264/7 (F), A/4264/8 (M), A/4264/10 (M) - Kanyanga (UTM: S453142, E9613034, 1080m); A/4263/1 (F), A/4263/1 (F) - Sagalla forest patch (S454596, E9612536, 1464 m); A/4484/3 (M) - Mwanjika; A/4656 (F) - Kishamba (S454282, E9612844, 1384 m); A/4803 (F) - Mashighati; A/4757/2(F) - Sagalla (UTM: S454221, E9611136, 1389 m); A/4758/1 (F) - Kizumani (UTM: S454041, E9615969, 1139 m).

Boulengerula taitanus: A/4335/1 (M), A/4767(M), A/4335/2 (F), A/4752 (M), A/4752 (F), A/4752 (F), A/4752/4 (M) -Ngangao forest (UTM: S426665, E9627510, 1854 m); A/4586/1 (M), A/4586/2 (F), A/4822 (F) - Sungululu plantation (UTM: S428943, E9625202, 1483 m); A/4589/1 (M) - Boma forest (UTM: S428847, E9624462, 1439m; A/4764/4(M), A/4405/3 (F), A/4764/1 (M), A/4405/3 (F), A/4405/4 (M), A/4405/2 (M), A/4405/5 (F), A/4405/1 (M) - Kasigau forest (UTM: S462435, E9577222, 1645 m); A/4336/2 (M), A/4336/1 (M), A/4142/2 (M) - Mghambonyi (UTM: S429199, E9629466, 1546 m); A/4473/3 (F), A/4473/2 (M), A/4473/3(F), A/4473/1 (F) - Mbololo forest (UTM: S438781, E9632602, 1600 m); A/4749/2 (F), A/4749/3 (F), A/4147/18 (M), A/4147/19 (F), A/4147/5 (M), A/4147/10 (M), A/4147/9 (F), A/4147/13 (F), A/4147/3 (F), A/4147/20 (F), A/4147/11 (F), A/4147/14 (F), A/4022/25 (F), A/4022/11 (M), A/4022/17 (F), A/4022/7 (M), A/4022/19 (F), A/4022/26 (F), A/4022/22 (M), A/4022/4 (F), A/4022/23 (M), A/4022/5 (F) - Wundanyi (UTM: S429291, E9624396, 1405 m.

Xenopus borealis: A/4536/1 (M), A/4480/2 (M), A/4480/1 (F), A/4536/2 (F)- Wundanyi (UTM: S429291, E9624396, 1405 m); A/4338/2 (M) - Ngangao forest (UTM: S426665, E9627510, 1854 m); A/4339/4 (M), A/4339/3 (M), A/4339/2 (M), A/4339/1 (F) - Mghambonyi (UTM: S429141, E9629362, 1543 m.

Amietophrynus garmani: A/4410/1 (M), A/4410/2 (F) - Bungule-Kasigau (UTM:S463079, E9575538, 617 m); A/4478 (M) - Kanyanga, Sagalla (UTM: S453142, E9613034, 1080m); A/4437(M) - Lata dam-Sagalla (S452646, E9613184, 1064 m); A/4657/4 (M), A/4818 (M), A/4794/3 (M), A/4798/3 (M), A/4642 (F), A/4794/2 (F), A/4794/3 (F), A/4798/3 (F), A/4765 (F), A/4657/2 (F), A/4657/1 (F) - Jora, Kasigau (UTM: S460316, E9575722, 594 m); A/3614 (F) - Kasigau.

Amietophrynus gutturalis: A/4476 (M) - Kanyanga Sagalla (UTM: S453142, E9613034, 1080m; A/4531 (M) - Kiagungu, near Iyale plantation; A/1191/1 (M), A/1191/4 (M), A/1191//4 (M), A/1191/5 (F), A/1191/2 (F), A/1191/3 (F), - Mwasungia, Wundanyi (UTM: S429397, E9624628, 1376 m); A/4688 (M), A/4486 (M) - Wundanyi (UTM: S429291, E9624396, 1405 m); A/3554/1 (M), A/3698 (F), A/3554/2 (F), A/4139 (F) - Ngangao forest; A/3528/3 (F), A/3528/6 (F), A/4345 (F), A/3700 (F), A/4610 (tadpoles) - Chawia forest (UTM: S428779, E9615986, 1604 m); A/4145 (F) - Mghambonyi (UTM: S429480, E9629080, 1534 m); A/4797 (F) - Mwasange, Mbololo (UTM:S 437290, E 9630988, 1309 m); A/4593 (F) - Kinyesha Mvua plantation (UTM:S430766, E9628982, 1612 m); A/191 (F) - Wusi, Chawia; A/3529/4 (F), A/3529/1 (F), A/3529/2 (F) - Mwachora forest (UTM: S429839, E 9622390, 1644 m); A/4527 (tadpoles) - Mbololo; - Chawia forest.

