

AMPHIBIAN COMMUNITY ALONG ELEVATIONAL AND HABITAT DISTURBANCE GRADIENTS IN THE TAITA HILLS, KENYA

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Abstract: We evaluated the relationship between amphibian composition along anthropogenic habitat disturbance and elevational gradients in the Taita Hills. We tested the hypotheses that there is a clear amphibian species turnover with elevation, and that human habitat disturbance influence abundance of amphibian reproductive strategies. Transects were used in surveying amphibians. Sampling was done in two broad habitat types (terrestrial forests/ plantations, and aquatic streams/dams). We used Kruskal-Wallis to test the differences in amphibian species richness and diversity among the habitat types, while EstimateS program was used to estimate species diversity and abundance. Comparison of species richness was done using Sørensen similarity index with amphibian communities as zoogeographic indicators. Multivariate cluster analysis was used to examine the community similarity in terms of habitat type and elevation. Cluster analysis of community similarity revealed distinct species assemblages in terms of elevation and habitat type. Amphibian species richness increased with increased habitat disturbance from forests to streams and dams but decreased with increasing elevation. However, abundance of species with direct developing mode of reproduction decreased with increased habitat modification/disturbance. These findings clearly demonstrate that conservation investment in protection of the Taita Hills should be directed towards terrestrial indigenous forests which are home to the three area endemics and direct developers (*Boulengerula taitana*, *Boulengerula niedeni* and *Callulina dawida*). We therefore strongly support efforts to protect a network of these indigenous forest fragments with some form of connectivity alongside the human modified habitats. Recognizing the role of ecosystem restoration in protecting biodiversity in fragmented habitats, this study strongly supports restoration efforts involving gradually replacing exotic forest plantations with indigenous plants.

Key words: Anurans, Gymnophiona, habitat change, altitude, primary productivity, climate, biogeography, species richness, Africa.

Resumen: Patrick K. Malonza y Michael Veith. "Comunidad de anfibios a lo largo de gradientes altitudinales y de perturbación de hábitat en Taita Hills, Kenia" Evaluamos la relación entre la composición de anfibios a lo largo de gradientes altitudinales y con perturbación antropogénica de hábitat en Taita Hills. Pusimos a prueba las hipótesis de que hay un claro recambio de especies con la altura, y que la perturbación humana de hábitat influye en la abundancia de estrategias reproductivas en anfibios. Transectas fueron empleadas en el inventario de anfibios. El muestreo fue llevado a cabo en dos tipos de hábitats amplios (bosques/plantaciones terrestres, y riachuelos/represas acuáticas). Empleamos Kruskal-Wallis para poner a prueba las diferencias en la riqueza de especies de anfibios y la diversidad entre los tipos de hábitat, mientras que el programa EstimateS fue usado para estimar la diversidad y abundancia de especies. La comparación de riqueza de especies fue realizada usando el índice de similitud de Sørensen con comunidades de anfibios como indicadores zoogeográficos. Análisis cluster multivariado fue empleado para examinar la similitud de comunidad en términos de tipo de hábitat y elevación. Análisis cluster de similitud de comunidad reveló distintos ensambles de especies en términos de tipo de hábitat y elevación. La riqueza de especies de anfibios se incrementó con perturbación de hábitat incrementada de bosques a riachuelos y represas pero disminuyó con el incremento en elevación. Sin embargo, la abundancia de especies con modo de reproducción de desarrollo directo disminuyó con modificación/perturbación de hábitat incrementada. Estos hallazgos claramente demuestran que la inversión de conservación en la protección de Taita Hills debe ser dirigida hacia bosques terrestres nativos que son hogar de los tres endemismos con desarrollo directo (*Boulengerula taitana*, *Boulengerula niedeni* y *Callulina dawida*). Por consiguiente nosotros apoyamos fuertemente los esfuerzos para proteger una red de estos fragmentos nativos de bosque con alguna forma de conectividad a lo largo de hábitats modificados por el hombre. Reconociendo el papel de la restauración de ecosistemas en la protección de biodiversidad en hábitats fragmentados, este estudio apoya fuertemente los esfuerzos de restauración que involucran el reemplazo gradual de plantaciones forestales exóticas con plantas nativas.

