DIVERSITY AND HABITAT PREFERENCES OF ANURANS IN THE ATEWA RANGE FOREST RESERVE, EASTERN REGION, GHANA

BY

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DECLARATION

I declare that this thesis submitted for the award of Master Philosophy in Zoology, is the result of research undertaken by me. References to other people's work have been duly acknowledged.

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ABSTRACT

This study investigated anuran diversity and habitat preferences in the Atewa Range Forest Reserve, Eastern Region, Ghana. The study analysed the effect of habitat variables (leaf cover, leaf litter depth, canopy cover and altitude) on anuran species richness and abundance. Sampling was carried out in four habitats (farmland, *Cedrela* plantation, riparian forest and swamp forest). A total of 16 plots (200m x100m) established along an altitudinal gradient from 300 - 800 meters above sea level were sampled . Visual and acoustic encounter techniques were used in surveying anurans. Leaf litter depth, leaf cover, canopy cover and altitude were measured or approximated in the plots and analysed to determine their effects on species richness and abundance of frogs. The results indicated a record of 762 anurans belonging to 20 species and eight families over the entire study period. The most abundant species was the West African screeching frog (*Arthroleptis* spp.) which is associated with degraded habitats. Species composition was most similar between the *Cedrela* plantation and riparian forest habitats. Species richness increased with elevation and diversity peaked at upland elevations. The swamp forest (H'=1.947) was the most diverse habitat followed in that order by farmland (H'=1.468), riparian forest (1.076) and the *Cedrela* plantation(0.505) . Species richness was highest in the swamp forest, indicating that swamp forest habitats may be more favourable habitats for anurans. Significant differences were found between farmland and swamp forest habitats (R=0.292, $P<0.009$), suggesting that altitude affected anuran species composition and distribution. Leaf cover, canopy cover, altitude and leaf-litter depth were correlated with species richness and abundance of the anurans, however, only altitude (r= -0.534, P<0.05) and leaf cover

(R= 0.585, P<0.05) were significant in predicting abundance and richness. The Atewa Range Forest Reserve is an important site for rare and endangered species (*Conraua derooi* and *Amietophrynus togoensis*). It is therefore recommended that the boundary and mid-altitudinal habitat sites at Atewa should be protected against further disturbance. To enable more reliable conclusions on the effect of habitat variables on anuran diversity, future research should include other habitat factors like disturbance, soil moisture, humidity and type of leaf cover.

CHAPTER ONE

INTRODUCTION

1.1 Background

The Upper Guinean forest of West Africa ranks as one of 34 biodiversity hotspots worldwide (Bakarr *et al.* 2004, Myers *et al.* 2000). The forests of this region originally covered 420,000 km^2 but estimates of existing forests suggest a loss of nearly 70% (Bakarr *et al*. 2001, Pooter *et al*. 2004). Within the western part of the Upper Guinea forest, mountainous forests are particularly under pressure from deforestation, degradation and fragmentation (Ernst and Rodel, 2005; Ernst *et al.*, 2006) and mining (McCullough *et al.* 2007). Montane forests are unique with exceptional species with considerable high levels of endemism in general (Bakarr *et al.*, 2004) and amphibians in particular (Rodel *et al.*, 2004). Like many tropical countries, Ghana continues to lose its remaining closed forests at an alarming rate. According to Poorter *et al*. (2004), only 15% of the original forest cover remains intact.

In tropical forests throughout the world, amphibians comprise a significant portion of vertebrates, and in these ecosystems they are important, both as predators and as prey (Duellman,1990). They also play very important roles in conserving biological diversity in these forests. Furthermore, amphibians are a major group that allow for a reliable judgement of the status of West African forests (Ernst and Rodel, 2005; Ernst *et al.* 2006). However, the whole taxonomic group remains threatened by habitat degradation and conversion as well as diseases (Stuart *et al*. 2004). While the major factor attributed to amphibian declines and extinction has historically been habitat loss and degradation, many of the declines have now been attributed to the rapidly dispersing infectious fungus *Bactrachochtrium dendrobatidis* with more than 50% of species wiped out within four to six months (Lips *et al*., 2006). According to the IUCN Red List, 41% of 6,300 described extant amphibian species are at risk of extinction (IUCN, 2010), making them the most threatened vertebrates to date. Amphibians are the most affected because they are sensitive to environmental change (Hopkins, 2007). The complexity of amphibian requirements is partly the result of their biphasic cycles, relying on both aquatic and terrestrial habitats during some part of their life-cycle (Pough, 2004).

Between the Upper Guinea and Cameroon Highlands, only the Atewa Range in Ghana, the Volta Highlands in the Ghanaian/Togolese border region, and Jos Plateau in Nigeria harbour significant upland forest patches. Of these three areas, moist evergreen forest is found only in the Atewa Range (Swaine and Hall, 1977). The Atewa Range Forest Reserve (hereinafter Atewa Forest) is one of the only two forest reserves in the Eastern region of Ghana where Upland Evergreen Forest occurs (Hall and Swaine, 1981; Abu-Juam *et al.*, 2003). The other is the Tano Ofin Forest Reserve, which is already highly degraded. Atewa harbours new species to science, rare and threatened floral and faunal species, and is an exceptionally important site for national and global biodiversity conservation as well as being an ideal site for amphibian studies (McCullough *et al.*, 2007). The Atewa Forest has also been ranked by the Priority-Setting Workshop for Upper Guinea (Bakarr *et al.*, 2001)) as of “very high” priority for overall biodiversity conservation.

1.2 Justification

Throughout the world's ecosystems, amphibians comprise a significant proportion of vertebrates, playing important roles both as predators and prey (Duellman, 1990). The decline of amphibians may thus cause other faunal species as well as aspects of ecosystem function to become threatened (Matthews *et al.*, 2002; Whiles *et al.*, 2006). The Atewa Forest has received considerable attention, because the area is an exceptionally important site for national and global biodiversity conservation (McCullough *et al.*, 2007).

The amphibian community of the Atewa forest is exceptional, comprising of almost exclusively forest species, an indication of a very intact forest ecosystem. Additionally, the area contains a very high percentage of species that are endemic to the Upper Guinea forests or even much smaller parts of these forests, as well as an extremely high proportion of threatened species. The amphibian community of the Atewa forest is poorly-known. A Rapid Assessment Programme (RAP) survey carried out in Atewa Forest in 2006 by Conservation International, recorded a total of 32 species even though predicted species richness of the area was 40-50 species (McCullough *et al.*, 2007). Previous studies of amphibians (Kouame *et al.*, 2007; Ofori-Boateng *et al.*, 2012) have largely focused on diversity and population dynamics of specific species (e.g. *Conraua derooi)*, neglecting studies of amphibian habitats along altitudinal gradients and species richness in the reserve.

Data on effects of microhabitat on amphibians is limited and there is no data on how microhabitat characteristics of the forest such as leaf litter and altitude may affect amphibian assemblages. When Fauth *et al.* (1989) analysed the effect of leaf litter depth and elevation on herpetofaunal density, richness and evenness at different sites in Costa Rica, none of the variables affected the density of herpetofauna, but leaf litter depth significantly affected species richness. Giaretta *et al.* (1999) compared the relative importance of litter elements on the community structure of frogs in the Atlantic Forest of south-eastern Brazil and found that frog abundance was related to soil cover and depth, altitude, leaf-litter mass and fallen trunk area.

Factors that have been hypothesized to influence patterns of species richness at medium and large scales include geography (altitude, orography), climate, abiotic and historical influences (Fraser,1998). Altitudinal gradient is a known important factor that causes changes in environmental factors. It is thus predicted that along such gradients, there will be changes in abundance and species richness of amphibians. Studies exploring the relationship between elevation and amphibian species richness have mainly been conducted in Kenya, Nepal and Thailand (Malonza and Veith, 2012; Khatiwada, 2011; Phnochayavanich *et al.*, 2010). This study aimed to determine the pattern of abundance and species richness, as well as influence of elevation and some environmental factors on amphibian diversity in the Atewa Forest. Such information is vital for conservation initiatives in forests, and forms the basis for monitoring the state of reserves and analyzing trends in amphibian declines. The findings of this study are expected to provide important information for the management of Atewa Forest and for making informed decisions about conservation of rare and threatened amphibian species.

1.3 Objectives

The general objective of the study was to determine the influence of microhabitat variables on anurans in different habitat types in the Atewa Forest in the Eastern Region of Ghana. The specific objectives were to:

- compare the relative abundance and species richness of anurans in different habitat types in the Atewa Range Forest Reserve
- determine the effect of altitude, leaf cover, leaf litter depth and canopy cover on anuran species richness and relative abundance

CHAPTER TWO

LITERATURE REVIEW

2.1 Biology, Ecology and Diversity of Amphibians

Amphibians are ectothermic, primitively quadrupedal vertebrates that have glandular skin and breathe by lungs, gills or skin. They are the survivors of one of the two major branches of tetrapod phylogeny, the other one being represented today by the amniotes (Hickman *et al*., 2000). The name *amphibian*, derived from the Greek word *amphibios* meaning "living a double life," reflects this dual life strategy. Some species are terrestrial, while others have a completely aquatic mode of life (Encyclopædia Britannica, 2013). Most **amphibians** have a biphasic live cycle that begins with an aquatic larva that later metamorphoses to produce a terrestrial adult that returns to water to lay eggs (Beebee, 1996; Hickman *et al*., 2000). While this pattern is familiar, some frogs, salamanders and caecilians have evolved direct development that omits the aquatic larval stage and some caecilians have evolved viviparity (Hickman *et al.,* 2000).

The modern **amphibians** consist of three major evolutionary groups: (i) Anura/Salientia (frogs and toads) with 6,200 species of which nearly 90% are frogs, (ii) Caudata/Urodela (salamanders) with 652 species, and (iii) Gymnophiona/Apoda (caecilians) with 192 species (Frost,2013; Amphibiaweb, 2013). During the Carboniferous era, the early **amphibians** improved their adaptations for living in water (Hickman *et al.,* 2000), with their bodies becoming flatter for moving about in shallow water. This specialization was enhanced by the swampy surroundings of the

Carboniferous era, but presented desiccation problems for life on land. Modern **amphibians** are an enormously diverse group of vertebrates comprising 7,044 species, and with more being described every year, they represent a greater proportion of living vertebrates than mammals, which are often considered the dominant terrestrial vertebrates (Glaw and Kohler, 1998).