Amietophrynus xeros: A/4491/1 (M), A/4491/2 (M) - Mwatate dam (UTM:S431351, E9612026, 839 m); A/3714 (M) -Tsavo East National Park, Aruba dam; A/4768/3 (M), A/4768/4 (M), A/4768/2 (F), A/4768/1 (F), A/4635 (F), A/4660 (F) - Jora, Kasigau (UTM:S460316, E9575722, 594 m); A/4636 (F), A/4790 (F) - Marapu, Sagalla nyika (UTM: S451276, E 9612358, 651 m).

Mertensophryne taitanus: A/4591 (M), A/4240 (F) - Mwambirwa plantation (UTM:S436798, E9629662, 1327 m); A/4600 (M) - Mwasange, Wongonyi (UTM:S437290, E 9630988, 1309 m); A/3532 (M) - Macha forest (UTM:S428765, E9622214, 1650 m); A/4780/4 (M), A/4780/3 (M), A/4780/5 (F), A/4780/1 (F), A/4780/2 (F), A/4780/6 (F) - Kilumaluma, Wongonyi (UTM: S436519, E9632041, 1320). A/4526 (Tadpoles)-Mchanga, Wongonyi.

Phrynomantis bifasciatus: A/3745 (F) - Taita- Rukinga Ranch; A/940/4 (F), A/940/2 (M), A/940/1 (M), A/940/3 (M) - Tsavo West National Park between Ngulia Hills and Mtito Andei; A/4821/3 (F), A/4821/2 (F), A/4821/1 (F), A/4779/1 (M), A/4779/2 (M), -

Hezron Dam-Jora, Kasigau (UTM:S458077, E 9575856, 563 m); A/350/5 (F), A/350/1 (M), - Kenani, Tsavo East National Park; A/363/4 (F), A/363/3 (F) - Voi; A/4796 (M) - Kauze, Sagalla (UTM:S453142, E 9613032, 1081 m).

Callulina sp. (cf. *kreffti*): A/4344/1 (F), A/4344/1 (F), A/4344/2 (M), A/3703 (M) - Chawia forest (UTM:S426690, E9615280, 1600 m); A/3617 (F) - Fururu forest; A/4343 (F), A/4594 (F), A/4492 (F), A/4268/1(M), A/4268/2 (M), A/1499 (M) - Ngangao forest (UTM:S426665, E9627510, 1854 m); A/4684 (F) - Mbololo forest (UTM:S438781, E9632602, 1600 m); A/4645 (F) - Boma forest, Wundanyi (UTM:S428847, E9624462, 1439m); A/3647/1 (M), A/3647/5 (M) - Ndiwenyi forest; A/4267 (M) - Kiangungu forest fragment, Iyale (UTM:S426787, 962392, 1705 m).

Hemisus marmoratus: A/4411/1 (M) - Bungule, Kasigau (UTM:S463079, E9575538, 617 m); A/4494 (M) - Piringa, Mbale (UTM:S430237, E9626134, 1187 m); A/4429 (M) - Mwangoni, Sagalla (UTM:S453274, E9612859, 1100 m); A/4820/4 (M), A/4340/1(M), A/4820/2 (F), A/4820/3 (F); A/4415/2 (F), A/4820/1 (M), A/4415/1 (M), A/4481 (F), A/4415/3 (F) - Wundanyi (S429372, E922405, 1400 m); A/4687 (M), A/4341 (M), A/4342 (F)- Mghambonyi (UTM:S429141, E9629362, 1543 m); A/4411/2 (F) - Bungule, Kasigau; A/4571/1 (F) - Mtangoni, Sagalla (UTM:S453275, E9612860, 1101 m); A/4494 (F) - Jora, Kasigau; A/4508 (F) - Mwatate, Tadpoles:- A/4515 (tadpoles),Sagalla; A/4516 (tadpoles) - Mt. Kasigau (UTM:S461009, E9577334, 1099 m); A/4608 (tadpoles)- Mwatate; A/4606 (tadpoles) - Mwasungia-Jora, Kasigau.