Palabras clave: Anuros, Gymnophiona, cambio de hábitat, elevación, productividad primaria, clima, biogeografía, riqueza de especies, África.

INTRODUCTION

Spatial patterns in species richness have fascinated biologists for decades and the search for their causes has been a centre of focus in the field of community ecology and/or conservation biogeography for decades (Heaney 2001). What is clear is that the distribution

of organisms is not random (Rahbek 1997). The need to document and understand species patterns especially for the lower taxa are increasingly becoming important as threats to biodiversity escalates.

Modern interest has focused on distributions along latitudinal and elevational gradients and the processes that control these patterns

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(Colwell *et al.* 2004, Watkins *et al.* 2006). In both patterns there is an inverse relationship between species richness and elevation and latitude (Rahbek 1997, Willig *et al.* 2003, Carpenter 2005, Watkin *et al.* 2006). Studies on elevational gradients have observed two main patterns of species richness: first a monotonical decrease in richness with increasing elevation and second, a “humped” distribution, with species richness highest near the middle of the gradient (Watkins *et al.* 2006).

Irrespective of elevation, human disturbance of habitats continue to change species composition and distribution world-wide. Habitat loss and fragmentation is one of the major threats to biodiversity (Fahrig 2003, Ross *et al.* 2002, Kupfer *et al.* 2005, Taberelli and Gascon 2005, Ewers and Didham 2006, Cayuela *et al.* 2006, Bell and Donnelly 2006). Consequently, throughout the world, previously extensive tracts of natural habitat now exist as isolated fragments scattered across inhospitable landscapes (Benedick *et al.* 2006). 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 (Raman 2006, Benedick *et al.* 2006). In tropical areas, amphibian studies have mainly focussed on species diversity and richness, with some conducted in anthropogenically fragmented environments (e.g. Marsh and Pearman 1997, Wind 2000, Vallan 2000, Pineda and Halffter 2004, Ernst and Rödel 2005, Neckel-Oliveira and Gascon 2006, Bell and Donnelly 2006, Cushman 2006, 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 too small to support viable populations (Watson *et al.* 2004). Rare species, species with low dispersal abilities, large area requirements, low fecundity, low population densities, abundance or high population variability, habitat and food specialists are most affected by habitat loss and fragmentation (Bell and Donnelly, 2006).

Understanding species richness patterns in montane regions is important as most of them are centres of species diversity and endemism in the tropical regions (Smith *et al.* 2007). Currently little is known about the underlying factors that govern species distribution patterns. However, extensive literature suggests that contemporary climate with its control on energy dynamics constrains terrestrial taxonomic richness over broad geographic extents (Hawkins *et al.* 2003a). Climatic, biological, and historical factors have been suggested as causes of variation in species richness along elevational gradients (Rahbek 1997, Sanders *et al.* 2003). Climate through water-energy dynamics hypothesis has influence on primary productivity (Hawkins *et al.* 2003b) which in turn is positively correlated with species richness (Sanders 2002, Hawkins *et al.* 2003a).

No study has examined patterns of amphibian species richness and composition at different disturbance and elevation levels in the Eastern Arc Mountains (EAM) of Eastern Africa. The Taita Hills is one of the EAM Mountain blocks suitable for understanding the response of amphibian to elevation and anthropogenic habitat disturbance. Otherwise it is imperative to understand how amphibian

communities and individual species are distributed in order to formulate viable conservation and management options. The Taita Hills has the least amount of remaining forest (about 2% of the original forest) making it the most fragmented and endangered block in the EAM (Newmark 1998). Despite having the smallest remaining forest area, it has three endemic amphibians; namely, *Boulengerula taitana* Loveridge, 1935, *Boulengerula niedeni* Müller, Measey, Loader *et Malonza*, 2005 and *Callulina dawida* Loader, Measey, de Sá *et Malonza*, 2009.

It is therefore essential to ascertain how amphibian communities and individual species are affected by deforestation, habitat fragmentation and modification to derive appropriate ecosystem management options.