The most common feature of **amphibians** include shell-less eggs, a smooth and moist skin richly endowed with secretory glands but without fur, feathers or scales. Most **amphibians** therefore require high levels of humidity, or a fully aquatic environment, in which to live (Beebee, 1996). Though the three extant **amphibians** (frogs, salamanders and caecilians) are thought to have descended from a common ancestor, their body forms vary greatly from each other from an elongated trunk with a distinct head, neck, and tail to a compact, depressed body with fused head and trunk and no intervening neck. They are usually tetrapod, although some species are legless and others have small limbs. Feet are often webbed and often with no true nails or claws. The first and largest of the orders is the Anura or Salientia (frogs and toads), which are specialized for jumping with greatly enlarged hind legs, shortened bodies, no tail and large heads and eyes (Wells, 2007). In addition to been the order with a wider distribution, they are also the most studied group. In Ghana, almost all the amphibians are anurans (84) , hence they are the focus of this study. In size, frogs vary from the smallest, *Paedophryne amauensis* (common name) of Papua New Guinea measuring about 0.77 cm in head and body length to the largest, *Conraua goliath* (Cameroon Goliath frog) of Africa attaining a head and body length of 33 cm and weighing 3.5 kg.

Frogs and toads are usually small, and even when measured with legs outstretched, most do not measure a centimetre in length (Smyth, 1962).

The second order is the Caudata or Urodela, comprising the salamanders and newts, many of which are lizard-like in body form, but lacking skin scales and claws. Salamanders vary tremendously in length and girth, but most are small, ranging from the size of an earthworm, to the giant salamander (*Megalobatrachus maxima*) of Japan measuring over 1.6 m long and weighing 10 kg. The giant salamander is not only the largest salamander, but also the largest amphibian in the world (Smyth, 1962). The Apoda or Gymnophiona (caecilians), the third order, contains only 192 described species. They are the least diverse of living amphibians but also the most specialized. They are tailless, legless, blind, and subterranean, resembling earthworms in form and habits.

Despite all the above differences, **amphibians** share certain physiological characteristics that set them apart from other terrestrial vertebrates. One such feature is their scale-less, highly permeable skin which allows for rapid exchange of gases, and is the interface between the animal and its surroundings, also providing mechanical protection (Wells, 2007). Skin glands are also important for courtship, sex recognition, and other aspects of chemical communication (Wells, 2007). Despite their name, amphibians only survive in fresh or mildly saline water; no species can survive prolonged exposure to sea water (Beebee, 1996).

An essential attribute of any surviving species or population is the ability to produce offspring. Classically, ideas concerning **amphibian** reproduction have centred on north temperate species of salamanders and anurans, most of which undergo brief, annual periods of mating and leave unattended eggs to develop into aquatic larvae (Duellman and Trueb, 1986). **Amphibians** accomplish fertilization in a variety of ways. External fertilization, employed by most frogs and toads, involves a male holding a female in a pose called amplexus, in which the male releases sperm over the female's eggs as they are laid. Many salamanders employ a less risky method, with the male depositing a packet of sperm (spermatophore) onto the ground, and the female pulling it into her cloaca where fertilization occurs internally (Hebert and Ontario, 2013). Caecilians and tailed frogs use internal fertilization like reptiles, birds and mammals.

Nearly all **amphibians** are either insectivorous or carnivorous, with insects being the principal food item, although worms and larvae are also eaten. Frogs and toads are carnivorous as adults and omnivorous as larvae. It has been reported that neither frogs nor toads have marked food preferences (Smyth, 1962) with adult **amphibians** consuming a wide variety of foods dominated by earthworms in burrowing caecilians. Insects and other arthropods are the main diet of anurans and salamanders, with large salamanders and some large anurans eating small vertebrates, including birds and mammals.

2.2 Distribution and Patterns of Species Richness of Anurans

Duellman (1999) identified 43 locations worldwide with exceptionally high numbers of anuran species. Nineteen of these high-diversity areas are in the western hemisphere, Eurasia, Africa and the Papuan-Australian region, but are absent in Antarctica and remote deserts. Since the 1950s, ecologists have held the view that animal communities are not simply random assemblages of species. Threats like habitat fragmentation, and degradation, as well as environmental factors, were pointed as being responsible for the variation in species diversity and distribution in these environments and/or spatial and temporal gradients (Chase and Leibold, 2003). Determinants of species richness include (i) history of the region, (ii) history of the lineages inhabiting the region, (iii) past and present climatic topographic conditions, (iv) physiological and life-history adaptations of the lineages, and (v) availability of resources, food, shelter and breeding sites (Duellman, 1999).

The distribution and abundance of anurans largely depends on microhabitat conditions such as leaf litter, humidity, and litter depth (Giaretta *et al.*, 1997). Anurans inhabit areas with high moisture levels and moderate temperatures (Duellman and Trueb, 1994; Wells, 2007) because of their physiology and biphasic life-style. According to Ernst and Rodel, 2005), 82% of **amphibian** species are forest- dependent, and thus even slight habitat splits (Becker *et al*.2007) of forests may affect the distribution, species richness and population size of anuran assemblages that depend on forest microhabitats . For example, Hillers *et al.* (2008) showed that habitat degradation, rather than fragmentation, alters the dynamics and composition of **anuran** assemblages in tropical forests. Although fragmentation does not affect the composition of **anurans** directly, it makes the environment drier. This may affect the composition of animal communities (Bickel *et al.* 2006).

In Ghana, anurans have broad distribution, most occurring in forests with others in savanna and coastal thickets. Leache (2005) reported that relatively more **anurans** were recorded in semi-deciduous forest and coastal thickets than savanna. Also, several studies have reported that the vast majority of anuran species in southern Ghana were forest specialists, with a few reports of typical farmbush and savanna species such as *Amietophrynus maculatus* (Rodel *et al.*, 2005; Rodel and Agyei, 2003; Hillers *et al.*, 2008).

2.3 Habitat Preferences and Microhabitat Conditions

The physiology of anurans varies with seasons and internal rhythms of the animal (Alford and Richards, 1999). It can thus be expected that anuran abundance may vary considerably among habitats with different microhabitat conditions. The larval period of anurans lasts for weeks, but since adults spend most of their lives on land, most of them spend the majority of their lives in terrestrial habitats.

The spatial and temporal utilization of different habitats by animals depend on age, sex, predation and availability of resources (Buskirk and Ostfeld, 1998). Some anurans, such as the Arthroleptidae and Bufonidae are strictly terrestrial, the Hyperoliidae are arboreal, the Ranidae are semi-aquatic, with others exhibiting great variation in habitat use (Wells, 2007). Microhabitat conditions may be thus important in determining the distribution and abundance of anuran species (Pope *et al*., 2000). Begon *et al.* (1996) found out that there was a correlation between habitat selection by animals and improved fitness, with ideal habitats supporting high population growth. Several other studies have also tested the effect of habitat characteristics such as fragmentation, humidity, thickness of leaf litter, understory density, patch size, canopy cover and availability of water bodies and found that these factors were major determinants for the occurrence of anurans (Marsh & Pearman, 1997; Bell & Donnelly, 2006; Urbina-Cardona *et al*. 2006,Cabrera-Guzman and Reynoso, 2012, Pearman, 1997 and Hillers *et al.* 2008).

2.4 Effects of Environmental Variables on Anurans

The occurrence of a species is limited by its tolerance limits to environmental factors like altitude, temperature, rainfall, habitat structure, and availability of resources. Anurans in particular need unaltered habitats and specific microhabitat conditions due to their physiological requirements (Moore and Moore, 1980). This determines their distribution and habitat preferences leading to most species having restricted home ranges (Zug *et al*., 2001; Duellman, 2005). Global temperatures appear to be the main limiting factor influencing the diversity and distribution patterns of herpetofaunal distribution (Zug *et al*., 2001). However, on a local scale, there are several other environmental factors that can also influence anuran diversity and distribution (e.g. altitude, plant communities, soil texture, seasonal variations, light and canopy cover, anthropogenic factors, leaf litter) (Phochayavanich, 2010; Woinarski *et al.*, 1999; Allmon, 1991).

Several studies have identified environmental parameters that most likely predict the geographical distribution of species. Within that broad scale, however, other microhabitat conditions may produce further structuring of the species distribution. A number of studies have demonstrated that species composition and abundance of leaf-litter amphibians can be influenced by a variety of environmental factors which correlate with herpetofaunal richness and abundance. These factors include climate and elevation (Giaretta *et al.* 1999; Fauth *et al.* 1987), litter moisture, depth and average dry litter mass (Allmon1991), litter depth and proportion of leaves in the leaf-litter (Sluys, 2007), understory vegetation density and topography (Vonesh, 2001; Pearman,1997).

Environmental factors and history may limit the kinds of anurans that may be able to inhabit a given area (Duellman, 1999). For example, throughout most of the world, toads (*Bufo*) are diverse in semi-arid habitats, but bufonids are not native to Australia, a continent that is largely arid and semi-arid. It is evident that within environments suitable for anuran habitation, the greatest richness exists in areas of climatic stability, which in turn supports high habitat heterogeneity. Constancy of climatic and vegetation creates a stable environment for animals and allows them to specialize on food and microhabitat, as was demonstrated among three types of habitats in Thailand (Ingar and Colwell, 1977).

2.5 Anuran Conservation

In the late 1980s, global loss of biodiversity came to light as herpetologists reported the loss of amphibian species within protected areas. Since then, research has shown that amphibian declines and extinctions have no precedent in any animal class over the last few millennia (Stuart *et al*. 2004). The Global Amphibian Assessment (globalamphibians.org) reported declines in the status and abundance of anuran species. Documenting these statistics has created awareness, and investigations are being conducted on the distribution, ecology, causes of decline and environmental context of anurans. The goal of these investigations is to conserve and restore anuran populations (IUCN, 2006). However, lack of accurate data on anuran distributions, especially for tropical forests where diversity and declines are concentrated (IUCN 2006), presents a challenge to effective conservation and management.

The urgency of the current global biodiversity crisis regarding anuran conservation necessitated the initiation of rapid biodiversity assessment programmes (Sayre *et al.*, 2000). For example, the Rapid Assessment Programme (RAP) for **amphibians** and other taxa initiated by Conservation International at Atewa Range Forest Reserve in Ghana listed a third of the 32 anuran species recorded as threatened on the IUCN Red List (McCullough *et al*. 2007; Kouamé *et al.* 2007). Based on these results, the area was recommended for elevation to the status of a National Park.