Arthroleptis xenodactyloides: A/4432/4 (M), A/4544/4 (M), A/4544/3 (M), A/4544/8 (M), A/4544/10 (M), A/4544/4 (M), A/4544/1 (F) - Sagalla forest (UTM:S454858, E9612866, 1504 m); A/4538/25 (M), A/4538/26 (M), A/4538/14 (F), A/4538/13 (F), A/4538/4 (F), A/4538/22 (F), A/4538/17 (F), A/4538/23 (F) - Fururu forest (UTM:S426463, E9620811, 1710 m); A/4541 (M), A/4541/1 (M), A/4541/21 (M), A/4541/2 (M), A/4541/25 (M), A/4541/8 (M), A/4541/7 (M), A/451/20 (M), A/4541/14 (M), A/4541/3 (M), A/4541/17 (F), A/4541/9 (F), A/4541/6 (F), A/4541/5 (F), A/4541/4 (F), A/4541/15 (F), A/4538/15 (F),A/4541/15 (F) - Ngangao forest (UTM:S426665, E9627510, 1854 m; UTM:S427057, E9627713, 1774 m); A/4544/9 (M) - Sagalla plantation (UTM:S454790, E9612494, 1345 m; A/4150/1(M), A/4540/16 (M), A/4150/4 (F), A/4150/3 (F), A/3708/2 (F), A/4150/2 (M), A/4540/9 (F), A/4540/11 (M), A/4541/9 (F), A/4540/12 (F) - Mbololo forest (UTM:S43896, E9632681, 1691 m; S438781, E9632602, 1600 m); A/4543/3 (M), A/4543/2 (M), A/4543/5 (M), A/4543/5 (M) - Mwambirwa forest plantation (UTM:S436945, E9629581, 1261 m; UTM:S436945, E9629581, 1300 m); A/4537/20 (M), A/4537/5 (F), A/4537/4 (M) - Chawia forest (UTM:S426690, E9615280, 1600 m).

Leptopelis concolor (all males): A/4467/2, A/4467/6, A/4467/5, A/4467/3, A/4467/4, A/4467/1, A/4497/2, A/4497/1 - Mwatate dam (UTM:S431351, E9612026, 839 m); A/4438/2, A/4438/3, A/4479, A/4438/5, A/4438/4, A/4438/1- Kanyanga, Sagalla (S453142, E9613034, 1080m); A/4471/1A/4471/3, A/4622, A/4471/5, A/4471/2 - Wongonyi, Mbololo; A/4403/3, A/4403/4, A/4403/1, A/4403/2, A/4403/5 - Bungule, Kasigau (UTM:S463079, E9575538, 617 m); A/4811, A/4823 -Jora, Kasigau (UTM:S460316, E9575722, 594 m).

Hildebrandtia macrotympanum: A/362/4 (F), A/362/2 (M), A/362/1 (M), A/362/7 (M), A/362/3 (M), A/362/6 (M), A/362/5 (M)- Aruba dam, Tsavo East National Park; A/194 (M) - Between Aruba dam and Galana River, Tsavo East National Park.