In this paper we aim to assess how anthropogenic habitat disturbance along the Taita Hills elevational gradient affect amphibian community. We test the hypotheses that (1) there is a clear amphibian species turnover with elevation, and (2) human habitat disturbance and elevation influence abundance of amphibian reproductive strategies. Predictably sites within similar disturbance regime and/or elevations should group together. Amphibians have been used as bio-indicators because they are easy to quantify and have relatively narrow moisture and temperature tolerances (Duellman and Trueb 1994). Forest loss has been found to cause micro-climate alteration such as higher temperatures, lower soil and atmospheric humidity as well as increasing wind velocity in the tropics (Pineda and Halffter 2004, Ernst *et al.* 2006). Previous studies have shown that deforestation and habitat modification affect amphibian communities in tropical forests (e.g. Pearman 1997, Vallan 2000, 2002, Vallan *et al.* 2004, Pineda and Halffter 2004, Bell and Donnelly 2006). In particular, species with direct development reproductive mode (e.g. deposit eggs on leaf) are very sensitive to changes in moisture regime and leaf litter depth (Marsh and Pearman 1997).

MATERIALS AND METHODS

Study area

The Taita Hills is the northern outlier of the EAM, a well known biodiversity hotspot (Myers *et al.* 2000). The EAM is a chain of 13 ancient, crystalline blocks, arranged as an arc, and located in Eastern Africa (Tanzania and Kenya) overlooking the Indian Ocean (Lovett 1990). The Taita Hills complex consists of the main block (Dawida, 2228 m) c. 25km north-west of Voi and three other blocks: Mt. Mbololo (2149 m), Sagalla Hill (1520 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) (Fig. 1). 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. The lower slopes of the hills are covered by dry bush land that change abruptly after c. 1000 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 totalling 400 ha. 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). 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 in the foothills of each block. 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°C) while rainfall increases (600 to 1400 mm) with elevation (Jätzold and 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.

Definition of habitats

The habitats investigated include:

- 1) **Terrestrial:** a) Forests: In this study, this refers to indigenous montane cloud forest and, b) plantations comprising a mixture and/or pure stands of eucalyptus (*Eucalyptus* spp.) and pine (*Pinus* spp.) most of which were re-planted in areas that used to be covered by indigenous forests. Both forests and plantations are located at high elevations (> 1000 m).
- 2) **Aquatic habitats:** These were mainly streams and man-made dams. All were within agricultural lands on the foothills and/or highland valleys.