2.6 Importance of Anurans

Humans have had negative perceptions of many anurans over the years (Mittermeier *et al*. 1992), but since Aristotle was enthralled that frogs and humans share similar organ systems and biological needs, humans have studied and utilized anurans for several purposes (Tyler *et al*. 2007). Frogs are important storehouses of biomedicines, because frog skins contain compounds that provide analgesics, antibiotics, stimulants, and other potent medicines for treatment of specific diseases such as measles, stroke, seizures, cancer, edema, leprosy, and tumours. The skin secretions of tropical anurans are known to have hallucinogenic and other effects on the central nervous and respiratory systems of humans. Some secretions have been found to contain magainin, a chemical with a natural antibiotic effect. Other skin secretions, especially toxins, have potential uses as anaesthetics and painkillers. Current biochemical research involves investigations of these substances for medicinal use (Tyler *et al*. 2007; Adum, 2012). These treatments are especially crucial for rural communities in developing countries, where western medicine may either not be available or affordable.

A number of significant scientific breakthroughs can be attributed to studies with frogs. To date, approximately 10% of Nobel Prizes in Physiology and Medicine have resulted from investigations involving frogs (Nobel Prize, 2014). Frogs are an integral part of the food web, serving as both predator and prey. Tadpoles keep waterways clean by feeding on algae, and adult frogs eat large quantities of insects, including disease vectors that can transmit fatal illnesses to humans (e.g. malaria). Frogs also serve as an important food source to a diverse array of predators, including dragonflies, fish, snakes, birds, beetles, centipedes and even monkeys. Thus, the disappearance of frog populations disturbs an intricate food web, and results in negative impacts that cascade through the ecosystem (Adum, 2012). Frogs are bio-indicators, since most of them require suitable habitat in both the terrestrial and aquatic environments, with permeable skins that easily absorbs toxic chemicals. These traits make frogs especially susceptible to environmental disturbances, and thus accurate indicators of environmental stress. The health of frogs is thought to be indicative of the health of the biosphere as a whole. In addition to their importance in biomedical research and education, frogs are exploited as food, both for local consumption and commercially for export, with thousands of tons of frog legs harvested annually (Tyler *et al*. 2007).

2.7 Anuran Studies in Ghana

Ghana has a diverse herpetofaunal assemblage of more than 220 species (Hughes, 1988). Many of which are endemic to the Upper Guinean forest zone (IUCN, 2007). Generally, knowledge on the herpetofauna of West Africa is still scanty, especially anurans associated with forest habitats. Despite early herpetological studies over 100 years ago, biological data on many anurans is still completely lacking (Rodel *et al.*, 2008). Leaché (2005) stated that since Schiøtz's (1964a,b, 1967) herpetological investigations in Ghana in the 1960s, there have been very few publications on anurans in Ghana. Some of these include Hughes (1988), Leston and Hughes (1968), Hoogmoed (1979; 1980), Raxworthy and Attuquayefio (2000), and Rödel and Agyei (2003). Leaché (2005) and Leaché *et al.*, (2006) provided detailed information for particular localities and taxa, and Hughes (1988) provided a country checklist of 71 amphibian species some of which are uncertain or do not exist in Ghana at all. These authors concluded that the herpetological diversity of Ghana is underestimated.

The anuran fauna in Ghana seemed to be less diverse than well-known communities in other countries like Guinea and Côte d‟ Ivoire. In these countries, the documented species richness in forests ranges from 40 to 57 species (Rödel & Branch, 2002; Rödel, 2003; Rödel & Ernst, 2003), while the few investigations focusing on Ghanaian anurans revealed only 10 to 20 species per site (Schiøtz, 1964a, 1967). Previous investigations in Ghana were not focused on anurans living in forest habitats. However, recent studies have shown that Ghana's anuran communities are not necessarily less diverse, but just incompletely explored (Rödel & Agyei, 2003; Rödel *et al.*, 2005; Leaché *et al.*, 2006; Kouamé *et al.*, 2007). The conclusion was that the southern forests of Ghana could support far higher diversity of anurans than previously recorded. Rödel *et al.* (2005) hypothesized that thorough and intensive surveys, including more of the remaining forests of southern Ghana, might reveal higher species richness than presently recorded.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Size

The Atewa Range (5º 58' - 6 º 20' N 0º 31' - 0º 41' W) is one of Ghana's two Upland Evergreen Forest Reserves (Hall and Swaine, 1981, Abu-Juam *et al.*, 2003) and currently the last intact stand of Upland Evergreen Forest. It covers an area of 236 km^2 and peaks at 842 meters above sea level (Figure1). Many new, rare and threatened species have been discovered in the reserve, which is one of the largest remaining blocks of tropical forest in West Africa (McCullough *et al.* 2007). The area was established as a national Forest Reserve in 1925 and has since been designated as a Globally Significant Biodiversity Area (GSBA) as well as an Important Bird Area (IBA) (Abu-Juam *et al*. 2003). There are two forest blocks, Atewa Range and Atewa Range Extension.

Atewa has been officially classified in various ways over the past 90 years, with changes due mainly to new initiatives by the Government of Ghana and not to any changes in Atewa's biodiversity or ecological values. The area was classified as a Special Biological 'Protection Area in 1994, a Hill Sanctuary in 1995 and one of Ghana's 30 Globally Significant Biodiversity Areas (GSBAs) in 1999 (Abu-Juam *et al*., 2003). Designation as a GSBA is equivalent to IUCN's Category IV, a protected area mainly for conservation through management intervention (IUCN, 1994). In 2001, Atewa was listed as an Important Bird Area (IBA) by BirdLife International based on its avian diversity, one of 36 such areas in Ghana (Ntiamoa- Baidu *et al*., 2001).

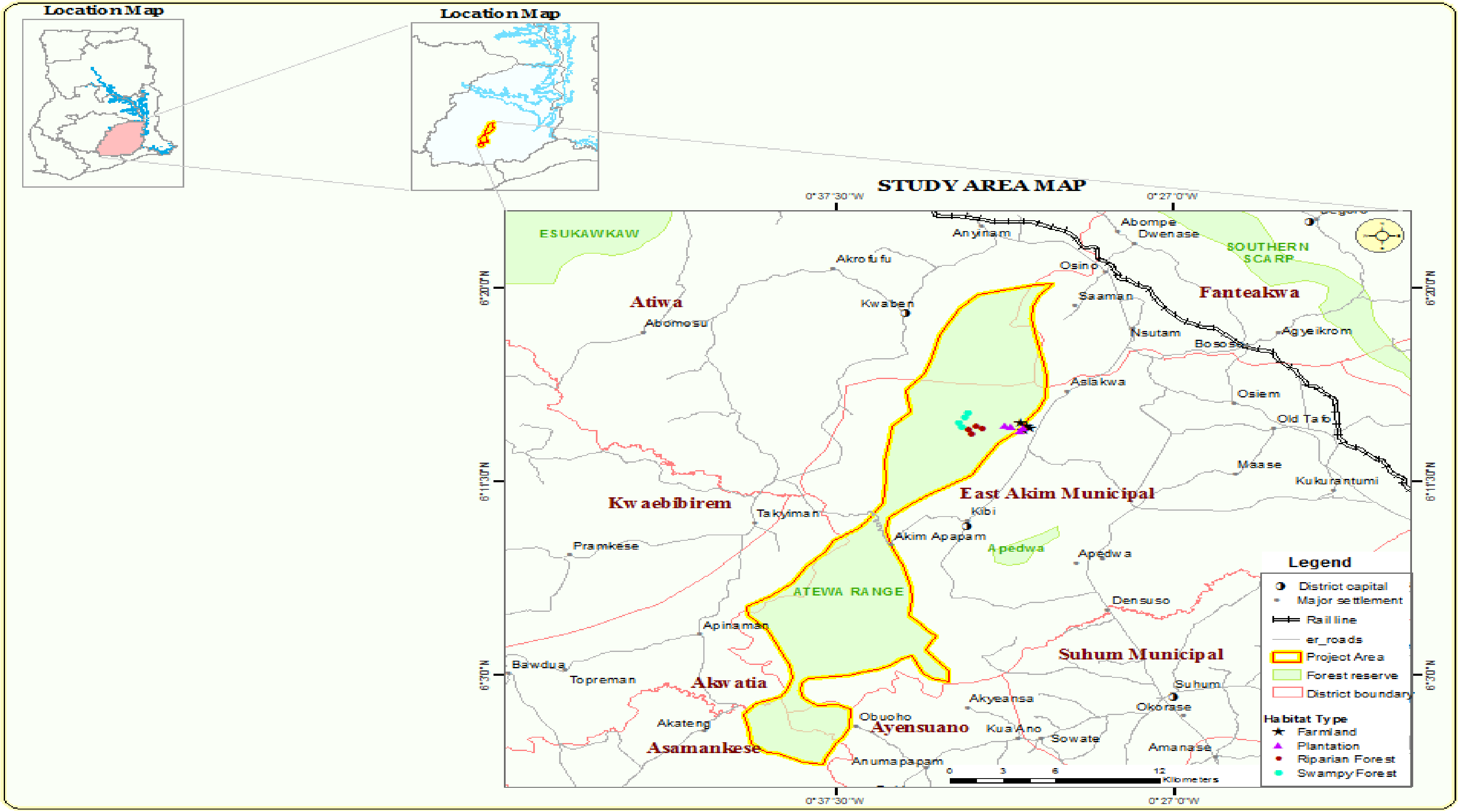

Figure 1: Map of the study area

3.1.2 Climate and Vegetation

Between the Upper Guinea and Cameroon Highlands, only the Atewa Range in Ghana, the Volta Highlands between Ghana and Togo, and the Jos Plateau in Nigeria, harbour significant upland forest patches. Among these three, Upland Evergreen Forest is found only in the Atewa Range. The area represents about 33.5 % of the remaining closed forest in Ghana's Eastern Region. The other forest of this type in Ghana is the Tano Ofin Forest Reserve, which is smaller and significantly more disturbed. Atewa is home to many endemic and rare species, including black star plant species (Hawthorne, 1998; Larsen 2006) as well as seasonal marshy grasslands, swamps and thickets (Hall and Swaine, 1981).

Atewa lies in the Moist Semi-deciduous forest type which occurs on isolated hill ranges 500-750 meters above sea level within Upland Evergreen Forests (Hall and Swaine, 1981). The forest is characterized by high temperatures and a double maxima rainfall regime. It has a mean monthly temperature of between 24 °C and 29 °C, and experiences a mean annual rainfall of between 1,200 mm and 1,600 mm. The first rainfall peak occurs in May-July, while the second one occurs in September-November (Swaine and Hall, 1977).