Ptychadena anchietae: A/4435/5 (F), A/4435/4 (F), A/4435/3 (M) - Kanyanga, Sagalla (UTM:S453142, E9613034, 1080 m); A/4334 (F) - Mghambonyi (UTM:S429199, E9629466, 1546 m); A/4435/2 (F), A/4435/1 (M) - Kauze, Sagalla (UTM:S453142, E 9613032, 1081 m); A/3697/1 (F), A/3697/2 (M), A/3697/3 (M), A/3697/5 (M), A/3697/4 (M) - Mazola Primary School, Chawia (S427383, E9615733, 1610 m); A/3696/1 (F), A/3649 (F), A/3696/2 (M) - Mbololo forest; A/4332/2 (F), A/4332/1 (F) - Chomboke,Wundanyi (UTM:S429652, E9623866, 1402 m); - A/4684/1 (F), A/4684/1 (M), A/4485/2, A/4485/1 (M), A/4424 (M), - Wundanyi (UTM:S429290, E9624395, 1407 m); A/4812/2 (F), A/4812/2 (M), A/4809/2 (M), A/4809/1 (M), A/4632 (M) - Jora, Kasigau (UTM:S460316, E9575722, 594 m); A/4464 (F) - Wongonyi, Mbololo; A/4658 (F), A/4746/1 (F), A/4746/2 (F), A/4407/1(M), A/4407/2 (M) - Bungule, Kasigau (UTM:S463079, E9575538, 617 m); - A/4774/13 (F), A/4774/15 (F), A/4666 (M), A/4474/21 (M), A/4474/33 (M), A/4474/6 (M), A/4474/20 (M), A/4474/18 (M), A/4474/25 (M) - Mshiri dam Rukanga, Kasigau (UTM:S459975, E9578454, 640 m); A/3620 (M) - Ndiwenyi forest; A/4083/2 (M), A/4083/1, A/4669 (M) - Rukanga water intake, Kasigau (S461009, E9577334, 1099 m).

Ptychadena sp. (cf. *mascareniensis*): A/4330/3 (F), A/4428/2 (F), A/4330/8 (M), A/4330/7 (M), - Mghambonyi (UTM:S429199, E9629466, 1546 m); A/4428/1 (F), A/4330/5 (F), A/4330/2 (F), A/4330/6 (F), A/4330/1 (F), - Mghange, Sagalla (UTM:S454848, E9614526, 1273 m); A/4333/2 (F), A/4333/1 (M) - Tambaru, Wundanyi (UTM:S429291, E9624396, 1405 m); A/4618 (F), A/4548/3 (F), A/4548/1 (F), A/4683/1(M), A/4683/2 (M), A/4425 (M), A/4548/3/2 (M) - Wundanyi (UTM:S429290, E9624395, 1407 m); A/4431 (F) - Kanyanga, Sagalla (S453142, E9613034, 1080 m); A/4630 (F) - Chale, Mbololo (UTM:S435541, E9631190, 1236 m); A/4331/4 (F), A/4331/7 (F), A/4331/6 (F), A/4331/2 (F), A/4331/1 (F), A/4331/5 (M), A/4331/3 (M) - Shate, Wundanyi (UTM:S428939, E9620150, 1417 m); A/4621/1 (M) - Chawia forest (UTM:S426690, E9615280, 1600 m).

Ptychadena mossambica: A/4775 (F) - Jora, Kasigau (UTM:S460316, E9575722, 594 m); A/360/25 (F), A/360/22 (F), A/360/28 (M), A/360/24 (M), A/360/26 (M), A/360/21 (M), A/360/23 (M), A/360/29 (M), A/360/20 (M) – Voi.

Ptychadena schillukorum: A/4770 (F), A/4806 (F) - Jora, Kasigau (UTM: S460316, E9575722, 594 m); A/4810 (F) - Marapu, Sagalla nyika (UTM: S451276, E 9612358, 651 m); A/359 (M) - Voi.

Phrynobatrachus scheffleri: A/4577 (M), A/4358/3 (M) - Mghambonyi (UTM:S429480, E9629080, 1534 m); A/3559/7 (M), A/3559/11, A/3559/7 (M), A/3559/13 (M), A/3559/11 (F), A/3559/5 (F), A/3559/5 (F), A/3559/7 (F), A/3559/4 (F)- Chawia forest (UTM:S426690, E9615280, 1600 m); A/4760/53 (M), A/4760/39 (M), A/4760/24 (M), A/4760/37 (M), A/4760/51 (M), A/4760/19 (M), A/4760/38 (M), A/4769/56 (M), A/4747/5 (M), A/4760/28 (F), A/4760/26 (F), A/4760/32 (F), A/4760/4 (F), A/4760/3 (F), A/4760/1 (F), A/4760/34 (F), A/4747/4 (F) - Bungule, Kasigau (UTM:S463079, E9575538, 617 m); A/4778/2 (M), A/4778/1 (M), - Macha, Mbololo; A/4616/3 (M), A/4573 (M), - Mtangoni, Sagalla (UTM:S453275, E9612860, 1101 m); A/3560/1 (M) - Ngangao forest; A/4661/3 (M), A/4670 (F), A/4784/4 (F) - Rukanga, Kasigau (UTM:S459975, E9578454, 640 m); A/4081/3 (M), A/4081/2 (M), A/4784/5 (M), A/4641/1 (F), A/4641/2 (F), A/4762 (F), A/4081/1 (F), A/4641/1(F), A/4641/2 (F)- Rukanga water intake, Kasigau (UTM:S461009, E9577334, 1099 m); A/4585 (M), A/4413 (F) - Kasigau forest (UTM:S461693, E9576684, 1544 m); A/4358/2 (F) - Mghambonyi; A/4639/2 (F), A/4639/1 (F) - Mwatate (UTM:S431351, E9612026, 839 m).