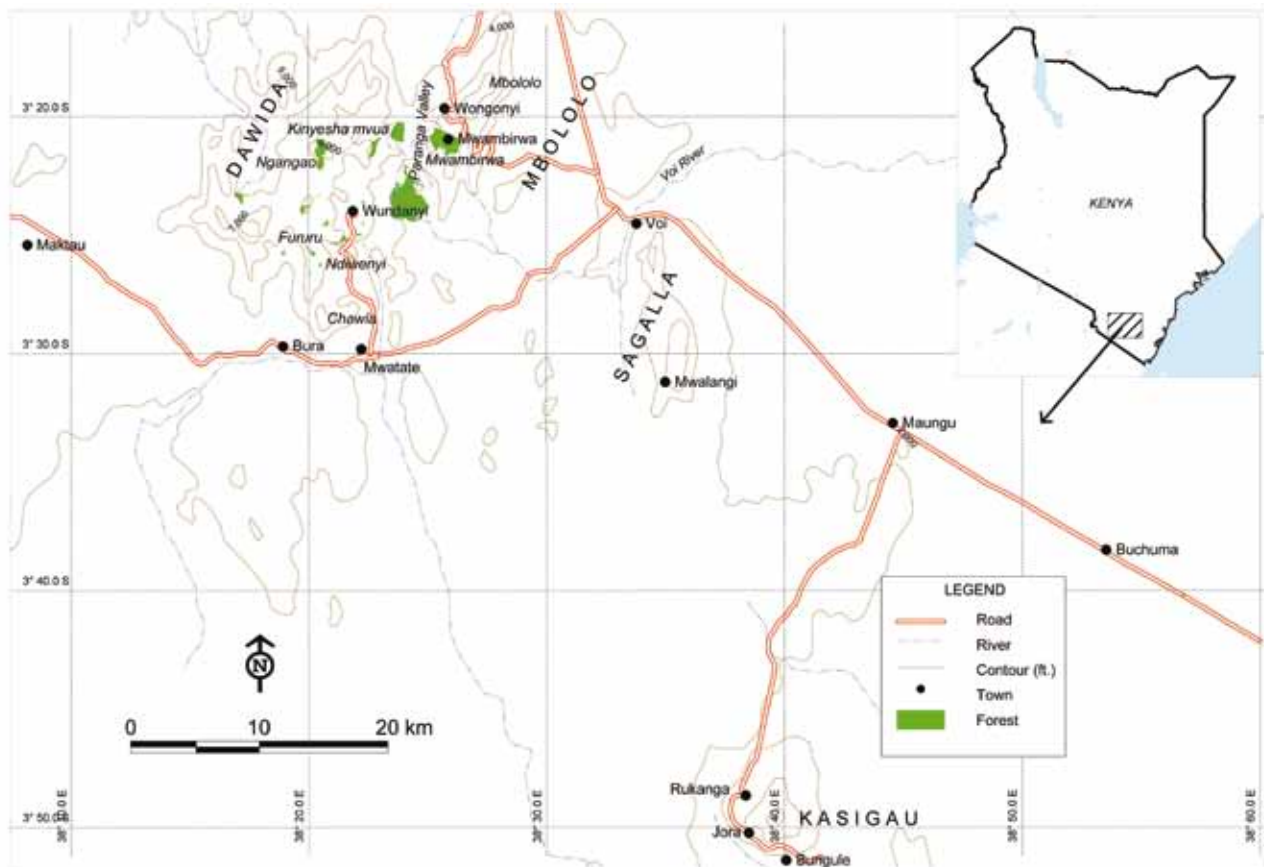


FIG. 1. Map of the Taita Hills showing the four mountain blocks (Dawida Mbololo, Sagalla and Kasigau). Inset a map of Kenya showing the location of the Taita Hills.

Mapa de las Taita Hills donde se muestra los cuatro bloques montañosos (Dawida Mbololo, Sagalla and Kasigau). Insertado un mapa de Kenia donde se muestra la localización de las Taita Hills.

Sampling sites

1. Terrestrial.

1a) **Forests** (n = 8): Ngangao (1854 m), Chawia (1610 m), Mwachora (1644 m), Macha (1650 m), Boma-Wundanyi (1439 m), Mbololo (1770 m), Sagalla (1504 m), Mount Kasigau (1600 m).

1b) **Plantations** (n = 4): Kinyesha-mvua (1612 m), Sungululu (1483 m), Mwambirwa (1300 m), Sagalla (1384).

2. Aquatic.

2a) **Aquatic - streams** (n = 11): Chale (1236 m), Mwalenjo (1292 m), Mwasange (1309 m), Marapu (651 m), Mghange (1273 m), Kauze (1081 m), Piringa (1187 m), Mndangenyi (1397 m), Mbirwa (1430 m), Mghambonyi (1546 m) Madungunyi (846 m).

2b) **Aquatic – dams** (n = 6) Bafwe (577 m), Hezron (563 m), Lata (1064m), Makandenyi (1647 m), Ngulu (1600 m), Mwatate (839 m). Sites below 1000 m were designated as lowland and those above 1000 m as highland.

Sampling methodology

We sampled amphibians using 600 x 1 m transects (Rödel and Ernst 2004, Veith *et al.* 2004) continuously from April 2006 to January 2007. In total we had 29 transect sites within the two broad habitats (terrestrial and aquatic). There were six observers assignable to six clusters of transects, meaning that each observer had a maximum of five transects to sample. Each transect was sampled at least once every week covering both dry and wet seasons. A standard time of 1 hour sampling was spent in each transect and interrupted only when recording data. The number of samples for each transect are given in Table 1.

