THE DISTRIBUTION AND DIVERSITY OF LAND SNAILS IN SHIMBA HILLS NATIONAL RESERVE, KENYA

BY

NDALILA MERCY NELIMA, B.Sc. (HONS) UNIVERSITY OF NAIROBI

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DECLARATION

I hereby declare that this is my original work and has not been presented for award of a degree in any other University.

..... DATE..10th September 2009

MERCY N. NDALILA

This thesis has been submitted for examination with my approval as academic supervisor.

..... DATE...11TH September 2009

DR. JOHN GITHAIGA

UNIVERSITY OF NAIROBI

..... DATE..11th September 2009

DR. RAPHAEL OKOOLA
UNIVERSITY OF NAIROBI

..... DATE.....11/09/2009.....

DR. CHARLES LANGE
NATIONAL MUSEUMS OF KENYA

DEDICATION

Dedicated to my parents Evans Ndalila and Truphena Ndalila, my brothers and sisters who have stood by me in joy and hardship; specifically my dad who, even in sickness, has always encouraged me to embrace education up to the highest level possible.

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ABSTRACT

The objective of the study was to investigate the distribution and some ecological aspects of land snails in Shimba Hills National Reserve, Kenya. This study was important because no scientific study on snails has been done in this forest, therefore this study will increase malacological knowledge which will in turn necessitate proper management plan for both ecosystem and the terrestrial snails. Molluscs were sampled using standardized direct search and litter sample methods in plots measuring 1m x1m in the different habitat types. Environmental parameters notably temperature, relative humidity, soil, vegetation were investigated. Soil parameters analysed were soil pH, electro-conductivity, soil calcium and soil texture. For vegetation, sampling was done for trees, shrubs and herbs and the plant species identified.

In total, 1,748 snail specimens were recorded during the entire study; yielding 28 species from eight families, with family Streptaxidae having the highest number of species with nine species, followed by Subulinidae with six species. The families Maizaniidae, Pomatiasidae and Endodontidae had one species each. The most abundant species was *Gonaxis quadrilateralis* belonging to family Streptaxidae, and comprised 12% of the total specimens recorded. The least abundant species was Morphospecies 2.

Comparison of snail metrics in three different seasons showed that the wet season had the highest number of individuals with 703 followed by the dry/wet season with 579 individuals and the least in the dry season (466). There were significant influences of

season on land snail diversity ($F_{(2,407)} = 6.324$, $P < 0.05$) with the wet season recording the highest diversity.

When snail abundance was tested using ANOVA, there were significant differences of land snails due to vegetation types ($F_{(4,407)} = 56.039$, $P < 0.05$). Shannon Weiner diversity levels of land snails were highest in the indigenous forest with 0.984 while the grasslands recorded the least diversity of snails with 0.009. Rainfall and other environmental variables such as litter cover, relative humidity and canopy cover had a positive and significant influence on the snail richness while the temperature significantly affected the abundance and richness.

The findings ranked Shimba Hills as the richest coastal forest in terrestrial snails in Kenya; having been compared with studies done in Arabuko Sokoke where 25 species were recorded. These results are important in exposing the role the forest plays in conservation of land snails and therefore sound conservation strategies should be put in place to protect the ecosystem.

CHAPTER ONE

INTRODUCTION TO THE STUDY

1.0 Introduction

The coastal forests of Eastern Africa are recognized as areas of global importance due to high concentration of biodiversity some of which are rare and endemic plant and animal species. It is believed that the levels of endemism in the coastal forests would rank these forests as one of the top ten priority ecosystems for biodiversity conservation on the African continent (Myers *et al.*, 2000). Despite the biodiversity conservation significance of these forests, many remain unexplored for several taxa such as land snails. Previous incidental land snail collections among few coastal forests in Kenya have shown potential existence of high levels of endemism among the coastal forests such as Shimba Hills (Verdcourt, 2006). Such potentially high biodiversity content though remains to be registered and indeed it is important to execute a land snail biodiversity survey to document the biodiversity before any major impacts of environmental change or disturbance occur. Such information will in addition provide basis for deriving sound conservation planning of the taxa and the ecosystem.

Molluscs comprise the second-most diverse animal phylum globally after Arthropoda, with an estimated 80,000 species worldwide. Majority of the species are aquatic (marine and freshwater) with the terrestrial species (snails and slugs) comprising about 25% of total fauna (Emberton *et al.*, 1997). Land snails have been observed to have a number of ecological roles in the forest ecosystems: they help in decomposition of organic matter in

the soil, they contribute in soil mineralization, they provide food for vertebrates and some are excellent indicators of environmental conditions. Some freshwater molluscs are vectors of human and livestock diseases. They have also contributed in understanding genetics and the process of evolution (Tattersfield *et al.*, 1998).

Land snails have received little attention, yet, this group of animals has several characteristics that make them useful as an indicator of diversity assessment (Schilthuizens & Rutjes, 2001). First of all, molluscs can be sampled easily and non-destructively even foresters can rapidly learn basic sampling methods. Secondly, they can be surveyed throughout the year since they are inhibited with respect to mobility.

1.1 Literature review

The phylum Mollusca is divided into a number of classes that include Gastropoda (land molluscs), Bivalvia (mussel, oyster), Cephalopoda (octopus, squid, and cuttlefish), Aplacophora (fossil), Scaphopoda (tusk shell), and Amphineuria (chitons) (Trueman & Clarke, 1985). The focus of the study is the Class Gastropoda which is the most diverse and widely distributed. The class is sub-divided into 2 sub-classes: Prosobranchia that makes up to 3% of the class and Pulmonata which is the most dominant of all gastropods occurring both in terrestrial and aquatic environments (William & Gordon, 1987). Families under Prosobranchia include among others Hydrocenidae, Maizaniidae, Pomatiasidae while those under Pulmonata include Enidae, Subulinidae and Streptaxidae among others.

Terrestrial molluscs make a total of approximately 35,000 species comprising of slugs and snails which live on the surface or in the top 30 cm of the soil. These soft-bodied, "belly-footed" organisms creep by progressive waves of contraction and expansion of a ventral, muscular foot (Martin, 2000). The difference between slugs and snails is that the former has a very small, inconspicuous shell or none at all while snails have a shell which is formed from the mantle and is important in preventing desiccation and predation. Molluscs have a number of characteristics that include a bilateral symmetrical, soft compact body which is divided into the head, visceral mass, mantle and foot. They lack an internal skeleton and instead have an external exoskeleton (shell) formed by secretion of an organic substance, conchiolin from glands at the edge of the mantle (Seddon *et al.*, 1996). The shell is made of two distinct layers comprising inner, thick ostracum made of calcium carbonate, and the outer periostracum made of proteins.