Amietia angolensis: A/4329/1 (F), A/4329/2 (F), A/4329/3 (F), A/4417 (tadpole) - Wundanyi (UTM:S429291, E9624396, 1405 m); A/4328 (F) - Mghambonyi (UTM:S429480, E9629080, 1534 m); A/4691/1(F) - Shingharo; A/3694/1 (F), A/3694/2 (M), A/3694/3 (M) - Chawia forest (UTM:S426690, E9615280, 1600 m); A/4631/1 (M), A/4631/2 (M) - Chale, Mbololo (UTM:S435541, E9631190, 1236 m); A/4637 (M) - Piringa, Mbale (UTM:S430237, E9626134, 1187 m); A/3693/1 (M), A/3693/4 (M), A/3693/2 (M), A/3693/3 (M) - Iyale forest; A/3695/1 (M), A/3695/4 (M), A/3695/3 (M), A/3695/2 (M) - Ngangao forest; A/4470 (tadpoles) - Mwambirwa plantation (UTM:S436798, E9629662, 1327 m).

Pyxicephalus adspersus: A/384/1 - Kenani near Mtito Andei, Tsavo East National Park; A/1300, A/290 - Ngomeni, Mwingi.

Tomopterna cryptotis: A/4426 (M) - Nyache; A/358/11 (M), A/358/13 (M), A/358/6 (M), A./358/10 (M), A/358/3 (M), A/358/7 (M), A/358/12 (M), A/358/5 (M), A/358/1 (M), A/358/4 (M), A/358/14 (M), A/358/8 (F), A/358/9 (F), A/358/2 (F)- Voi; A/4819/1 (M), A/4819/3 (M), A/4819/5 (M), A/4819/2 (M), A/4819/4 (M), A/4804 (F) - Jora, Kasigau (UTM :S460316, E9575722, 594 m); A/4604 & A/4605 (tadpoles) - Mwasungia-Jora, Kasigau.

Hyperolius glandicolor: A/4362/1 (F), A/4362/7 (F), A/4362/3 (F), A/4362/11 (F), A/4420/6 (F), A/3702/13 (F), A/3702/26 (F), A/3702/19 (F), A/3702/12 (F), A/4420/4 (M), A/4362/12 (M), A/4362/8 (M), A/3702/4 (M), A/3702/8 (M), A/3702/3 (M), A/3702/14 (M), A/3199/4 (M), A/4352 (tadpoles) - Chawia forest (UTM:S426879, E9615986, 1604 m); A/4439/3 (F), A/4570/2 (F), A/457/1 (M), - Kauze, Sagalla (UTM:S453142, E 9613032, 1081 m); A/4551/3 (F), A/4466/5 (F), A/4466/1 (F), A/4466/9 (F), A/4466/7 (M), A/4551/2 (M), A/4466/7 (M) - Wongonyi, Mbololo; A/4550/4 (F), A/4550/2 (M), A/4550/1 (M), A/4550/5 (M), A/4550/3 (M) - Kiangungu, Iyale (UTM:S426787, E962392, 1705 m); A/4472/2 (F), A/3199/2 (F), A/3199/3 (F), A/3199/1 (F), A/4472/1 (M) - Mwatate dam (UTM:S431351, E9612026, 839 m); A/1445/4 (F), A/1445/3 (M), A/1445/2 (M) - Bura (UTM:S423915, E9613546, 968 m); A/4418/2 (F) - Wundanyi (UTM:S429372, E922405, 1400 m); A/4646 (F) - Piringa, Mbale (UTM:S430237, E9626134, 1187 m); A/4360/2 (M), A/4360/3 (M), A/4360/1(M) - Ngangao forest; A/4504 (M) - Mghambonyi (UTM:S429199, E9629466, 1546 m); A/4490/2 (M), A/4169/1 (M) - Kanyanga, Sagalla (UTM:S453142, E9613034, 1080 m); A/4418/4 (M), A/4418/1 (M) – Wundanyi.