Identification of the specimens was made using published taxonomic keys and followed taxonomy by Frost *et al.* (2006) and Frost (2007). Selected individuals of underrepresented species were kept as voucher specimens and deposited in National Museums of Kenya (NMK). Tissue samples for future DNA analysis were taken for majority of the specimens and stored in absolute ethanol.

Climatic variables

The explanatory power of climatic factors on amphibian species richness patterns was assessed. Average minimum and maximum daily rainfall and temperature were estimated from data gathered from daily records for most sites. Geographic location was based on GPS data, Garmin® 12XL (Garmin International, Olathe, Kansas, USA).

Data analysis

Species richness and diversity for each transect was estimated using EstimateS 7.5.1 program (Colwell 2006). Amphibian species diversity among transect sites was measured with Shannon Index (H'). Non-parametric Kruskal-Wallis H test was used to compare amphibian species abundance and species richness among transects within the same elevation cluster and habitat type.

Amphibian similarity between sampling sites was calculated using Sørensen similarity index. This index is based on the probability that two randomly chosen individuals, one from each site, belong to a species shared by both sites (but not necessarily to the same species (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 on amphibian species composition, a distance matrix based on Sørensen qualitative similarity index was generated. Using STATISTICA 6.0 (StatSoft 2001) the resultant matrix was converted into a dendrogram using complete linkage cluster analysis.

Mt. Kasigau was omitted in the diversity analyses because no species was recorded during all the transect surveys. For uniform comparability we compared data from only the streams and dams in high altitude areas, excluding the lowland sites. Data was analyzed with STATISTICA 6.0 software (StatSoft 2001), with significance levels set at $\alpha = 0.05$.

RESULTS

Species richness and diversity

We recorded 5577 amphibian individuals of 23 species from all the 29 transect sites (Table 2). In terrestrial habitats we recorded five and three species in forests and plantations respectively. However, there was no significant difference in richness and the Shannon diversity index (H') (Kruskal-Wallis: richness, $H = 1.96$, $df = 1$, $N = 177$, $P = 0.16$; diversity, $H = 2.91$, $df = 1$, $N = 11$, $P = 0.08$). Again, comparing every survey (sample), the number species observed was also not significant ($H = 1.96$, $df = 1$, $N = 177$, $P = 0.16$).

Eleven and twelve species were observed in highland streams and dams respectively. Species diversity among streams and dams was not significantly different ($H = 1.93$, $df = 1$, $N = 12$, $P = 0.16$). However, comparing the number of species observed per sample (survey) they were significantly higher in dams than streams (Kruskal-Wallis: richness, $H = 19.059$, $df = 1$, $N = 196$, $P < 0.001$).

Patterns of species richness along elevation and disturbance gradient

There was clear altitudinal species turnover from lowland to highland. While there were some widespread species there were notable lowland species such as *Hyperolius tuberlinguis* (Smith, 1849), *Hildebrandtia macrotympanum* (Boulenger, 1912), *Chiromantis kelleri* Boettger, 1893 and *Ptychadena mossambica* (Peters, 1854). *Boulengerula taitana*, *Callulina dawida*, *Arthroleptis xenodactyloides* Hewitt, 1933 and *Amietia angolensis* (Bocage, 1866) were restricted to the highlands. The results of cluster analysis of all transects produced two major clusters of species assemblages according to their responses to the habitat type and elevation band (highland streams/dams and forests/plantations) plus a sub-cluster of typical lowland streams and dams (Fig. 2). Generally, there were more amphibian species at low to mid-elevation streams and dams and less in forests and plantations at high altitudes.

Species response to habitat disturbance level

The results on patterns of species distribution clearly show absence of certain species in some habitats. The frog *Callulina dawida* was only found in indigenous forests. The leaf litter frog *Arthroleptis xenodactyloides* was confined mainly to forests and plantations, while *Amietia angolensis* occurred in highland streams. Dams were mainly dominated by open water breeders.