Physical and chemical features of the environment, especially moisture and calcium carbonate for making shells play major roles in influencing snail distributions. Vegetation influences snail distribution and abundance by its effect on soil chemistry and the quality of leaf litter. Land snails can live in areas of calcium-poor soils if the local trees concentrate calcium in their leaves (Burch & Pearce, 1990). The importance of calcium to land snails may vary with physiographic region, depending on forest types and soil chemistry, forest age and disturbance history, past glaciation, and climate (Hotopp, 2002). Snails obtain calcium from calcareous rocks, vertebrate bones, or shells of dead molluscs by absorbing dissolved calcium carbonate through their moist skins, or from the upper layers of the soil, or by rasping large rocks or cement.

In forest habitats, snails live among low plants, within leaf litter and woody debris in the upper soil horizons, though they may climb trees or follow crevices deeper underground (Hotopp, 2002). Most snails are herbivores and feed on plant matter in form of live vegetation, rotting leaves and wood sap, while others are mycophagists, and detritivores although a few species are carnivorous feeding on other snails, nematodes, insects or other invertebrates (Pilsbry, 1939). Calcium in snails is essential for reproduction, shell development and other physiological needs. In times of calcium demand, such as egg laying, the snails mobilize calcium from their own internal organs and shells.

Land snails are preyed on by a variety of predators both vertebrate and invertebrate. Vertebrate predators include frogs, lizards, moles, squirrels, snakes, salamanders, shrews and some birds like blackbirds, thrushes, and ruffed grouse, while invertebrate predators are larvae of lampyrid beetles, other snails, adult ground beetles, sciomyzid fly larvae, ants and millipedes (Burch, 1962; Hotopp, 2002; and Martin, 2000).

Snails move for feeding and mating, to avoid predators, to adjust their microenvironments, and in response to environmental, seasonal, and diurnal influences. Snails do not move far over their lifetime since they are slow-moving animals and therefore are range-restricted.

1.2 Ecological importance of land snails

Land snails contribute significantly to the food chain. They might be considered "low" on the food chain and will consume virtually any organic and many inorganic materials that are available. Feeding and searching for food, are the life functions on which land snails seem to spend a lot of their active time. Moving up the "food chain," a variety of animals eat land snails. While there are a number of invertebrate predators of snails, the animals that consume the calcium-rich shell are mainly vertebrates. Circumstantially, these animals have a high demand for calcium to build bones.

By contributing to biodiversity, snails enhance the conditions and functioning of terrestrial ecosystems. With regard to ecosystem function, shelled land snails are important in calcium cycling as suggested by Hotopp (2000). The snails glean calcium from their food, concentrate it in their shells that are made mainly from calcium carbonate, and pass it up the food chain as they are consumed by predators. Both shelled snails and slugs can be categorized as decomposers though they play only a small role compared to other decomposing organisms.

Snails are potential indicators of ecosystem health as they are sensitive to changes in the environment such as temperature, moisture content and habitat disturbances (Warui, 1998). There are some snail species that are confined to undisturbed ecosystems whereas others are indicative of habitats that have been degraded by human activities (Tattersfield *et al.*, 1998). Land snails have been found to be excellent indicators of site history and site conditions. Because shelled land snails have a high calcium demand, they are sensitive to calcium availability from soils and plants. Site moisture and past land

clearing or fire also strongly influence snail populations. Land snails have been used extensively in European archaeology to interpret past environments. They can also be indicators of pollution, as they take up environmental toxins such as cadmium (Hotopp & Pearce, 2006). They do this by ingesting the environmental contaminants and hold, or sequester those contaminants in their tissues and are thus useful indicators of pollution.

1.3 Importance of land snails to humans

Land snails such as *Helix pomatia* have been cultured and used as food for humans throughout the world for centuries. Other species that are delicacies include *Oreohelix sp.* consumed in the western world and the giant African land snails eaten in West Africa.

Whereas fresh water snails that include *Biomphalaria sp.*, *Bulinus sp.*, and *Lymnea sp.* are intermediate hosts to Schistosome parasites, land snails can also have negative interactions with other organisms (Martin, 2000). Snails are intermediate hosts to a variety of mammalian parasites and *Zonitoides nitidus,* is a host for a meningeal worm that infests white-tailed deer and moose. Mammals become infected by accidentally ingesting gastropods that contain the worm's larvae.

The most serious ecosystem and agricultural impacts attributed to land snails are often related to non-native pest populations. The introduced European white garden snail, *Theba pisana,* which damages ornamental and citrus plants has been the subject of eradication programs in California (Mead, 1971) while the giant African land snail has

been reported to cause massive agricultural losses in various parts of the world where it has been introduced (Mead, 1961).

1.4 Importance of the coastal forests

The coastal forests of Eastern Africa comprise a stretch of lowland rainforests covering an area of approximately 3170 km^2 from southern Somalia through the Kenyan and Tanzanian coasts to northern Mozambique and include small forests in south-eastern Malawi and eastern Zimbabwe (Burgess *et al.*, 2000). In Kenya and Tanzania, these forests are recognized as areas of global importance and earmarked as part of the 25 world's hotspots of biodiversity for their concentration of many narrowly range restricted or endemic plants and animal species in exceptionally small areas (Myers *et al.*, 2000).

Despite the forests biodiversity conservation significance, they also constitute some of the critically threatened ecosystems in Eastern Africa. The coastal forests ecosystem was once a continuous block of pristine lowland rainforest but has undergone human induced alterations through exploitations to the current numerous fragments sandwiched between human settlements. In Kenya for instance, most of these coastal forests are smaller than 5 km^2 with the largest remnant being the Arabuko Sokoke forest (370 km^2) followed by Shimba Hills covering about 190 km^2 (Wass, 1995). They however continue to experience further disturbance.

In an attempt to protect these biodiversity hotspots from extinction, increased conservation efforts have been initiated by the government and relevant conservation

agencies. In Kenya several remnants now operate under Kenya Wildlife Service (KWS), Kenya Forest Service (KFS) whereas several others are managed by the National Museums of Kenya as monuments (Luke, 2005). These formal conservation initiatives have contributed in fostering the conservation of these forests through formal protection. The greatest drawback to drawing effective and efficient scientifically guided conservation programs has been the lack of research data and information for many taxa. This is more so particularly for forest floor invertebrates such as land snails comprising many of which are endemic and range restricted species and may therefore be compromised when setting conservation borders and agendas. This implies that research to gather information for as many taxa as possible particularly from the un-sampled large forest remnants that include Shimba Hills is necessary as this will provide vital guidance for the forest managers. Moreover, the information will provide a foundation for long term biodiversity and ecosystem monitoring programme for prompt response to biodiversity conservation issues.

1.5 Justification

The need to conserve invertebrates has been recognized mostly in the temperate regions but this does not imply any lack of need for invertebrate conservation in the tropics. In fact, some of the highest priorities are to assess and conserve biodiversity, and the greatest threat to its sustainability occurs in regions where invertebrate conservation has 'no role' on conservation agenda (New, 1995). Invertebrate species have received much less publicity and attracted less research effort relative to vertebrates.