Unlike the other forest types, the most characteristic species of Upland Evergreen Forest are herbaceous rather than woody plants. Ferns, both epiphytic and ground-dwelling plants are abundant and diverse. The tree fern *Alsophila [Cyathea] manniana* is common in swamp valleys in the Atewa Range Forest Reserve. A number of plant species found here are not known to occur elsewhere in Ghana. The bowals (seasonal marshy grasslands on bauxite outcrops), and swamps are also thought to be nationally unique. About 17,400 ha of the reserve is Upland Evergreen Forest, and together with the Tano Ofin forest reserves, hold approximately 95 % of the country's Upland Evergreen Forest. Overall, Atewa is considered to have a forest condition score of 3 (on a scale of 1-6), which indicates that it is slightly degraded but is a predominantly good forest with healthy and abundant regeneration of timber trees and other forest plants (Hawthorne and Abu-Juam, 1995).

3.1.3 Geology and Soils

Atewa runs roughly from north to south and is characterized by a series of plateaus, which are remnants of a Tertiary peneplain. In addition to high biodiversity, Atewa is known to harbour mineralogical wealth including both gold and bauxite deposits. The terrain of the range encompasses a lowland forest, gallery forest within the valleys, and highland forest in the upper elevation as a result of the plateau formations.

3.1.4 Limnology and Watershed

Atewa Range has long been recognized as a nationally-important reserve because it contains the headwaters of three river systems, Ayensu, Densu and Birim. These water bodies are the most important sources of domestic, agricultural and industrial water for local communities around Atewa. There are also associated standing water habitats, with headwaters located within the reserve as well as freshwater sites outside the reserve.

3.1.5 Flora and Fauna

There are about 314 plant species belonging to 71 plant families including 106 Upper Guinea endemics (Siaw and Dabo, 2007). Amongst these include some black star species like *Gilbertiodendron splendidum, Psychotria longituba, P. subglabra, Neolemonniera clitandrifolia, Sapium aubrevillei* and *Ixora tenuis.* However, *N. clitandrifolia* and *S. aubrevillei* are categorised in the IUCN Red List as 'Endangered' and 'Vulnerable' respectively. Other species include *Aframomum atewae* (Zingiberaceae), *Asplenium schnellii* (Aspleniaceae), *Cola boxiana* (Sterculiaceae), *Costus deistelii* (Costaceae), *Epistemma assianum* (Apocynaceae, Asclepioideae), *Hymenocoleus multinervis* (Rubiaceae), *Justicia guineensis* (Acanthaceae), *Lasianthus repens* (Rubiaceae), *Medinilla mannii* (Melastomataceae), *Selaginella blepharophylla* (Selaginellaceae), *Strephonema pseudocola* (Combretaceae) and *Vernonia titanophylla* (Compositae).

Atewa is known to harbour numerous endemic and rare faunal species, due to its unique floristic composition generated by the misty conditions on top of the plateaus (Swaine and Hall, 1977). According to Hawthorne (1998) and Larsen (2006), the Atewa forest is home to several endemic butterfly species and is on record as having the highest butterfly diversity of any site in Ghana. There is also high diversity of dragonflies, katylids, fishes, amphibians, birds and mammals.

There are 72 species of Odonata (dragonflies and damselflies) in Atewa with *Atoconeura luxata* as the only regionally-threatened dragonfly in western Africa. It is also a species which confirms the naturally unique ‘montane’ character of the site. In addition, there are 143 butterfly species belonging to 55 genera from five families, indicating that Atewa is a good forest habitat. *Neaveia lamborni* and *Bicyclus auricruda* are endemic to Atewa since they have not been recorded in any protected area in Ghana. There are 16 species of butterflies endemic to the West Africa sub-region, of which two (*Euphaedra mariaechristinae* and *Ceratrichia maesseni*) are endemic to Ghana. There are also some rare butterfly species which are known either exclusively from Atewa or from just one other protected area in Ghana. Four of these rare species (*Mimeresia cellularis*, *Heteropsis peitho, Vanessula milca* and *Euphaedra splendens*) have been recorded exclusively from Atewa (Aduse-Poku and Doku-Marfo, 2007).

Since Atewa also serves as a source of some rivers and streams, there is also a high diversity of fishes in these water bodies. There are 19 freshwater fish species belonging to nine genera and five families: Mormyridae, Characidae, Cyprinidae, Cyprinidontidae and Cichlidae. Some of the fishes include *Brienomyrus brachyistius*, *Brycinus leuciscus, B. longipinnis, Epiplatys dageti dageti, E. chaperi schreiberi, E. c. spillmanni*, *Tilapia busumana and T. zillii* (Abban,2007).

Thirty-two exclusively forest amphibian species have been recorded in Atewa, including the ‘Critically Endangered’ *Conraua derooi*, recorded in 2006. It has been proposed that Atewa is likely to harbour the largest remaining population of this species in the world. Other amphibian species include *Geotrypetes seraphini,* *Leptopelis spiritusnoctis, Amietophrynus maculatus, Afrixalus nigeriensis, Aubria subsigillata* and *Ptychadena longirostris* (Kouame *et al*., 2007).

There is a high diversity of birds in Atewa with a record of 155 species of which six are of conservation concern, with three classified as 'Vulnerable' and three as 'Near Threatened' (BirdLife International, 2000). Atewa also harbours six of the 11 species restricted to the Upper Guinea Forest Endemic Bird Area and 115 (64%) of the 180 Guinea-Congo Forest biome species now known from Ghana (McCullough *et al.,* 2007). Some of the birds recorded include the Nimba Flycatcher *(Melaenornis annamarulae),* Green-tailed bristlebill *(Bleda eximius),* Yellow-bearded greenbul *(Criniger olivaceus),* brown-cheeked hornbill *(Bycanistes cylindricus),* rufous-winged illadopsis *(Illadopsis rufescens)* and copper-tailed glossy starling *(Lamprotornis cupreocauda)* (Domey and Ossom, 2007).

Twelve bat species, three terrestrial small mammal species and one shrew, were some of small mammals recorded at Atewa (Weber and Fahr, 2007). Among the bats include two rarely-recorded species (*Hypsugo crassulus bellieri* and *Pipistrellus* aff. *grandidieri*), which were also the first reports in Ghana. The three terrestrial small mammals include Edward's swamp rat *(Malacomys edwardsi),* Tullbergi's soft-furred rat *(Praomys tullbergi)* and the white-toothed shrew *(Crocidura grandiceps).* Twenty-two large mammals species were recorded in Atewa (Sam *et al*., 2007) including Pel's flying squirrel (*Anomalurus pelii*) which is ranked as 'Near Threatened', yellow-backed duiker (*Cephalophus silvicultor*), black duiker (*C. niger*), bay duiker (*C. dorsalis),* Maxwell's duiker (*Philantomba maxwellii*) and royal antelope (*Neotragus pygmaeus)* classified as 'Lower Risk'/'Near Threatened', and western palm squirrel (*Epixerus ebii*) listed as 'Data Deficient' on the IUCN Red List. Other species include the African civet (*Civettictis civetta*), African palm-civet (*Nandinia binotata*), and long-tailed pangolin (*Uromanis tetradactyla*). The potto (*Perodicticus potto)* and Demidoff's galago *(Galagoides demidoff)*, are two of the six primate species found in Atewa. The other four include Geoffroy's pied colobus *(Colobus vellerosus)* reported as 'Vulnerable', olive colobus *(Procolobus verus)* which is 'Near Threatened', lesser spot-nosed monkey *(Cercopithecus petaurista buettikoferi)* and Lowe's monkey *(Cercopithecus campbelli loweï).*

3.1.6 Socio-economics

The culture of the people living around the Reserve is inextricably linked with the forest. Locally, the forest is referred to as *kwaebibirem* (dark forest), typifying the dense and lush vegetation that once characterised the area. The forest has traditionally been regarded as the home of ancestral spirits who provide protection, success and progress to the Abuakwa Stool and the people of the Akyem Abuakwa Traditional Area. The Reserve is also a rich source of Non-Timber Forest Products (NTFPs) such as bushmeat, snails, mushrooms, chewing sticks, plant medicine, wild fruits and rattan.

3.2 Methods

3.2.1 Selection of Study Sites

The Atewa Range Forest Reserve, despite its national protection status, is being severely logged from different parts (McCullough, *et al*. 2007). The off-reserve habitat types comprise of cocoa, cassava and plantain farms with fragments of secondary or regenerating forests. Four habitat types identified and selected as representative vegetation are; (i) farmland (FM), (ii) *Cedrela* plantation near the boundary line of the reserve (CP), (iii) riparian forest gallery (RF), and (iv) swamp forest surrounded by trees (SF).

3.2.1.1 Farmland (F) (06º 13.809' N - 000º31.525' W)

This habitat has a minimum altitude of 311 metres above sea level. Plant species cultivated consist mainly of cocoa (*Theobroma cacao*), plantain (*Musa* sp.), cocoyam (*Colocasia esculenta*) and oil palm (*Elaies guineensis*). The ground is covered with dry leaves and weather conditions are dry compared to the upland habitats (Plate 1).

Plate 1: Farmland

3.2.1.2 Cedrela Plantation (CP) (06º 13.716'N - 000º31.781'W)

This area has an altitude of 327 – 435 metres above sea level, and is an interface between the farmlands and the boundary line of the forest reserve. Common tree species include *Cedrela odorata*, *Trichilia monadelpha* (tanuro), *Ficus exasperata* (nyankyerene), and *Terminalia ivorensis* (emire). There is evidence of anthropogenic influences like logging and hunting (Plate 2).

Plate 2: Cedrela plantation

3.2.1.3 Riparian Forest (RF) (06º13.967' N- 000º33.116' W)

This area comprises of rocky streams surrounded by trees with an altitude of 676 meters above sea level. The level of water flow indicated fast-flowing streams which appeared to have slowed down, probably due to the reseeding rainfall in the area. The water body serves as the only habitat for the critically-endangered Togo slippery frog (*Conraua derooi)* (Kouamé *et al.2007*). Dominant trees include *Triplochiton scleroxylon* (wawa*)*, *Albizia zygia* (okoro*)*, *Ceiba pentandra* (onyina) *Terminalia superba* (ofram), *Celtis mildbraedii* (esa) and fruntum (*Funtumia elastica*). The area is characterized by remnants and new stumps of trees indicating that the area is being logged (Plate 3).

Plate 3: Riparian forest

3.2.1.4 Swamp Forest (SF) (06^{0}14.541'N- 000^{0}33.421 'W)

This area, with altitude of 807 meters above sea level, is characterized by marshy soils, with weather conditions being mostly foggy and wet. Trees have closed canopies, the common species being raffia (*Raphia hookeri*) (Plate 4).