DISCUSSION

Response of species to habitat disturbance and elevation gradient
The results on local amphibian species richness in the Taita Hills

show that species abundance and richness differs significantly among the two broad habitat types (terrestrial and aquatic). Aquatic streams and dams in the highlands contained significantly more species than terrestrial forests and plantations. The results show that plantations were very depauperate in both species richness and number of individuals. Overall species richness and abundance positively increased with disturbance level from forests through streams to dams. However, considering species reproductive phylogeny (strategy) forest associated direct developing species (*Arthroleptis xenodactyloides*, *Callulina dawida* and *Boulengerula taitana*) decreased with increased disturbance from forests to aquatic

TABLE 1. Number of samples and species observed in different transects in both terrestrial and aquatic habitats.

TABLA 1. Número de muestras y especies observadas en diferentes transectos en ambos hábitats terrestre y acuático.

Transect	Habitat type	Number of samples	Number of species observed (\pm SD)
Ngangao	Forest	17	2 \pm 0.53
Chawia	Forest	16	2 \pm 0.49
Mwachora	Forest	16	1 \pm 0.40
Macha	Forest	15	2 \pm 0.51
Boma	Forest	18	2 \pm 0.23
Sungululu	Plantation	16	1 \pm 0.48
Kinyesha-mvua	Plantation	14	3 \pm 0.36
Mndangenyi	Aquatic stream	16	4 \pm 0.70
Mbirwa	Aquatic stream	17	5 \pm 0.72
Mghambonyi	Aquatic stream	13	5 \pm 0.59
Makandenyi	Aquatic dam	12	6 \pm 0.78
Piringa	Aquatic stream	18	5 \pm 1.15
Ngulu	Aquatic dam	16	7 \pm 1.37
Mwatate	Aquatic dam	19	8 \pm 1.99
Madungunyi	Aquatic stream	18	7 \pm 1.35
Mbololo	Forest	21	2 \pm 0.30
Mwambirwa	Plantation	17	2 \pm 0.44
Mwasange	Aquatic stream	19	8 \pm 1.24
Mwalenjo	Aquatic stream	19	6 \pm 0.85
Chale	Aquatic stream	16	5 \pm 1.12
Sagalla	Forest	15	2 \pm 0.26
Sagalla	Plantation	16	1 \pm 0.34
Mghange	Aquatic stream	13	5 \pm 1.28
Kauze	Aquatic stream	17	6 \pm 1.34
Lata	Aquatic dam	18	9 \pm 1.21
Marapu	Aquatic stream	16	4 \pm 0.92
Hezron	Aquatic dam	14	9 \pm 1.76
Bafwe	Aquatic dam	16	10 \pm 1.80
Kasigau	Forest	16	0 \pm 0

habitats. 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 (Pineda and Halfpeter 2004).

Species richness was high at low to mid elevations and few at high elevations. In Taita Hills, rainfall increases with elevation while temperature decreases (Jätzold and Schmidt 1983). This pattern agrees with that reported by many previous studies on a wide range of taxonomic groups (Heaney 2001, Smith *et al.* 2007). Despite the high rainfall at high elevations in the Taita Hills, much of the water as observed elsewhere settles on mid-elevations and the rest on the foot hills therein creating breeding sites for open water breeders (Hofer *et al.* 2000). This observation is in agreement with past studies that have demonstrated high species richness as a product of high energy (temperature) and primary productivity (Hawkins *et al.* 2003b, Willig *et al.* 2003). Energy in form of temperature and rainfall (water) are known indirect measures of net primary productivity and hence increased species richness (Sanders *et al.* 2003).

In Taita Hills, certain species (with direct developing reproductive mode) are restricted to high elevation forests (e.g. *Callulina dawida*). Similarly, on Mount Kupe, Cameroon, Hofer *et al.* (2000) 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 as evident in Taita Hills, they observed a significant response to amphibian species that do not depend on streams for development (i.e. direct developers) to elevational gradient variables. In cluster analysis, sites similar in disturbance and elevation clustered together reflecting their similarity in amphibian community.