In the entire Kenyan coast, Arabuko Sokoke is the only forest that has been investigated for land snails. Other forests such as Shimba Hills which is the second largest Kenyan coastal forest remain to be properly investigated though some incidental collections have shown that the forest potentially supports many species some of which are likely to be endemic (Verdcourt, 2006). The forest, like many other coastal forests, experiences some anthropogenic and natural changes that may have profound impact on these less motile species to extent that some may disappear undocumented.

Previous studies have reported that the Eastern Africa coastal land snail malacofauna is characterized by many range restricted species likely sensitive to environment changes (Tattersfield, 1998). In this regard it is of great biodiversity conservation interest that land snail studies on this coastal forest are executed in order to gather information for enhancing biological knowledge of these coastal forests, document these habitat change sensitive species and provide sound basis for initiating biodiversity conservation strategies. More so, such studies may provide vital basis for further standardized habitat/biodiversity change monitoring in order to understand the impact of various management practices and natural events such as climate change.

1.6 Objectives of the study

1. To describe diversity and abundance of land snails in the Shimba Hills National Reserve.
2. To determine the diversity and abundance of land snails within various habitats in the study area.
3. To investigate microhabitat characteristics that influence the diversity patterns of land snails in the Shimba Hills National Reserve.
4. To determine the influence of season on diversity patterns of land snails in the Shimba Hills National Reserve.

1.7 Hypotheses

1. Snail abundance and diversity is different for the different habitats
2. Abundance and diversity of land snails are influenced by seasonality

CHAPTER TWO

THE STUDY AREA

2.0 Introduction

The Shimba Hills National Reserve, located about 33 km south of the largest coastal Kenyan town (Mombasa) comprise the second largest remnant of native lowland rain forest in the Kenyan coastal region after Arabuko Sokoke forest. It covers an area of 21740 hectares and is situated between 39° 25' E longitude and 4° 15' S latitude. The Shimba Hills were originally designated as a Forest Reserve in 1903. In 1924, grassland areas were incorporated and several subsequent extensions took place to bring the Reserve to its present size (see www.kws.org/shimba.html). Discussions within the government were done to determine the feasibility of Shimba Hills being a National Park and studies undertaken including that done by Risley (1966) strongly recommended that the area receives the National Park status. This was opposed by the Forestry Department leading to the adoption of a multiple land use approach whereby the Reserve, at present, falls under a joint management by Kenya Wildlife Service and Kenya Forest Service. The area was therefore re-gazetted as a National Reserve in 1968.

Two Kayas, Kwale and Longomwagandi, are situated within the National Reserve and a fenced elephant corridor connects the Shimba Hills with Mwaluganje Forest Reserve to the north. Several rivers flow from the hills supplying water to Mombasa and other towns like Kwale in addition to being important for conservation of aquatic biodiversity.

2.1 Geology and soils

The hills are composed of Triassic Duruma sandstones made up of quartz and feldspar grains (Glover, 1969). The cementing elements, micas and feldspars, are leached leaving sand and silt composed almost entirely of quartz. The soils of the plateau region were derived from the Magarini sands and vary from deep sand on plateaus to valley soils composed of colluvial material mainly composed of sandy clays. Being extremely porous, these sandy clay soils have poor to very poor fertility status owing to very low water retention capacity, cation exchange capacity, moderate acidity, low organic matter and deficient in calcium and other elements (Andanje, 1994; Makin, 1968; and Ross, 1984).

2.2 Climate

Climatic parameters for the area were obtained from meteorological station in Kwale town. The mean annual rainfall is 1,200 mm (Luke, 2005) with a monthly average of about 100 mm, but is not evenly distributed over the year. Figure 1 shows the mean monthly rainfall averaged for five years. Seasonality is not very pronounced though there is minimum rainfall between January and March; substantial amount of rainfall between November and December while highest rainfall is observed between April and June. The mean annual temperature is 24^0C (Figure 2) and the mean relative humidity is 80%.

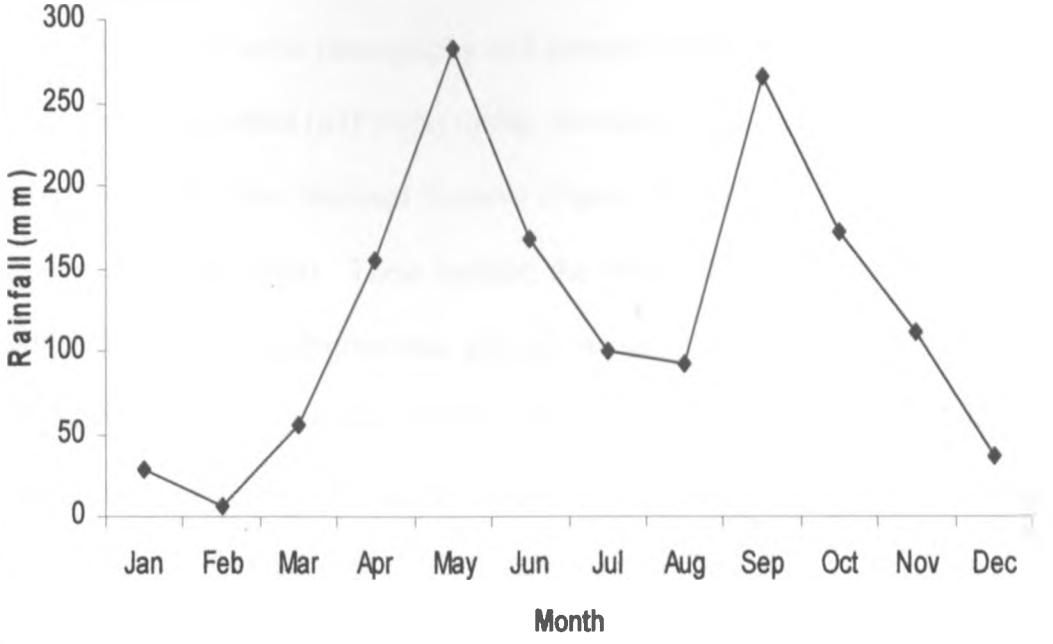


Figure 1: Mean monthly rainfall (mm) at the KWS Kwale station (averaged for 2003-2007)