Plate 4: Swamp forest

3.2.2 Study Design

Following a stratified random design based on a reconnaissance, Four plots, each measuring 200m x 100m were established on each of the four habitat types (farmland, *Cedrela* plantation, riparian forest, and swamp forest) given a total of 16 plots. The four habitats were located at an altitude from 300 to 800 meters above sea level. Geographical locations of the study plots are listed in Appendix 1. All the plots were at intervals of 200 meters from each consecutive plot to minimize overlapping of habitats. The plots were marked with flagging tape.

3.2.3 Sampling Protocol

Sampling was done between August 2013 and January 2014. This was preceded by a reconnaissance study in July 2013. The reconnaissance survey involved the initial visit to Atewa to collect information on the topography and vegetation and also mark out the area for the survey . There were five survey days per month for six months, at six visits per plot. Relative searching time was one hour for each plot with diurnal surveys from 07:00 to 14:00 hours GMT, and nocturnal surveys from 18:00 to 21:00 hours GMT.

3.2.4 Survey Methods

Two sampling methods were employed in the surveys; Visual encounter survey (VES) and acoustic encounter survey (AES) methods (Heyer *et al.* 1994) . The VES involved field personnel systematically searching for anurans in a plot for a prescribed time period, expressed as the number of hours of searching at each study plot (Crump and Scott, 1994). Three people constituted the survey team, with protection provided by a forest guard. Search techniques included visually scanning the vegetation and ground and by lifting rocks, logs, and debris. Acoustic encounter surveys were carried out simultaneously with the VES in the evening, when calling activity was its highest. The combination of visual and acoustic methods gave the most reliable results in terms of species presence or absence (Heyer *et al.*, 1994; Branch and Rodel, 2003; Rodel and Ernst, 2004). It enabled the determination of species richness, but cannot be used for estimation of relative abundance and densities within an assemblage. This is because not all individuals present in the area are likely to be counted during the survey (Heyer *et al*., 1994). Visually-encountered frogs were captured by hand-picking or by using small plastic bottles cut in half.

3.2.5 Handling of Captured Animals

Each animal encountered or captured was identified, and the species name, microhabitat type, habitat type, number of individuals, and number of species were recorded on a data sheet, after which the animal was released at the point of capture. Animals that could not be immediately identified in the field were euthanized with formalin and preserved for later identification and storage in the Museum (Biodiversity Centre) at the Department of Animal Biology and Conservation Science (DABCS), University of Ghana. All captured animals were photographed for later confirmation of identification. References for amphibian identification included Rödel (2000), Rödel and Agyei (2003) and Rödel *et al.* (2005) and Hillers *et al.* (2008). Some ecological parameters recorded included: (i) altitude/location, (ii) habitat type, (iii) canopy cover, (iv) plant species, (v) leaf litter depth, (vi) leaf litter cover, and (vii) microhabitat type. The presence and absence of water bodies were also noted.

3.2.6 Recording of Environmental Variables

Environmental variables that could influence the abundance and habitat preference of amphibian species within the various habitats were recorded at five randomly selected data points within the plot: four in the corners and one in the middle. The following variables were measured or estimated:

- *Leaf Litter Depth (cm)*: Average depth of litter from the surface to the bare ground within a plot was measured using a meter rule, and the mean depth calculated from five values within the demarcated area.
- *Plant Species Composition*: dominant tree species in the habitats were identified with the assistance of a plant taxonomist.
- *Canopy Cover*: Mean percentage canopy cover was measured from visual estimation of the canopy cover in four corners and the middle of the plots (Hillers *et al* .2008)
- *Altitude*: Location of sites was recorded using a hand-held GPS
- *Leaf Litter Cover:* Percentage leaf litter cover was estimated within five categories- (i) 0-5%, (ii) 5-25%, (iii) 25-50% (iv) 50-75% and (v) >75% (simplified after Braun-Blanquet, 1964)
- *Water Body:* Presence of water in the plot, ranked as 1 for presence and 0 for absence

3.2.7 Analysis of Data

3.2.7.1 Species Richness and Abundance

For the purpose of this study, the number of species recorded in each habitat represented the observed species richness, and the total number of individuals in each plot represented abundance. To calculate relative abundance, only the data from anuran visual encounters was used as follows:

Relative Abundance (RA) = (N/T) x 100..(1)

Where:

N= number of individuals of a particular species in a plot

T= total number of individuals in the plot

3.2.7.2 Species Diversity

Diversity consists of two components: species richness (variety) and relative abundance (evenness). Various indices are used to measure diversity, some focusing on only the species richness and others focusing on both species richness and abundance. The following diversity indices were estimated using the software PAST version 3.0 (Hammer *et al.*, 2001). To compare the diversity between habitats, diversity test (t-test) were performed.

- *Shannon-Wiener Diversity Index (H')*

This index gives a good measure of both species richness and abundance as a single value and caters for both the sampled and unsampled individuals of an infinite population. The greater the index, the higher the diversity, and the index is normally between 1.5 – 3.5,rarely reaching 4.5 (Magurran, 1988).

- *Simpson's Diversity Index (1-D)*

The Simpson's Diversity Index is a dominance measure that is weighted towards the abundance of the commonest species, and it gives the probability of any two individuals drawn at random from an infinitely large community of belonging to different species. The greater the index the lower the diversity, hence, 1/D would be used so that, the greater the value the greater the diversity (Magurran, 1988).

- *Margalef Diversity Index (DMg)*

The Margalef Diversity Index gives a good measure of species richness (number of species present), and the greater the index the greater the diversity (Magurran, 1988).

- *Pielou's Evenness* (J^1)

This index does not take into account the proportion and distribution of each subspecies within an area. The Pielou's Evenness, is also known as Shannon Evenness index, is a measure of evenness which is estimates of how similar the abundances of different species are. When there are similar proportions of all subspecies then evenness is one, but when the abundances are very dissimilar (some rare and some common species) then the value increases.

- *Similarity:* The similarity in composition of species in all the plots was analysed using the Bray-Curtis Cluster analysis in Primer 6 software. Further an Analysis of Similarity (ANOSIM) to test if differences in assemblage structure are statistical significant between different habitat types and altitude. Abundance data was square root transformed for this analysis. Primer software (Version 6.1; Clark and Gorley, 2005) was used to run the analysis.

3.2.7.3 Species Accumulation Curve

A species accumulation curve was generated using the Jack-knife 2 and Chao1 richness estimators in EstimateS Program(Version 6.0;Collwell, 2005). The Chao 1 species estimators inculcate the abundance of species present into estimating the overall species richness while the Jack-Knife 2 just requires absence or presence data to predict species richness. The species accumulation curve was constructed for all the plots to verify the sampling effort with respect to the species recorded compared to what is expected.

3.2.7.4 Site Comparisons

Among-site comparisons of habitat variables were conducted using One-way ANOVA and Post-hoc Tukey's HSD test for significant differences (SPSS v16.0). The relationship between habitat variables and species richness and abundance of anurans was examined using correlation and regression in SPSS v16.0.

CHAPTER FOUR

RESULTS

4.1 Anuran Abundance

A total of 762 individual anurans (49 acoustically and 713 visually) belonging to 20 species and eight families were recorded during the study. The three species whose calls were recognized and heard in the plots were *Phrynobatrachus tokba*, *Ptychadena bibroni* and *Conraua derooi* (Table 1). There were 12 species recorded in swamp forest, 11 species in farmland, four species in riparian forest, and five species in the *Cedrela* plantation (Table 1). Majority (55%, 11 species) of the recorded species were forest specialists closely associated with swamp forest habitats. Four (20%) of the species were forest species which also inhabit riparian and *Cedrela* habitats, while 10 (50%) species occurred in farmland or open habitats. Some photographs of anuran species recorded at Atewa are shown in Appendix 2 .

The highest number of anurans (482) was recorded in farmland, followed by swamp forest (117), and the lowest (65) from the *Cedrela* plantation (Table1). The relative abundance of the species varied among the habitats being characterised by a few common species along with a large number of rare species. *Arthroleptis* sp. had the highest relative abundance (43.3%) and were found in all the habitats, followed by *Phrynobatrachus calcaratus* (17.3%), *Phrynobatrachus accraensis* (13.1%), *Phrynobatrachus gutturosus* (6.8%), *Hyperolius concolor* (3.6%) and *Ptychadena aequiplicata* (1.9%). All the remaining species combined recorded relative abundances of less than 1% (Table 2).

Table 1: Amphibian Species Recorded in Atewa

Species	Common Name	FM	CP	RF	SF	Preferred Habitat	Total
Arthroleptidae							
Arthroleptis spp.	West African screeching frog	215	57	25	33	F,SF	330
Bufonidae							0
Amietophrynus maculatus	Flat-backed frog	3		1	1	F	5
Amietophrynus togoensis					4	IF	4
Ranidae							0
Amnirana occidentalis		3	1			F,SF	4
Phrynobatrachidae							0
Phrynobatrachus accraensis	Accra puddle frog	100				F	100
Phrynobatrachus alleni					8	IF	8
Phrynobatrachus calcaratus	Horned puddle frog	94	1	30	7	F , SF	132

Phrynobatrachus gutturosus		44			8	F,IF	52
Phrynobatrachus plicatus	Coast puddle frog	6	5	10	5	IF,F	26
Phrynobatrachus tokba				2	1	IF,	3
Ptychadenidae							0
Ptychadena. Aequiplicata		9	1		5	F, SF	15
Ptychadena. Longirostris		1				F	1
Ptychadena bibroni		4		2	9	F	15
Petropetedidae							0
Conraua derooi	Togo slippery frog			28	3	IF	31
Hyperoliidae							0
Kassina arboricola -					1	CF	1
Hyperolius bobirensis -					28	CF	28
Hyperolius concolor	Variable reed frog				1	CF	1
Hyperolius fusciventris	Reed frog				1	CF	1
Hylarana occidentalis					3	CF	3

Hemisotidae							0
Hemisus sp.	Marbled shovel-nosed Frog	2				F	2
Total		**482**	**65**	**98**	**117**		**762**
Number of Species		**11**	**5**	**4**	**12**		

FM = Farmland; CP = *Cedrella* Plantation; RF = Riparian Forest; SF = Swamp Forest;

SF = Swamp Forest, IS = intermediate Forest, F = Open Habitat/farmland.

(Nomenclature of species followed Frost *et al*., 2006).