Implications for conservation management

In Taita Hills direct developing amphibian species in forests (*Callulina dawida*, *Arthroleptis xenodactyloides*, *Boulengerula niedeni*, *Boulengerula taitana*) occur only in terrestrial forests and are absent in aquatic habitats. 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). Elsewhere, microclimate change has

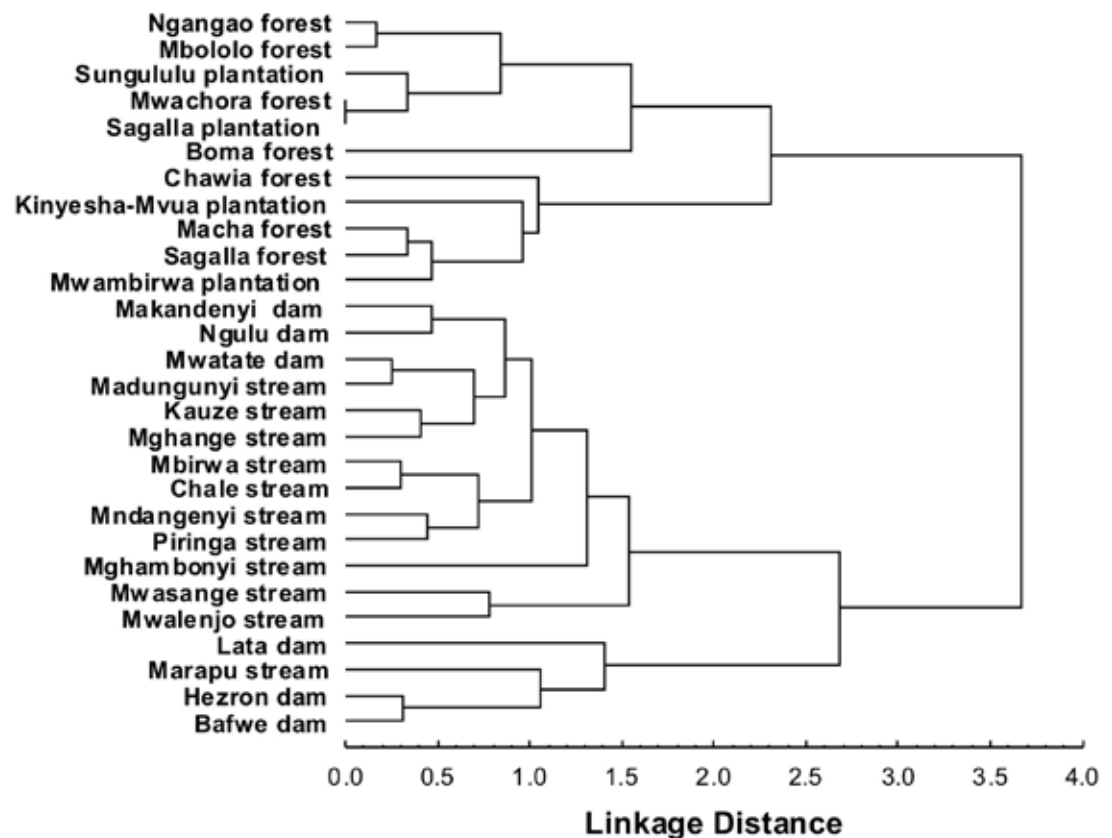


FIG. 2. Dendrogram from cluster analysis of the 28 transect sites from Taita Hills based on Sørensen's similarity. The dendrogram, in general, clusters transects together that are similar in habitat type and/or at similar elevations.

Dendrograma a partir de un análisis de cluster de los 28 sitios de transecta de las Taita Hills basado en la similitud de Sørensen. El dendrograma, en general, agrupa transectos.

TABLE 2. The 23 species and the respective number of individuals recorded in different habitats, plus their reproductive strategy.**TABLA 2.** Las 23 especies y su respectivo número de individuos registrados en diferentes hábitats, más su estrategia reproductiva.