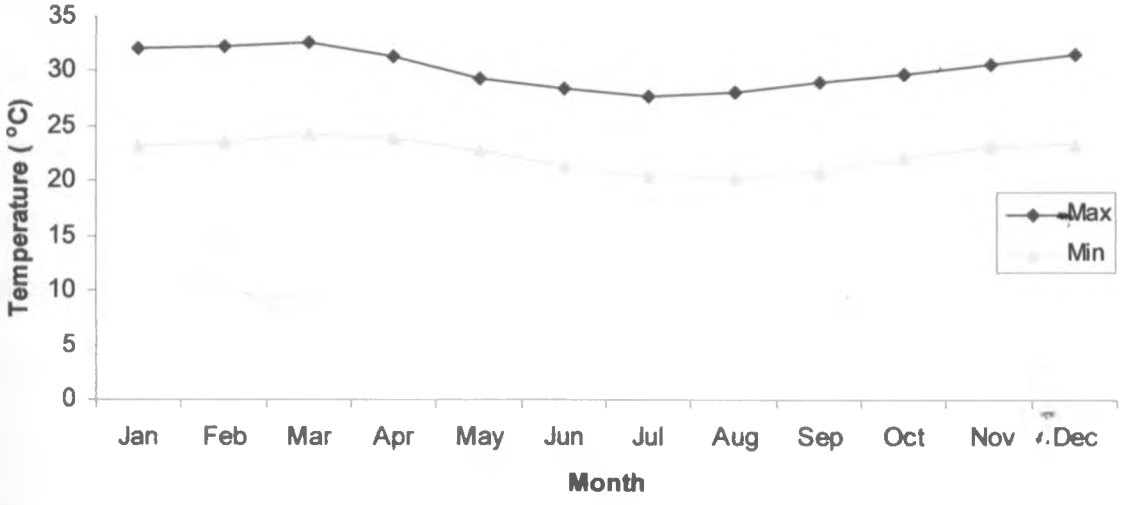


Figure 2: Mean monthly temperature (°C) at the Moi Airport Meteorology station

2.3 Vegetation

An interpretation of aerial photography and ground-truthing by Kenya Indigenous Forest Conservation Programme (KIFCON) timber inventory teams in the early 1990s produced a vegetation map of the National Reserve (Figure 3) using six rough vegetation-cover categories (Blackett, 1994). These include; the forest (9500 ha), forest/scrub (8000 ha), grassland (2700 ha), scrub/grassland, plantations and others (Luke 2005). Major forest types have been described and include *Milicia* forest, *Afzelia-Erythrophloem* forest, *Paramacrolobium* forests. A recent detailed examination of the Shimba Hills plants recorded a total of 1,396 taxa (Luke 2005). Some of the main plant genera from the Shimba Hills include: *Afzelia, Hymenaea, Sterculia, chlorophora, Memecylon* and *Combretum, Cynometra* among many others. During the survey, five vegetation types that include indigenous forest, scrub, grassland, Grassland/Scrub and pine plantations were redescribed.

2.4 Fauna

The National Reserve is an important hotspot for conservation of terrestrial biodiversity amongst which are globally threatened species. The fauna within the reserve include, mammals such as vervet monkey (*Cercopithecus aethiops*), elephants (*Loxodanta africana*), buffalos (*Syncerus caffer*), bush baby (*Galago senegalensis*), black and white colobus monkey (*Colobus guereza*) and the sable antelope (*Hippotragus niger*) (www.kws.org/shimba.html). Many invertebrates with potentially range restricted species like land snails also occur in the forest (Verdcourt, 2006).

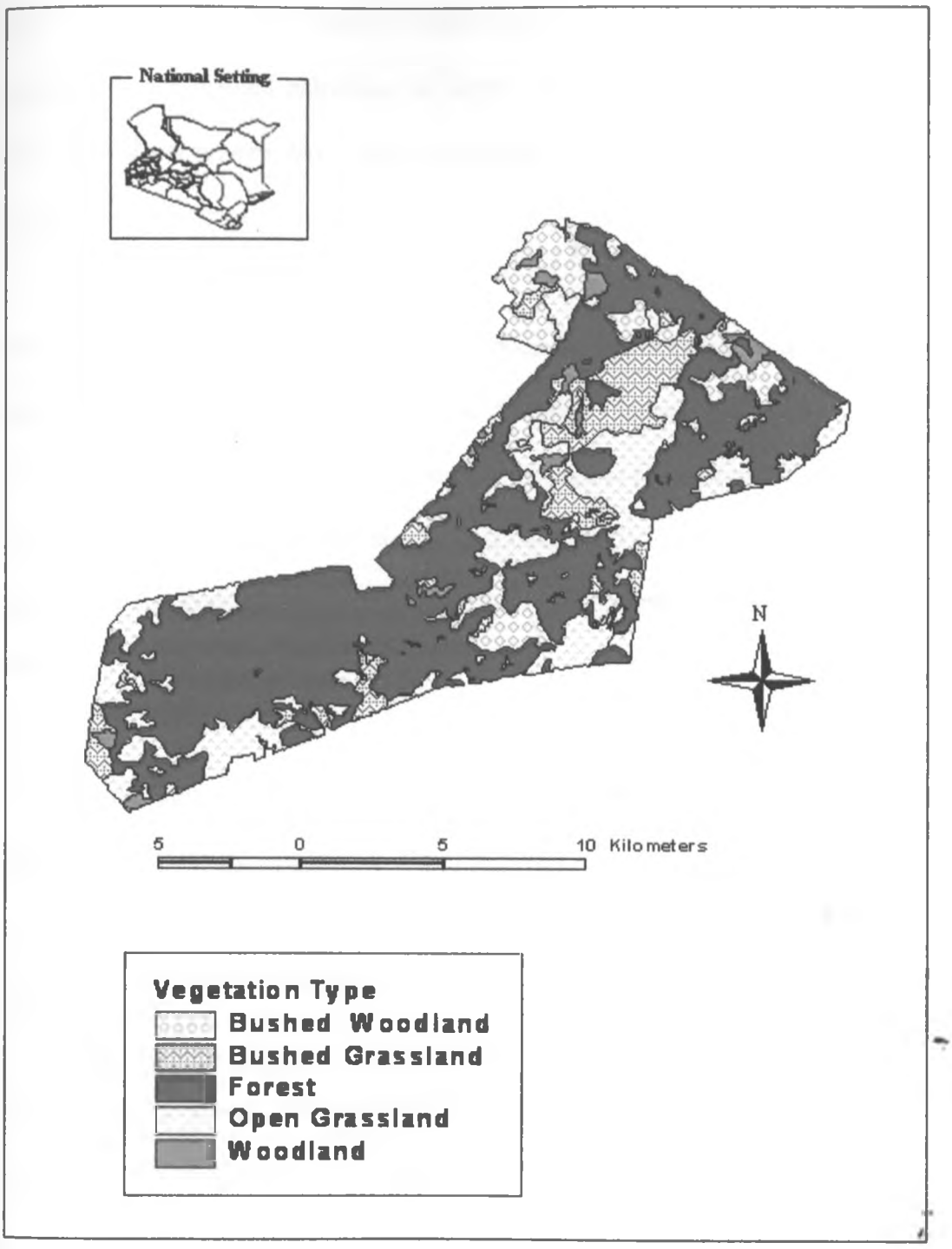


Figure 3: Vegetation cover of Shimba Hills National Reserve

2.5 Conservation challenges

Like other coastal forests, Shimba Hills has suffered drastic habitat modification over years from commercial extraction of timber. *Milicia excelsia, Combretum schumannii* and *Afzelia quanzensis* have been particularly targeted though, for now, commercial exploitation is under control.