Table 2: Relative Abundance of Anurans in Atewa

Species	FM	CP	RF	SF	Total
Arthroleptis spp	44.6	87.69	25.51	28.2	43.3
Amietophrynus maculatus	0.62	0	1.02	0.85	0.65
Amietophrynus togoensis	0	0	0	3.42	0.52
Amnirana occidentalis	0.62	1.53	0	0	0.52
Phrynobatrachus accraensis	20.7	0	0	0	13.12
Phrynobatrachus alleni	0	0	0	6.84	1.05
Phrynobatrachus calcaratus	19.5	1.53	30.61	5.98	17.32
Phrynobatrachus gutturosus	9.1	0	0	6.84	6.82
Phrynobatrachus plicatus	1.24	7.69	10.2	4.27	3.41
Ptychadena aequiplicata	1.86	1.54	0	4.27	1.97
Ptychadena longirostris	0.2	0	0	0	0.13

Kassina arboricola	0	0	0	0.85	0.13
Hyperilous bobirensis	0.21	0	0	0	0.13
Hyperilous concolor	0	0	0	23.93	3.67
Hyperolius fusciventris	0	0	0	0.85	0.13
Hylarana occidentalis	0	0	0	2.56	0.39
Hemisus marmoratus	0.41	0	0	0	0.26

FM =Farmland, CP=Plantation, RF= Riverine forest, SF=Swamp forest

4.2 Species Accumulation Curve

A species accumulation curve was plotted for the 16 plots and the appropriate estimators evaluated. These estimators helped in comparing the sampling effort or species realised to the estimated species richness. Comparison of the species accumulation curve with the species numbers calculated by the estimators (Jack-knife 2; Chao1) showed that more than the 20 anuran species recorded were likely to occur in the four habitat types investigated. The Chao 1 and Jack-Knife 2 estimators, calculated 19 and 28 species respectively for Atewa (Figure 2). The continued increase of the curve's slope with increasing capture effort indicates that most of the amphibians living within Atewa were most likely not recorded during the study.

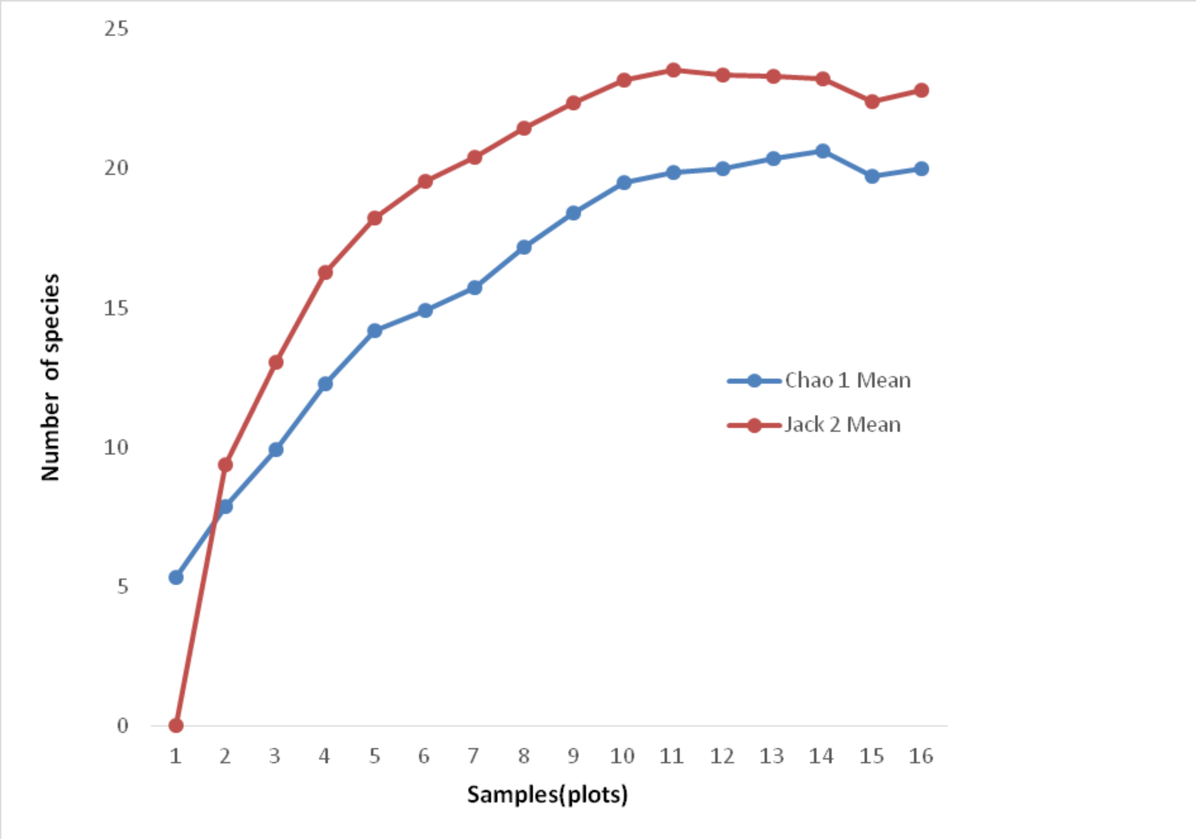

Figure 2: Species accumulation curve for anurans in the Atewa forest reserve

4.3 Species Richness and Diversity

Species richness and diversity differed among the sites, being greater in the swamp forest (SF, 12 species) than the riparian forest (RF, four species). Evenness (J') was highest in the riparian forest (RF) followed by the swamp forest, indicating that species in the riparian forest were more evenly distributed than the other sites. The most diverse habitat was swamp forest (Shannon (H') = 1.947), followed in that order by farmland (FM), riparian forest and the *Cedrela* plantation (Table 3). Comparing FM and CP plots, there was a significantly higher diversity ($t = 7.04$, $df = 79.12$, $p < 0.006$) in the farmland compared to the *Cedrela* plantation. Similarly, when the diversity of RF and SF plots were compared, the former differed significantly from the latter (t = -7.47, df = 168.76, $p < 0.004$).

Table 3: Species Diversity Values of Anurans in Atewa Forest

	HABITATS			
Diversity indices	FM	CP	RF	SF
Shannon index	1.468	0.505	1.076	1.947
Pielou's index	0.394	0.331	0.732	0.584
Simpson's index	0.706	0.224	0.626	0.803
Margalef's index	1.621	0.958	0.716	2.368
Species richness	11	5	4	12

4.4 Species Composition

Cluster analysis (Bray-Curtis similarity) indicated that the habitats were divided into three major clusters of species composition according to their responses to the habitat type (Figure 2). The first cluster separated farmland (FM) and swamp forest (SF) habitats, while a sub- cluster grouped all the plantation (CP) and riparian (RF) habitats together. The species compositions of all the FM plots were similar but differed from the species composition of the SF plots. The CP and RF plots showed the highest similarity but differed from both FM and SF plots. In spite of the latter two being positioned on two separate habitats and elevations, the pattern of association between habitats highlights the unique nature of similarity of amphibian species. Generally, there were more amphibian species in swamp forest and farmland than the plantation and riparian forest.

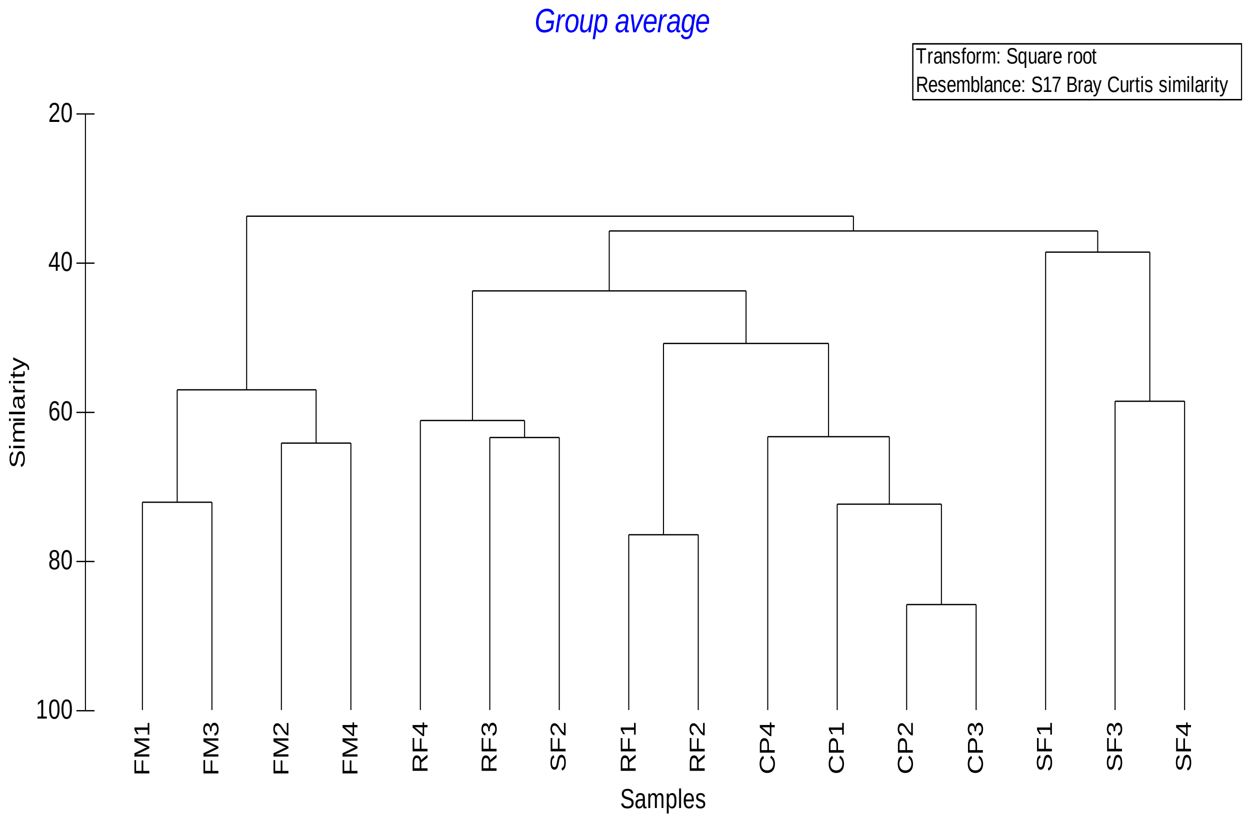

Figure 3: Dendrogram from Cluster Analysis of 16 Plots from Atewa Forest based on Bray-Curtis's Similarity Index.