Hyperolius tuberilinguis (all males): A/4598/2, A/4598/1, A/4598/3, A/4598/4, A/4644/1, A/4644/2, A/4644/3, A/4644/4, A/4644/5, A/4644/1, A/4786/4, A/4786/3, A/4786/2, A/4786/1, A/4786/5, A/4786/6, - Mwatate dam (UTM:S431351, E9612026, 839 m).

Kassina senegalensis: A/4468 (M), A/373 (M) - Mwatate dam (UTM:S431351, E9612026, 839 m); A/4434 (M), A/4783/1 (M), A/4783/2 (M), A/4783/3 (M), - Lata dam, Sagalla (UTM:S452646, E9613184, 1064 m); A/3746/1 (M), A/3746/2 (M) - Taita-Rukinga

Ranch; A/945/2 (M), A/945/7 (M), A/945/6 (M) - Ngulia Hills, Tsavo West National Park; A/959/4 (M), A/959/7 (M), A/959/6 (M), A/959/2 (M), A/959/3 (M), A/939/4 (M), A/939/5 (M), A/939/1 (F) - Between Ngulia Hills and Mtito Andei, Tsavo West National Park; A/945/1 (M), A/945/4 (M), A/945/5 (F), A/945/3 (F) - Old Ngulia Lodge, Tsavo West National Park; A/4766 (F) - Jora, Kasigau (UTM :S460316, E9575722, 594 m).

Chiromantis kelleri: A/4773 (F) - Bafwe dam, Jora Kasigau (UTM :S457742, E9577674, 577 m); A/1412/5 (F), A/1412/3 (F), A/1412/1(F), A/1412/4 (M), A/1412/7 (M), A/1412/6, A/344/2 (M), - Maungu; A/344/1 (F) - Kenani, Tsavo East National Park; A/354/9 (F), A/354/1 (M), A/354/6 (M), A/354/2 (M), A/354/8 (M), A/354/7 (M), A/354/4 (M), A/354/3 (M), A/354/5 (M) - Voi; A/4807 (F) - Jora, Kasigau (S460316, E9575722, 594 m); A/3722 (F) - Tsavo East National Park. *Chiromantis petersi:* A/4433/1 (M), A/4433/2 (M) - Kauze, Sagalla (UTM:S453142, E 9613032, 1081 m); A/4477 (M) - Mtangoni, Sagalla(UTM:S453275, E9612860, 1101 m); A/372 (M) - Mwatate; A/4649/2 (M), A/4640 (M), A/4769 (M), A/4762 (M), A/4649/1(F) - Bafwe dam, Jora (UTM:S457742, E9577674, 577 m); A/936/3 (M), A/936/6 (M), A/936/7 (M), A/936/1 (F), A/936/2 (F), A/936/4 (F) - Between Mtito Andei and Ngulia Hills, Tsavo West National Park; A/4806 (M) - Hezron dam, Jora (UTM:S458077, E 9575856, 563 m); A/3747(M) - Taita- Rukinga Ranch.

Appendix 9.5: Distribution of Taita warty frog (*Callulina*) recorded in different forest fragments showing life snout-vent length (SVL) and body weight (Wt), age group, recording date, recording method and comments. Indigenous forests sizes in parentheses is as follows:- Ngangao (92ha), Chawia (50ha), Mwachora (4ha), Ndiwenyi (3ha), Fururu (12ha), Boma (0.25ha), Makandenyi patch (negligible), Kiangungu patch (negligible), Vuria (1ha) and Mbololo (220ha). The 18 preserved specimens are shown with NMK catalogue numbers.