Fencing off the Reserve has helped in reducing both anthropogenic activities and the elephant problem externally. This has, however, increased internal pressure from elephants on the forests leading to extensive damage to plant species fed on by them with a substantial change in forest structure (Luke, 2005). They have altered the natural process of succession and promoted nearly mono-dominant stands of elephant- tolerant species.

The most visible threat to land snails in Shimba Hills is the continuous burning of grasslands to provide grazing for herbivores and the extensive road construction in the reserve (personal observation). Although the measures are aimed at increasing revenue in the reserve, they greatly affect slow-moving and range-restricted animals such as land snails which mostly occur on forest floors and any attempt to interfere with their habitat may threaten their existence. There is therefore need for sound management programs for all the species whether large or small.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Malacological surveys

Malacological studies for molluscs in most parts of the world have used a number of methods that include:

1. Direct searches for fixed lengths of time;
2. Direct search over a defined standard area; and
3. Indirect search (leaf litter method).

Direct search involves searching and collecting molluscs from their microhabitats that include forest floor litter, under dead fallen wood, under surfaces of leaves, on growing moss on tree trunks (Warui, 1998). This method is suitable for large species thus enables faster collection and the only limitation of this method is that minute cryptic molluscs may be missed.

Indirect search involves sieving of molluscs from leaf litter. This method allows sampling of burrowing species and small-sized species which would be difficult to see using the direct search method. Its limitation is that it requires more skills and is time-consuming. Therefore, each technique results in collection of snail species not found by the other, which is supportive of the idea that the two techniques sample different snail habitats and thus compliment each other in assessing species richness (Hotopp, 2002).

3.1 Methods

A preliminary survey was conducted in September/October 2007 to understand the forest structure and identify the various habitat types. Suitable sampling sites were identified in the different forest types and GPS points of these sites recorded. The GPS points aided in tracing the selected sampling areas when doing the actual sampling. Figure 4 shows the sampling points within the study site.

Sampling was done in the three seasons categorised as dry, dry/wet and wet season. Data collection for the dry season was in November/ December 2007 since the climatic conditions for this year was different from previous years. The second data collection for the dry/wet season was in April 2008 while the final sampling for the wet season was in June 2008. Other than snail sampling, vegetation sampling, soil sampling, and records of habitat and abiotic environmental variables such as percentage canopy cover, litter mass, temperature and relative humidity were also obtained.

3.1.1 Vegetation sampling

Seventeen sites were located in the different habitat types, with the indigenous forest having 5 sites while the other four habitats that include scrub, plantation forest, grassland/scrub and grasslands had three sites each. Within each site, a vegetation survey was done and a nested plot design employed where different size classes of vegetation were measured within the larger 100 x 100m quadrat. Trees were sampled in this larger plot while shrubs and tree saplings of above 2m were sampled in smaller subplots of 50 x 50m. The smallest subplots (5 x 5m) were used for short vegetation that included

herbaceous plants. Within the plots, trees/shrubs and herbs were identified using previously collected specimens as references, while others were identified in the herbarium (Appendix 1).