The clusters show plots that are similar in habitat type grouped together: *FM1 - FM4 = Farmland, RF4- CP3 = Riparian Forest* and *Cedrela Plantation, SF1 - SF4 = Swamp Forest*

4.5 Altitudinal Gradient and Anuran Species Composition

The compositions of anuran species were compared to determine whether altitude altered the community structure of anurans at different habitats. The results showed that pair-wise comparisons between 300m and 600m habitats showed that species composition at 300m differed significantly from 600m habitats (ANOSIM Global R = 0.333, $P < 0.009$) (Table 5), but there is no significant plot differences within the habitats. Also, significant differences were observed between the pairs: 300m-600m (ANOSIM Global R=0.292, P<0.009) and 600m-800m altitudes (ANOSIM Global R=0.313, P<0.009).

Table 4: Pair-wise Comparisons at 300, 600 and 800m.a.s.l Habitats (ANOSIM Global R, P = 0.009)

Pair-wise Groups	R
Lowland - Midland	0.333
Lowland - Upland	0.292
Midland - Upland	0.313

4.6 Comparisons of Habitat Variables Among the Four Habitats and their Significance

Table 5 showed that between habitats, there were significant differences in leaf cover, canopy cover, and altitude, but no significant differences within plots. There were no significant differences in leaf litter depth in all the habitats . There were significant differences in leaf cover (F=10.01, *P*=0.001) canopy cover (F=6.12, *p* = 0.009) and altitude (F = 61.5, *P*=0.000).

The results showed that swamp forest had the highest mean leaf coverage (7.55%), altitude (763.75m) and canopy cover (17%), while the *Cedrela* plantation recorded the lowest leaf cover (3.2%). However, the farmland had the highest leaf depth at 5.01cm though no significant differences were observed between habitats. As altitude increased, canopy cover and leaf cover also increased while leaf depth declined (Table 5).

Table 5: ANOVA Table Showing Differences in Environmental Variables among Habitats measured at Atewa and their significance.

Variable	FM	CP	RF	SF	F	*P*
Leaf cover(%)	5.40± 1.5a	3.2±0.90a	4.05±1.3a	7.55±0.8b	10.01	0.001
Leaf depth(cm)	5.01±2.2	3.65±0.4	3.90±1.1	4.05±1.7	0.68	0.582
Altitude(m)	314.50±12.9a	381.50±71.6a	702.50±69.7b	763.75±55.3b	61.50	0.000
Canopy cover(%)	9.55±2.3a	12.85±1.4a	16.25±4.1b	17.00±2.4b	6.12	0.009

FM = Farmland; CP = *Cedrella* Plantation; RF = Riparian Forest, SF = Swamp Forest

Mean ± standard deviation, means with the same letter in rows are not significantly different (*P*=0.05) according to Tukey's HSD test

Table 6 shows a correlation matrix. The results showed no significant differences between pairs of variables with the exception of altitude and canopy cover, which showed a highly significant positive correlation (r = 0.662, $P<0.01$). Positive correlations were obtained for leaf-litter depth and leaf cover (r = 0.301), canopy cover and leaf cover (r = 0.044), altitude and leaf cover (r = 0.426). Negatively associated variables were canopy cover and leaf-litter depth (r = -0.097), and altitude and leaf-litter depth (r= -0.142) (Table 6).

Table 6: Pearson Correlation(r) Matrix of Habitat Variables at Atewa

Parameter	1	2	3	4
Leaf Cover	1.000			
Leaf Litter Depth	0.301	1.000		
Canopy Cover	0.044	-0.097	1.000	
Altitude	0.426	-0.142	0.662**	1.000

□ □ .Correlation is significant at 0.01 level

The correlation analyses revealed a highly significant positive correlation between species richness and leaf cover (r = 0.585, *P* = 0.013). Sites with high leaf cover had high species richness, while sites with low leaf or ground cover had low species richness. Leaf cover accounted for most of the variation (34%) in species richness in the habitats. Leaf litter depth (r = 0.280, *P*= 0.294) was positively correlated with species richness but was not significant.

Also, canopy cover and altitude were weakly correlated with species richness and none of them showed a significant effect . In terms of abundance, altitude was the strongest predictor variable (r = -0.534, P = 0.033) which showed a significant effect on abundance. Canopy cover, leaf litter depth and leaf cover were correlated with abundance but had no significant effect (Table 7).

Table 7: Pearson Correlation Analyses of Species Abundance (SA), Species Richness (RS) and Habitat Variables

Parameter	r	R^2	p-value
LC vs. SR	0.585 □	0.342 (34%)	0.013
LLD vs. SR	0.280	0.078 (7.7%)	0.294
CC vs. SR	-0.086	0.004 (0.4%)	0.753
AL vs. SR	0.057	0.003 (0.3%)	0.835
LC vs. SA	0.064	0.004 (0.4%)	0.815
LLD vs. SA	0.228	0.051 (5.1%)	0.395
CC vs. SA	-0.437	0.191 (19.1%)	0.091
AL vs.SA	-0.534 □	0.285 (28.5%)	0.033

□ . Correlation is significant at 0.05 level

r = Pearson correlation coefficient, R^2= Regression coefficient

LC = leaf cover, LLD = leaf litter depth, CC = canopy cover, AL= altitude

CHAPTER FIVE

DISCUSSION

5.1 Anuran Abundance

A total of 20 (16 visual and three acoustic) anuran species were recorded in the Atewa forest. Among the 16 species observed, *Arthroleptis* sp. was the most abundant anuran recorded during this study, accounting for 43.3% of total captures. This observation is similar to other studies in forests and other habitats in Ghana (Kouame *et al*. 2007; Rodel and Bangoura, 2004; Hillers *et al*., 2008; Rodel *et al*., 2005; Rodel and Agyei, 2003).

In this study, the high relative abundance of *Arthroleptis* sp. in the area may be due to its classification as a habitat generalist extremely adaptable to degraded habitats. Compared to its counterparts; *Kassina arboricola*, *Hyperolius bobirensis* and *Hperolius concolor* which only prefer closed forest habitats. Rodel and Bangoura (2004) reported that *Arthroleptis* species are widely distributed and the most common leaf litter frog. This reason could further relate why this particular species was higher in the farmland and low in the riparian and swamp forest habitats. In addition, they are direct-developing species (Rodel and Bangoura, 2004) which do not require the presence of aquatic bodies for reproduction.

Furthermore, the high abundance of *Arthroleptis* sp. could also be related to the leaf cover in the farmland. The farmland plots surveyed contained a dense leaf cover/ground cover probably due to the fact that cocoa, the dominant plant, is deciduous with new leaves growing two to four times per year (Hensen,1983). This observation indicates that anuran abundance may be affected by microhabitat variables. In addition to this, a dense leaf cover may enhance abundance by retaining moisture in the leafs and also provide suitable conditions for egg laying

Phyrnobatrachus calcaratus was the second most abundant frog observed and accounted for 17.3% of visual observations. It was captured on all plots during the study. *Phrynobatrachus calcaratus* is a very common species with a wide distributional range from West Africa to Eastern D.R. Congo. It typically lives on the leaf litter of the forest floor, occasionally away from water (Rodel and Amiet, 2009) . This probably explains why the farmland recorded the highest number of individuals as these plots contained a lot of leaf litter and were located in open or degraded habitats.

Phrynobatrachus accraensis was the third most abundant and the results showed that all the individuals observed were recorded in the farmland . This species is an extremely common and widespread West African savanna species that inhabits degraded forests and farmland (Ofori- Boateng, 2011) and this could probably be the reason for its capture in only the farmland habitats.

Phrynobatrachus gutturosis is a small ranid frog with a pointed snout. This species was observed on all plots but not *Cedrela* plantation and riparian forest plots. The only individual of *Hyperolius concolor* captured was found within the swamp forest which duly confirms its preferred habitats reported by Ofori-Boateng (2011), that is forest and degraded forests, as well as cultivated land. There is therefore the possibility of observing such species in the farmland and *Cedrela* plantation.

The six most abundant species observed was *Ptychaedena equiplicata*. The species was recorded in all the habitats except the riparian forest. Even though it is widespread, it is never abundant. It prefers primary forest habitats but can inhibit other types of habitats (Werner, 1898). The absence of this species in the riparian forest could be attributed to less sampling effort.

5.2 Species Richness and Sampling Efficiency

In spite of employing the same sampling effort on all the plots, the species accumulation curve predicted that richness was more than the observed species richness during the study. Species richness estimators (Chao1;Jack-Knife 2) for all the surveyed plots showed that, the still increasing slopes indicates that additional anuran species remain to be added within the study area (Figure 2). Kouame *et al.* (2007) surveyed the same area and recorded 32 species and further predicted higher species richness for Atewa based on non-level species accumulation curves. The 20 anuran species recorded in this study is quite low compared to Kouame *et al.* (2007). The reason could be due to inadequate sampling methods employed for the present study. Aside sampling methods being a contributing factor to the richness estimates generated, some anurans are naturally rare and need longer periods of surveys to be detected. Since this present study allowed only a short time for survey, several species were most likely not encountered during this study.

Differences in species richness among plots could probably be due to habitat variability and favourable environmental conditions. The closeness of the values of species richness in the farmland and swamp forest habitats is unclear. However, the pattern of species richness in the farmland is consistent with Heinen's (1992) observation that recently-disturbed areas showed a lower diversity than non-disturbed areas. The disturbed areas had high percentage of open canopy, which may lead to temperature extremes and reduced moisture compared to undisturbed primary forest. Depending on the age of the farmland, however, it may support a higher diversity of amphibians. For example, old cocoa farms may promote faunal population stability similar to forest habitats and may also provide several microhabitats for animals moving from forest habitats (Rice and Greenberg, 2000).

Swamp forest habitats in this study may be preferred by most anurans because of the closed canopies, litter moisture, understory vegetation, topography, foggy weather conditions, sufficient ground cover and availability of many swamp and marshy microhabitats. The effect of these environmental variables on abundance and distribution of amphibians is widely accepted by several authors (Malonza and Veith, 2012; Sluys, 2007; Marsh & Pearson, 1997; Vonesh, 2001; Allmon, 1991; Fauth *et al*., 1989). As noted by Khatiwada (2011), low and mid- altitudinal areas are more disturbed than high altitudes . This could also contribute to the high species richness of the anurans at the swamp forest sites which were observed to be less disturbed.

This study demonstrates that the high species richness of anurans found at the swamp forest habitat in Atewa is consistent with the findings of Monney *et al.* (2011) who reported a similar pattern of diversity being higher in upland habitats at Kakum National Park in the Central region of Ghana. However, the results of this study are inconsistent with several other studies in other parts of the world. For instance, Fauth *et al.* (1989) found that herpetofaunal species richness was negatively-correlated with elevation, and leaf-litter amphibians were more diverse and abundant at lower elevations in Costa Rica . Khatiwada (2011) analysed the effect of altitude, soil temperature and disturbance level on amphibian species richness and found that species richness declined with altitude and more species were found at lower elevations in Nepal. Similarly, Phochayavanich (2010) found that diversity of frogs was highest at lower elevations in an Evergreen Forest, Thailand.