Specimen	SVL(mm)	Wt(g)	Age group	Site	Date	Method	comments
1	45	7.1	Female	Fururu	16/12/2004	Visual encounter survey	Preserved: NMK-A/4266
2	36	3.7	Female	Kiangungu	16/12/2004	Visual encounter survey	Preserved: NMK-A/4267
3	30	2.5	Male	Ngangao	28/12/2004	Visual encounter survey	Preserved: NMK-A/4268/1
4	29	1.8	Sub-adult	Ngangao	28/12/2004	Visual encounter survey	Preserved: NMK-A/4268/2
5	40.68		Female	Ngangao	20/04/2005	Pitfall trap	Preserved: NMK-A/4343
6	43.11	8.26	Female	Chawia	25/04/2005	Time limited search	Preserved: NMK-A/4344/1
7	30	2.59	Male	Chawia	26/04/2005	Leaf litter search	Preserved: NMK-A/4344/2
8	15		Juvenile	Mbololo	29/03/2006	Pitfall trap	Preserved: NMK-A/4574
9	19	0.6	Juvenile	Mbololo	03/04/2006	Night transect walk	Preserved: NMK-A/4582/1
10	20	0.79	Sub-adult	Mbololo	03/04/2006	Night transect walk	Preserved: NMK-A/4582/2
11	19	0.63	Juvenile	Mbololo	03/04/2006	Night transect walk	Preserved: NMK-A/4582/3
12	31		Male	Ngangao	07/04/2006	Time limited search	Released

13	35		Female	Ngangao	21/12/2005	Pitfall trap	Preserved: NMK- A/4492
14	10		Juvenile	Ngangao	06/01/2006	Pitfall trap	Released
15	10		Juvenile	Ngangao	17/01/2006	Pitfall trap	Released
16	45		Female	Ngangao	24/01/2006	Visual encounter survey	Released
17	40		Female	Ngangao	10/02/2006	Pitfall trap	Released
18	14		Juvenile	Ngangao	21/02/2006	Pitfall trap	Preserved: NMK- A/4594
19	11		Juvenile	Ngangao	21/02/2006	Pitfall trap	Released
20	15		Juvenile	Ngangao	22/02/2006	Pitfall trap	Released
21	12		Juvenile	Ngangao	22/02/2006	Pitfall trap	Released
22	34		Male	Ngangao	20/03/2006	Pitfall trap	Preserved: NMK- A/4590
23	40		Female	Ngangao	20/03/2006	Funnel trap against drift fence	Released
24			Adult	Ngangao	20/03/2006	Visual encounter survey	Disappeared before capture
25	29	2	Sub-adult	Vuria	16/04/2006	Visual encounter survey	Released
26	12		Juvenile	Mwachora	05/01/2006	Pitfall trap	Released
27	14		Juvenile	Mwachora	06/01/2006	Pitfall trap	Released
28	15		Juvenile	Mwachora	17/01/2006	Pitfall trap	Released
29	21		Sub-adult	Mwachora	14/III/2006	Pitfall trap	Preserved: NMK- A/4624
30	9		Juvenile	Fururu	06/12/2005	Visual encounter survey	Preserved: NMK- A/4416
31	50		Female	Chawia	07/02/2006	Leaf litter search	Released
32	38		Female	Chawia	22/02/2006	Leaf litter search	Released

33	21		Sub-adult	Chawia	08/03/2006	Leaf litter search	Released
34	46		Female	Boma	10/05/2006	Time limited search	Preserved: NMK- A/4645
35	45		Female	Mbololo	05/05/2006	Pitfall trap	Preserved: NMK- A/4684
36	25		Sub-adult	Mbololo	30/05/2006	Time limited search	Released
37	33		Male	Boma	03/07/2006	Time limited search	Released
38	51		Female	Boma	03/07/2006	Time limited search	Released
39			adult	Ngangao	26/06/2006	Time limited search	Released
40	20		Sub-adult	Ngangao	30/05/2006	Pitfall trap	Released
41			Adult	Makandenyi	/03/2006	Visual encounter survey	Released
42	30		Male	Chawia	08/08/2006	Pitfall trap	Released
43	33		Male	Ngangao	14/08/2006	Time limited search	Released
44	34		Male	Chawia	20/09/2006	Pitfall trap	Released
45	30		Male	Chawia	20/09/2006	Pitfall trap	Released
46	20		Sub-adult	Ngangao	25/09/2006	Patch sampling	Recaptured on 01/04/2007; SVL 42mm
47	44	7	Female	Ngangao	27/09/2006	Patch sampling	Released
48	22	1.25	Sub-adult	Ngangao	/10/2006	Patch sampling	Released
49	21	1.25	Sub-adult	Ngangao	/10/2006	Patch sampling	Released
50	35		Female	Chawia	11/10/2006	Patch sampling	Released
51	27		Sub-adult	Chawia	28/10/2006	Pitfall trap	Released
52	32		Male	Chawia	29/10/2006	Pitfall trap	Released