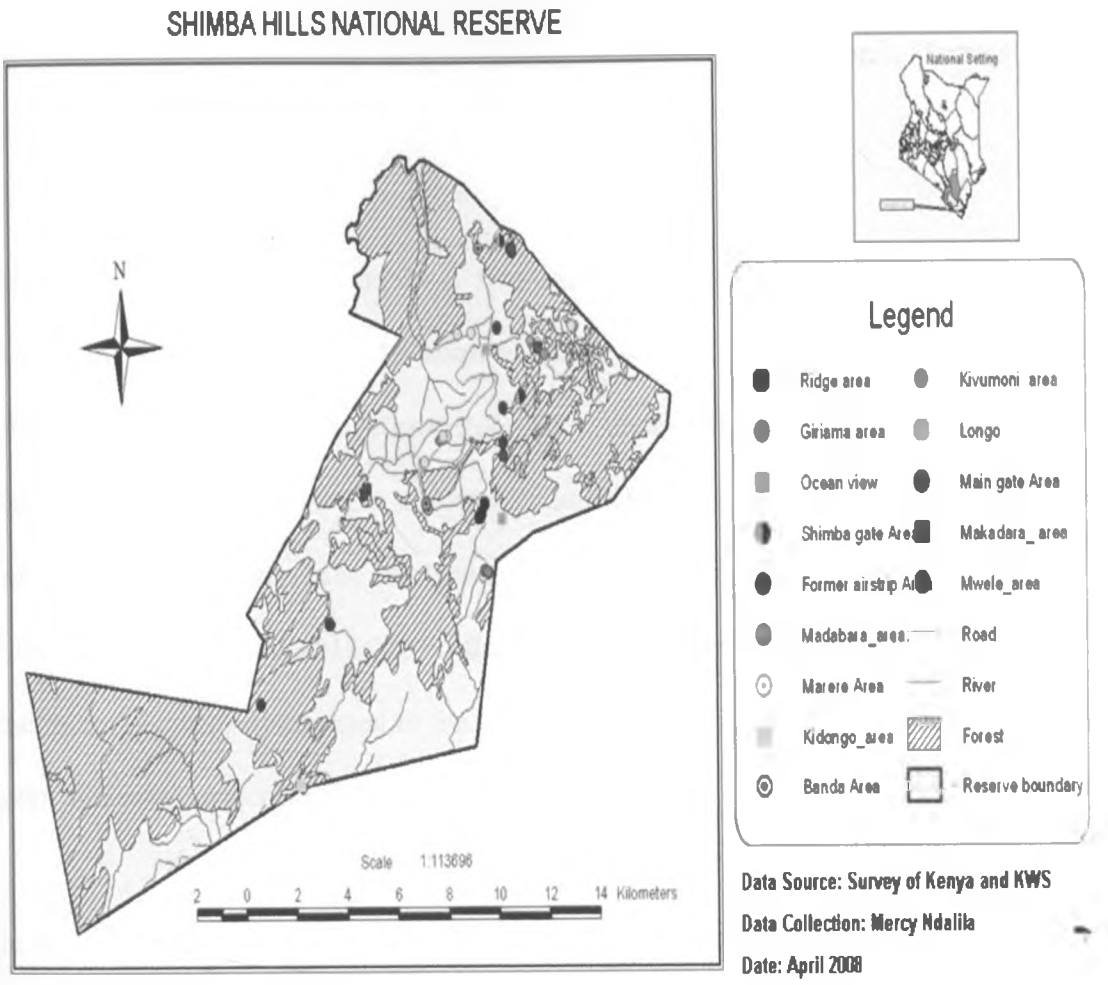


Figure 4: Study site and distribution of sampling plots

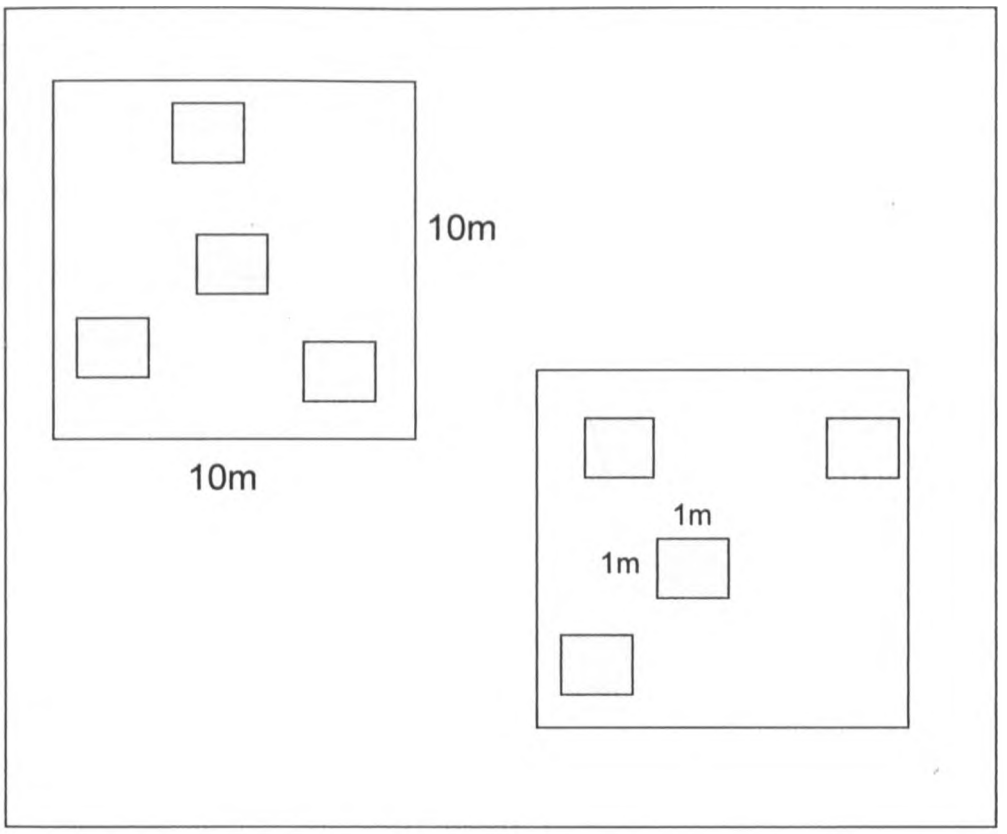
3.1.2 Snail sampling

Within the larger plot measuring 100m x 100m (used for vegetation survey), two sampling plots of 10m x10m were selected. In each of the plots, 4 sub-plots of 1m x1m were randomly selected (Figure 5) using a calculator that generates random numbers and the last number within a range of one to nine selected. Snails were sampled using a combination of indirect litter sample methods and timed direct search (Tattersfield, 1996 & Tattersfield *et al*., 2001).

In the timed direct search method, live snails and shells were searched and collected within the 1m x 1m plot for 15 minutes. They were searched in all microhabitats found within the plot that included forest floor litter, under dead fallen wood, under surfaces of leaves, on growing moss on tree trunks among others. Snails collected were kept in labeled specimen vials. Live snails and dead shells were separated at the end of each day. Live snails were preserved in 70% ethanol while shells were kept in dry labeled vials. All the materials were transported to the National Museums of Kenya for identification using keys and reference collection.

In the litter sample method, 4 litres of leaf litter was put in a polythene bag, air-dried and then sieved using a stacked sieve (top=2mm, bottom=0.5mm). The amount of litter collected varied, with the forest, scrub and ecotones having a relative constant amount while in the grasslands, a lower volume of litter was collected. The litter retained on the top sieve was briefly inspected for any live snail or dead shells and discarded. The litter retained on the bottom sieve was transferred in to another polythene bag or container and

later small macro-snails that may have been overlooked during the direct search sampling were sorted using a strong illumination at the laboratory at NMK. The retrieved snails were stored and identified.



N.B: The diagram is not drawn to scale

Figure 5: Sampling design employed in the study

3.1.3 Investigations of environmental variables

Four environmental variables namely, percentage litter cover, canopy cover, temperature and relative humidity were recorded. Percentage litter cover and canopy cover were estimated by visual observation using a score of 1-5 where score of 1 represents open canopy and 5 for closed canopy while temperature was determined using a meteorological thermometer and relative humidity determined by use of a hygrometer. Figure 6 shows rainfall recorded during the study period between November 2007 and May 2008. Rainfall data for the month of June have not been included because they were incomplete by the time field work was being conducted.

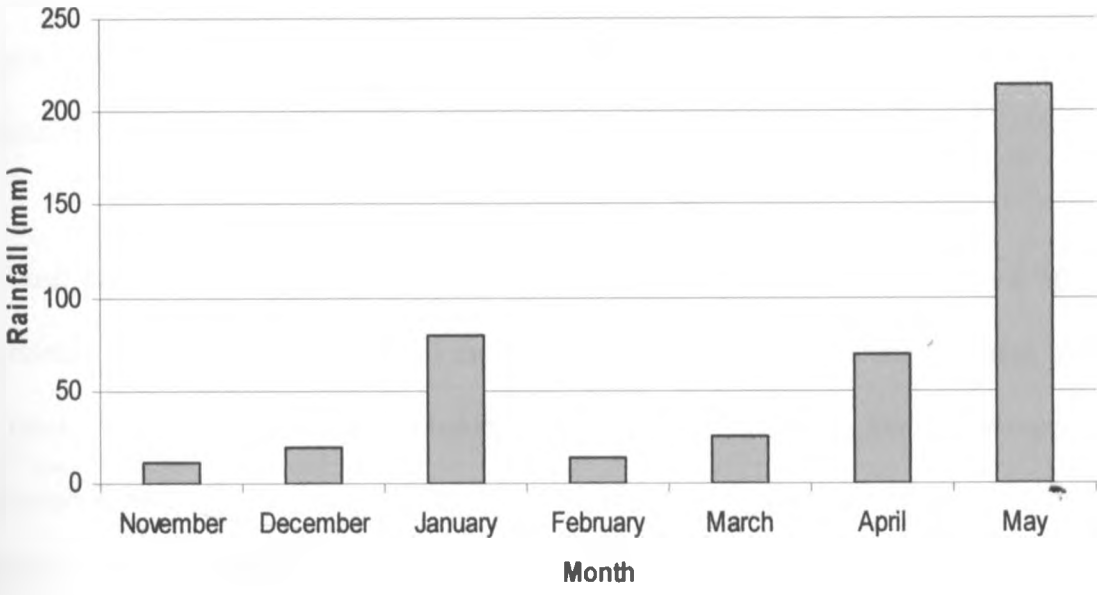


Figure 6: Rainfall statistics for the study period

3.1.4 Soil analysis

Within the two 10 x 1m plots, soil samples were collected with the use of a sharp metal knife (panga), in which a hole, 10 cm deep was dug. The samples were mixed to constitute a composite sample then stored in a labeled plastic bag and sent to the soil science laboratory in the University of Nairobi for analysis. Soil characteristics determined included soil pH, electrical conductivity, calcium and texture.