Generally, amphibians and reptiles show a monotonic decline in species richness along elevational gradients (Naniwadekar & Vasudevan, 2007; Fu *et al*., 2006 ; Rehbek, 2005; McCain, 2005; Rehbek,1995; Fauth *et al*., 1989) in which diversity decreases with increasing altitude. However, generalization of this widely-accepted pattern of diversity and mechanisms responsible for this process are still being debated. Nonetheless, Rehbek (1995) suggests that differences in sampling methods and size of study area may be considered as influencing richness patterns observed in many studies. The findings of this study suggest that though swamp forests are more favourable habitats for amphibians in Atewa, farmlands could also serve as important buffer zones for anurans in the forest.

The highest similarity was found among the *Cedrela* plantation and riparian forest , and both differed from the species composition of the farmland and swampy forest. The pattern of similarity between these two habitats may be due to difference in altitude or similar microhabitat and microclimate conditions existing in the habitats. This agrees with Phochayavanich *et al.* (2010) who found that species composition at the two lowest elevations (800 m and 950 m) were very similar, and also stream characteristics were similar at the two altitudes but different from the composition at the high elevation (1,250). Altitudinal gradient is a known factor that causes changes in environmental factors and so amphibian richness and abundance along such gradients maybe affected (Giaretta *et al.* 1999; Fauth *et al.* 1989). The results of the study demonstrated that difference in altitude significantly affected species composition and thus the similarity in species composition can be attributed to this factor .

5.3 Effect of Environmental Variables on Anuran Species Composition

Altitude is a factor which affects species richness and distribution of amphibians and reptiles (Fauth *et al.*, 1989). However, no significant differences were found for the relationship between species richness and altitude throughout the altitudinal range in this study (300m- 800m). Altitude was a poor predictor for anuran species richness, since in the correlation analysis it was weakly (0.3%) related to species richness. The weak relationship between altitude and species richness shows that species richness does not depend on altitude, suggesting that other environmental factors may have a more important role in determining species richness of anurans in Atewa.

Apart from altitude, leaf cover showed a significant positive effect on species richness in the study, being consistent with other studies on environmental factors. Chambers

(2008) and Hillers *et al*. (2008) reported that ground cover attributes such as grass, leaf litter cover, debris cover, herbaceous plant cover and vegetation structure (dominant plant species) were strong environmental factors influencing the presence of frogs in Australia and Côte d' Ivore respectively. Though leaf litter depth and canopy cover are also major determinants in amphibian species richness and abundance (Cabrera-Guzman & Reynoso, 2012; Hillers *et al.*, 2008; Sluys *et al.*, 2007; Fauth *et al.*, 1989), none of the two variables significantly affected anuran richness or abundance in this study.

The study also showed that although canopy cover and litter depth did not affect anuran abundance and richness, it may be possible that the presence of a closed canopy provides a lot of leaf cover which was found to have significant effect on anurans. Also, the reason why leaf litter depth did not affect richness or abundance may due to the fact that the leaf cover may provide more favourable microhabitats (surfaces for egg laying, protection from predators) for anurans than the litter depth. Other environmental variables not measured in this study such as leaf litter moisture, temperature, soil moisture may also affect the role of leaf litter depth and canopy cover.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Overall, 20 species of anurans were recorded from the Atewa forest, of which 11 species (55%) were forest specialists closely associated with swamp and riparian forest habitats, four (20%) were forest species which prefer *Cedrela*/secondary forest, and 10 (50%) species occurred in farmland or open habitats. Generally, the swamp forest had the highest species richness and diversity. The species composition, abundance and distribution of amphibians varied between the habitats and altitude . This study also found that leaf cover and altitude were important predicators of species richness and abundance, while leaf litter depth and canopy cover were weakly correlated to amphibian species richness and abundance showing no significant effect .

It cannot be immediately explained why leaf litter depth and canopy cover did not affect diversity even though they are important determinants of species richness and abundance according to literature. It can only be suggested that anurans may prefer to live on the surface/top of leaves rather than the bottom of the litter. The study provides important information on the relationship between species richness and abundance and habitat variables in Atewa forest. However, further extensive research on other variables such as leaf moisture content, temperature, type of leaf/ground cover, logging and mining not included in this study could affect amphibian diversity.

6.2 Recommendations

Since amphibians play an important role in the ecosystem, loss of amphibian species is likely to affect other terrestrial vertebrate (reptile ,bird and mammal) communities and their ecological roles in general. More field studies should therefore be undertaken to make information available for monitoring and comparisons. Also, since several species were restricted to one altitude, specific protection strategies suitable for each altitude will ensure the continual provision of favourable habitat conditions for species with restricted distribution. The high altitude areas in Atewa appear less disturbed than the low- and mid-altitudinal areas which are more impacted by farmlands. This clearly demonstrates that the low and mid sections of the Atewa must be protected against further disturbance. Farmlands, especially mature cocoa farms, have the potential of supporting high amphibian diversity similar to closed forests. Farmers should therefore be educated to preserve puddles and stagnant water bodies that serve as breeding places for amphibians.

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APPENDICES

Appendix 1: GPS Coordinates of the 16 Surveyed Plots

Plot ID	Habitat Type	Latitude	Longitude	Altitude
FM 1	Farmland	06°13.767'N	000°31.627'W	301.00
FM 2	Farmland	06°13.869'N	000°31.435'W	311.00
FM 3	Farmland	06°13.961'N	000°31.564'W	315.00
FM 4	Farmland	06°14.090'N	000°31.738'W	331.00
CP 1	Plantation	06°13.716'N	000°31.781'W	319.00
CP 2	Plantation	06°13.871'N	000°31.683'W	327.00

CP 3	Plantation	411.00	06°13.893’N	000°32.062’W
CP 4	Plantation	469.00	06°13.946’N	000°32.272’W
RF 1	Riparian forest	617.00	06°13.967’N	000°33.116’W
RF 2	Riparian forest	676.00	06°13.867’N	000°32.924’W
RF 3	Riparian forest	746.00	06°13.793’N	000°33.372’W
RF 4	Riparian forest	771.00	06°13.619’N	000°33.244’W
SF1	Swamp forest	712.00	06°14.541’N	000°33.421W
SF 2	Swamp forest	720.00	06°14.337’N	000°33.493W

SF 3	Swamp forest	807.00	06°13.892’N	000°33.580’W
SF 4	Swamp forest	816.00	06°14.070’N	000°33.705’W

Appendix 2: Some Anurans Recorded at Atewa

Plate 5: ***Amietophyrnus togoensis***

Plate 6: ***Hyperolius sylvaticus***

Plate 7a: ***Hyperolius bobirensis***

Plate 8: ***Hyperolius bobirensis***

Plate 9: ***Phrynobatrachus gutturosus***

Plate 10a : *Arthroleptis* spp.

Plate 11: *Arthroleptis* spp

Plate 12: ***Arthroleptis*** **spp**

Plate 9d : ***Arthroleptis*** **spp**

Plate 13a: *Aubria subsigillata* (juvenile)

Plate 14: ***Aubria subsigillata*** **(dorsal view)**

Plate 15: ***Phrynobatrachus calcaratus***

Plate 16: ***Hyperolius fusciventris***

Plate 17: *Phrynobatrachus plicatus*

Plate 18: ***Hemisus marmoratus***

Plate 19: ***Conraua derooi***

Plate 20: ***Hyperolius concolor***

Plate 21: ***Phrynobatrachus accraensis***

Appendix 3: Number of Individuals and Species of Anurans Recorded in the 16 Plots (F1-S4) at Atewa

Species	F1	F2	F3	F4	C1	C2	C3	C4	R1	R2	R3	R4	S1	S2	S3	S4
Amietophrynus maculatus	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	1
Amietophrynus togoensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Amnirana occidentalis	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0
kassina arboricola	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Arthroleptis species	40	22	66	87	19	13	17	8	13	6	2	4	10	8	5	10
Conraua derooi	0	0	0	0	0	0	0	0	19	9	0	0	0	0	1	2

Hemisus marmaratus	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hylarana occidentalis	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyperilous bobirensis	0	0	0	0	0	0	0	0	0	0	0	0	21	0	7	0
Hyperilous concolor	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Hyperilous fuscivotris	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Phrynobatrachus accraensis	0	70	13	17	0	0	0	0	0	0	0	0	0	0	0	0
Phrynobatrachus alleni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4
Phrynobatrachus calcaratus	3	49	7	35	0	1	0	0	2	4	7	17	0	7	0	0

Phrynobatrachus gutturosus	17	10	17	0	0	0	0	0	0	0	0	0	6	0	2	0
Phrynobatrachus plicatus	3	1	2	0	3	1	1	0	3	1	0	6	1	1	1	2
Phrynobatrachus tokba	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0
Ptychadena aequiplicata	2	1	2	4	1	0	0	0	0	0	0	0	4	1	0	0
Ptychadena longirostris	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptychadena bibroni	0	0	4	0	0	0	0	0	0	0	1	1	0	0	9	0

Appendix 3: Results of Correlation Analysis

		LC	LLD	CC	Elevation	SR	SA
LC	Pearson Correlation	1	0.301	0.044	0.426	.585*	0.064
	Sig. (2-tailed)		0.258	0.872	0.1	0.017	0.815
	N	16	16	16	16	16	16
LLD	Pearson Correlation	0.301	1	-0.097	-0.142	0.28	0.228
	Sig. (2-tailed)	0.258		0.721	0.599	0.294	0.395
	N	16	16	16	16	16	16
CC	Pearson Correlation	0.044	-0.097	1	.662**	-0.086	-0.437
	Sig. (2-tailed)	0.872	0.721		0.005	0.753	0.091
	N	16	16	16	16	16	16

Elevation	Pearson Correlation	0.426	-0.142	.662**	1	0.057	-.534*
	Sig. (2-tailed)	0.1	0.599	0.005		0.835	0.033
	N	16	16	16	16	16	16
SR	Pearson Correlation	.585*	0.28	-0.086	0.057	1	.520*
	Sig. (2-tailed)	0.017	0.294	0.753	0.835		0.039
	N	16	16	16	16	16	16
SA	Pearson Correlation	0.064	0.228	-0.437	-.534*	.520*	1
	Sig. (2-tailed)	0.815	0.395	0.091	0.033	0.039	
	N	16	16	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).