53	43	6.5	Female	Ngangao	02/11/2006	Time limited search	Released
54	35	3	Female	Ngangao	2/11/2006	Time limited search	Recaptured on 02/05/2007; SVL 48mm, wt 9g
55	30	2	Male	Ngangao	02/11/2006	Night transect walk	Released
56	45	6	Female	Ngangao	03/11/2006	Time limited search	Released
57	30		Male	Mbololo	05/12/2006	Night transect walk	Released
58	35		Female	Mbololo	05/12/2006	Night transect walk	Released
59	46		Female	Mbololo	06/12/2006	Time limited search	Released
60	55		Female	Mbololo	08/12/2006	Time limited search	Released
61	43		Female	Ndiwenyi	03/04/2007	Time limited search	Released
62	40		Female	Fururu	05/04/2007	Time limited search	Released
63	29		Sub-adult	Ndiwenyi	05/04/2007	Time limited search	Released
64	46		Female	Vuria	11/05/2007	Time limited search	Released
65	45		Female	Ndiwenyi	28/05/2007	Time limited search	Released
66	48		Female	Ngangao	02/05/2007	Time limited search	Released
67	43	12	Female	Mwachora	04/05/2007	Time limited search	Released
68	48	9.5	Female	Mbololo	17/05/2007	Time limited search	Recaptured on 09/12/2007, SVL 48mm
69	48	11	Female	Ngangao	09/06/2007	Time limited search	Released
70	40	6.5	Female	Ngangao	09/06/2008	Time limited search	Released
71	26	2	Sub-adult	Ngangao	09/06/2009	Time limited search	Released
72	47		Female	Vuria	23/06/2007	Time limited search	Released

73	50		Female	Vuria	24/06/2007	Time limited search	Released
74	30		Male	Vuria	24/06/2007	Time limited search	Released
75	47		Female	Vuria	25/06/2007	Time limited search	Released
76	55		Female	Vuria	25/06/2007	Time limited search	Released
77	52		Female	Vuria	25/06/2007	Time limited search	Released
78	33		Male	Vuria	25/06/2007	Time limited search	Released
79	50		Female	Vuria	26/06/2007	Time limited search	Released
80	30		Male	Vuria	26/06/2007	Time limited search	Released
81	12		Juvenile	Vuria	26/06/2007	Time limited search	Released
82	30		Male	Mwachora	14/08/2007	Time limited search	Released
83	45	7.5	Female	Fururu	12/11/2007	Time limited search	Released: female sitting on 30-40 egg clutch
84	48	9	Female	Ngangao	08/10/2007	Time limited search	Released
85	45	8	Female	Ngangao	28/10/2008	Time limited search	Released
86	45	6	Female	Chawia	30/10/2007	Time limited search	Released
87	47	8.5	Female	Chawia	03/12/2007	Time limited search	Released
88	47	12	Female	Ngangao	05/12/2007	Time limited search	Released
89	40	7.5	Female	Ngangao	05/12/2007	Time limited search	Released
90	50	7	Female	Mwachora	17/12/2007	Time limited search	Released
91	20	2	Sub-adult	Ngangao	6/I/2008	Time limited search	Released
92	46		Female	Mbololo	18/02/2008	Time limited search	Released

93	45		Female	Mbololo	22/02/2008	Time limited search	Released
94	40		Female	Mbololo	25/02/2008	Time limited search	Released
95	49	8.5	Female	Mwachora	26/02/2008	Time limited search	Released
96	50	8	Female	Mwachora	14/03/2008	Time limited search	Released
97	42		Female	Vuria	20/03/2008	Time limited search	Released
98	45		Female	Vuria	20/03/2008	Time limited search	Released
99	22		Sub-adult	Vuria	20/03/2008	Time limited search	Released
100	40		Female	Vuria	21/03/2008	Time limited search	Released
101	55		Female	Vuria	23/03/2008	Time limited search	Released

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-Sir Isaac Newton-

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