For soil pH, 50 ml deionised water was added to 20 ± 0.1g soil measured on 2.5: 1 water to soil suspension. The mixture was stirred for 10 minutes and allowed to stand for 30 minutes and stirred again for 2 minutes. The pH of the soil suspension was measured and the suspension allowed to settle for 1 hour before determining the conductivity of the supernatant liquid. Electroconductivity of the dissolved salts was measured using an electroconductivity bridge meter.

For soil calcium, 10 ml of a wet-digested sample solution was pipetted into a 50 ml volumetric flask and 10 ml of 0.15% lanthanum chloride added. The solution was made to mark with distilled water, shaken and sprayed into the atomic absorption spectrophotometer at wavelength 422.7 nm. From a calibration curve of standard series readings, the concentration of Calcium n the sample was read off.

For soil texture, Bouyoucos or hydrometer method was used (Bouyoucos, 1927). Here, 50 g of air-dry, 2 ml soil was weighed into a beaker. The soil was then saturated with distilled water, 10 ml of 10% calgon solution added and solution was allowed to stand for

10 minutes. 300 ml of tap water was added and shaken overnight on reciprocating shaker. The suspension was transferred into a graduated cylinder, a hydrometer inserted, water added to 1130 ml and hydrometer removed. The cylinder was covered with a tight-fitting rubber bung and the suspension mixed by inverting the cylinder carefully ten times. The time was noted and 2-3 drops of amyl alcohol were added and hydrometer placed into the column after 20 seconds. After 40 seconds, hydrometer reading was made and temperature of the suspension measured. Mixing of the soil suspension was repeated 120 times and cylinder allowed to stand undisturbed for 2 hours. The hydrometer and temperature readings were then made again. The percentage sand, silt and clay were calculated and soils assigned to textural classes based on particle size distribution using the soil textural triangle.

CHAPTER FOUR

RESULTS

4.0 Diversity and abundance of land snails in the study area

A total of 1,748 specimens belonging to twenty eight species/morphospecies were recorded during the study (Table 1). Two of the 28 species could not be identified and thus were assigned to Morphospecies 1 and 2. The species belonged to eight families in which the family Streptaxidae was the most abundant and had the highest species richness representing eight species, followed by Subulinidae with six species (Table 1). The families Maizaniidae, Pomatiasidae and Endodontidae had one species each.

A Chi-square test was performed to check if abundance of snails was uniformly distributed across families (Table 1). Results revealed significant difference in the abundance of land snails in the families (χ^2, 7 = 1126.03, $P < 0.05$) with families such as Streptaxidae having disproportionately higher species richness and abundance.

Table 1: A list of the 28 species/morphospecies and their respective families.

Family	**Species**	**Abundance**
Streptaxidae	*Gonaxis quadrilateralis* (Preston, 1910)	214
	Gulella vicina vicina (E.A. Sm., 1899)	125
	Gonaxis kibweziensis (E.A. Sm., 1894)	59
	Gonaxis gibbonsi (Taylor, 1877)	28
	Gonaxis enneoides (von Mts., 1878)	21
	Gonaxis sp.	5

	Gulella radius (Preston, 1910)	3
	Morphospecies 1	2
	Edentulina ovoidea (Bruguiere, 1789) (incl. affinis C.R. Bttgr., 1913)	6
	Total	**463**
Urocyclidae	*Trochonanina mozambicensis mozambicensis* (Pfr., 1855)	197
	Thapsia curvatula von Mts., 1897	138
	Trochonanina shimbiensis (Preston, 1910)	45
	Trochozonites sp.	3
	Total	**383**
Subulinidae	*Pseudoglessula.boivini* (Morelet) var.	212
	Opeas lamoense (Melv. & Ponson., 1892)	122
	Curvella calorhaphe Preston, 1910	34
	Pseudopeas sp.	22
	Pseudoglessula ingloria Connolly, 1923	21
	Morphospecies 2	1
	Total	**412**
Achatinidae	*Achatina fulica* rodatzi 1852 Dunker (incl. f. hamillei Petit, 1859)	176
	Achatina albopicta E.A. Sm., 1878	113
	Total	**289**
Enidae	*Rhachidina braunsi* (von Mts., 1869) (bloyeti Bgt., 1889; dubiosa Sturany, 1898)	65
	Edouardia alycaeoides Vercourt, 1957	25

	Rhachidina chiradzuluensis (E.A. Sm., 1899) (vicinus Preston, 1910)	4
	Rhachidina picturata (Morelet, 1889) (trichroa von Mts., 1891)	2
	Total	**96**
Maizaniidae	*Maizania hildebrandtii hildebrandtii* (von Mts., 1878)	54
	Total	**54**
Pomatiasidae	*Tropidophora letourneuxii* (Bgt., 1887) (cambieri Bgt., 1889)	15
	Total	**15**
Endodontidae	*Trachycystis ariel* var.	36
	Total	**36**

Figure 7 shows the relative abundance of the snail species found in the study area with the most abundant species being *Gonaxis quadrilateralis* belonging to family Streptaxidae and representing 12% of the total number of specimens found in the study area (Figure 7 & Appendix 2). This was closely followed by *Pseudoglessula boivini*. Among the least abundant species were *Rhachidina picturata* and Morphospecies 2. See Appendix 2 for full names of snail species represented by the numbers below.