Species	Terrestrial-Forest	Terrestrial -Plantation	Aquatic -Stream	Aquatic -Dam	Habits	Reproductive mode/strategy
<i>Boulengerula taitana</i>	2	0	0	0	Fossorial	Direct developer
<i>Xenopus borealis</i>	0	0	91	99	Aquatic	Open water
<i>Amietophrynus garmani</i>	0	0	5	23	Terrestrial	Open water
<i>Amietophrynus gutturalis</i>	2	2	219	116	Terrestrial	Open water
<i>Amietophrynus xeros</i>	0	0	4	125	Terrestrial	Open water
<i>Mertensophryne taitana</i>	0	0	1	0	Terrestrial	Open water
<i>Phrynomantis bifasciatus</i>	0	0	0	146	Terrestrial	Open water
<i>Callulina dawida</i>	7	0	0	0	Fossorial/	Direct developer
<i>Hemisus marmoratus</i>	0	0	0	22	arboreal	Open water
<i>Arthroleptis xenodactyloides</i>	441	159	14	0	Fossorial	Direct developer
<i>Leptopelis concolor</i>	0	0	84	201	Terrestrial	Open water
<i>Hyperolius glandicolor</i>	3	1	808	1581	Arboreal	Open water
<i>Hyperolius tuberilinguis</i>	0	0	0	86	Arboreal	Open water
<i>Kassina senegalensis</i>	0	0	0	86	Arboreal	Open water
<i>Hildebrandtia macrotypanum</i>	0	0	0	15	Terrestrial	Open water
<i>Ptychadena anchietae</i>	0	0	128	464	Fossorial	Open water
<i>Ptychadena mascareniensis</i>	0	0	137	229	Terrestrial	Open water
<i>Ptychadena mossambica</i>	0	0	2	0	Terrestrial	Open water
<i>Phrynobatrachus scheffleri</i>	0	0	11	12	Terrestrial	Open water
<i>Amietia angolensis</i>	0	0	20	0	Terrestrial	Open water
<i>Tomopterna cryptotis</i>	0	0	0	45	Terrestrial	Open water
<i>Chiromantis kelleri</i>	0	0	0	6	Fossorial	Open water
<i>Chiromantis petersi</i>	0	0	0	202	Arboreal	Open water

been found to negatively impact leaf litter frogs (e.g. Ernst and 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 (Marsh and Pearman 1997, Pineda and 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 and Trueb 1994). The eggs of such species (direct developers) are exposed to the atmosphere and with reduced humidity would be vulnerable to desiccation. Therefore, simplification of the vegetation structure could reduce the availability of oviposition sites mainly for species that deposit their eggs on leaf litter (Vallan 2000, 2002). Consequently, in Taita Hills certain species like *Callulina dawida* 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 *et al.* 2006, Bell and Donnelly 2006).

On the other hand, the proportions of arboreal and/or open water breeding species in Taita Hills increased from terrestrial forests to aquatic dams. 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 (Pineda and Halffter 2004), for these species the presence of a body of water (breeding sites) has stronger positive effect than that of the forest loss. This concurs with findings by Vallan (2002) in rainforests

of Madagascar, Pineda and Halffter (2004) in a montane forest in Mexico, and Hillers *et al.* (2008) in Tai National Park and selected forest fragments in Ivory Coast.

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

In Taita Hills, conservation investments should be directed towards the terrestrial indigenous forests. Although forests were generally poor in species richness than aquatic streams and dams, it is only here where you have direct developing amphibians. Among these are the three Taita Hills endangered endemics (Malonza 2008). The caecilian *Boulengerula niedeni* is caterogized by IUCN as Critically Endangered (CR) (www.iucnredlist.org/amphibians) while the *Boulengerula taitana* and the warty frog *Callulina dawida* are both proposed to be listed as Vulnerable (VU) and CR, respectively, following IUCN criteria (Malonza 2008). To protect these endemics, we therefore propose a framework for identifying priority areas for amphibian conservation that focus on indigenous forests. Hence, we recommend the continued maintenance of a set of forest fragments together with the human modified habitats extensively distributed (Pineda and Halffter 2004) including some form of habitat connectivity (e.g. corridors) (Cushman 2006, Akçakaya *et al.* 2007). We also strongly support restoration programmes of gradually replacing exotic plantations with indigenous plants.

CONCLUSIONS

This study clearly shows that species response to disturbance and elevation gradient depends on particular species reproductive strategy. Species with direct development mode of breeding are restricted to terrestrial forests in high elevations. These are as well the most affected by human habitat modifications. Most of these disappear with loss of indigenous forests and any conservation efforts should be directed towards their protection for continued survival of the Taita Hills endemics.

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