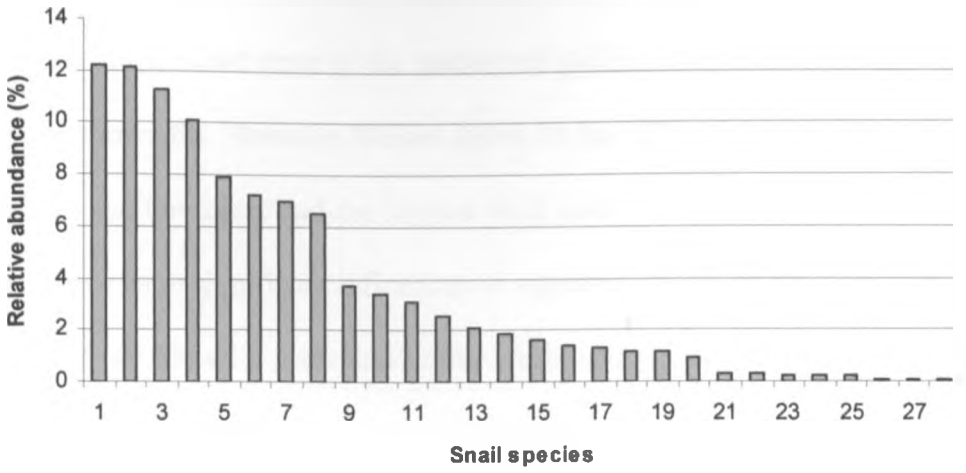


Figure 7: Relative abundance of the 28 species found in the study area

4.1 The diversity and abundance of land snails in the various habitat types

To determine species diversity (richness and abundance), Shannon-Weiner diversity index was employed (Table 3). This is a simple measure of the character of the community and is calculated as:

$$H' = -\Sigma P_i \log P_i$$

One way ANOVA was used to test for the differences in the abundance of the land snails among the different vegetation types. ANOVA was also used on the diversity indices to examine differences in land snail diversity between habitats and to further identify habitats supporting comparable and different levels of snail diversity.

Results of the ANOVA showed a significant difference in the abundance of land snails in the vegetation types ($F_{(4,407)} = 56.039$, $P < 0.05$). It was found that abundance of land snails in the plantation forest and the scrub were significantly different from those in the

other vegetation types (indigenous forest, grassland/scrub, and grassland). Table 2 shows the mean and standard error of the number of snail specimens in the vegetation types. Table 3 shows the Shannon Weiner index in the different vegetation types. From the observations, the forest had the highest land snail diversity while the grasslands had the least. There were significant influences of vegetation types on land snail diversity ($F_{(4,407)} = 74.31$, $P < 0.05$) with grassland/scrub, scrub, and plantation forest being different from the forest and grassland.

Table 2: Mean ± S.E of snail specimens in the different vegetation types

Vegetation types	Mean ± S.E of snail specimens	Sample size
Forest	7.12 ± 4.21	120
Grass/scrub	3.92 ± 3.42	72
Scrub	4.11 ± 2.33	72
Plantation	4.15 ± 2.84	72
Grassland	0.19 ± 0.55	72

Table 3: Diversity indices for snails in the different vegetation types

Vegetation types	Shannon index	Mean ± S.E	Sample size
Forest	0.984	0.98 ± 0.42	120
Grass/scrub	0.397	0.40 ± 0.47	72
Scrub	0.615	0.62 ± 0.42	72
Plantation	0.460	0.46 ± 0.41	72
Grassland	0.009	0.01 ± 0.08	72

Table 4 shows the species composition and abundance of land snails in the different habitat types. Species richness was highest in the indigenous forest with a total of 24 snail species followed by scrub (14 species). The plantation forest had 12 species, grassland/scrub with 10 snail species and the least was grassland having only 5 snail species. This was not very different for abundance where forests contributed the highest with 49.4% of the total number of snail specimens; the only difference being that snails were more abundant in the pine plantations (17.1%) than the scrub (16.8%). They were closely followed by grassland/scrub (15.9%) and finally the grasslands (0.8%).

Table 4: Number of specimens recorded from the different habitat types

Species	**Indigenous forest**	**Grassland/ Scrub**	**Scrub**	**Plantation forest**	**Grassland**
Gonaxis quadrilateralis	115	48	50	1	0
Gonaxis kibweziensis	34	15	0	10	0
Gonaxis enneoides	21	0	0	0	0
Achatina albopicta	87	0	10	16	0
Achatina fulica	88	0	18	70	0
Thapsia curvatula	114	0	0	23	1
Trochonanina mozambicensis	2	115	68	11	1
Trochonanina shimbiensis	38	6	0	0	1
Pseudoglessula boivini	135	14	25	38	0
Pseudoglessula ingloria	16	0	5	0	0
Pseudopeas sp	0	7	1	14	0
Rhachidina braunsi	27	26	12	0	0
Rhachidina chiradzuluensis	4	0	0	0	0
Rhachidina picturata	2	0	0	0	0
Edouardia alycaeoides	25	0	0	0	0
Edentulina ovoidea	6	0	0	0	0
Trochozonites sp.	2	0	1	0	0

Opeas lamoense	18	18	31	49	6
Maizania hildebrandtii	32	0	22	0	0
Gulella vicina	0	26	46	48	5
Gulella radius	0	3	0	0	0
Trachycystis ariel	36	0	0	0	0
Tropidophora letourneuxii	0	0	1	14	0
Morphospecies 1	2	0	0	0	0
Morphospecies 2	1	0	0	0	0
Curvella calorhaphe	34	0	0	0	0
Gonaxis sp.	5	0	0	0	0
Gonaxis gibbonsi	19	0	4	5	0
Number of species	**24**	**10**	**14**	**12**	**5**

A Chi-square test was performed to determine if species richness was uniformly distributed across vegetation types (Table 4). Results revealed significant difference in richness of land snails in the habitats (χ^2, 4 = 15.08, P < 0.05).

4.1.2 Association between snail metrics and vegetation types

This was determined by use of generalized linear models with quasipoisson as the link function because data were over dispersed. Vegetation, as a variable, significantly influences the abundance of snails ($F_{(4,403)}$ = 82.108, P <0.05) and richness ($F_{(4,403)}$ = 107.19, P <0.05). It explains 47% of abundance and 54% of richness; this therefore implies that vegetation had significant influences on snail richness. Figure 8 shows the association between the snail metrics and vegetation types and indicates that indigenous forest was both abundant and rich in snails. The short horizontal lines in the diagrams

represent the mean number of snail specimens while the dotted lines surrounding the line represent the standard error.

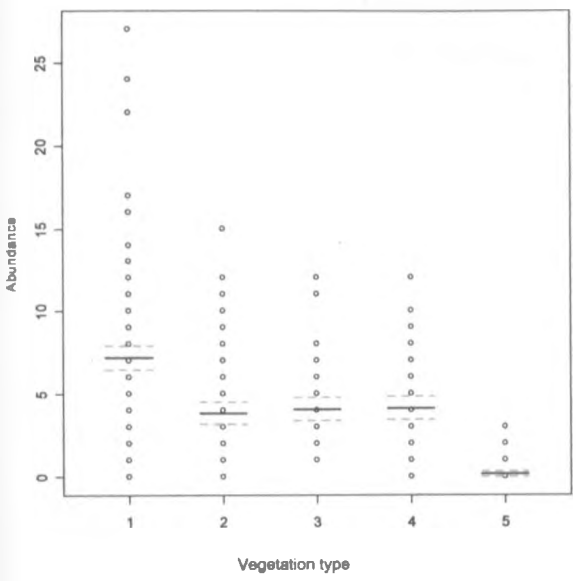


Figure 8a

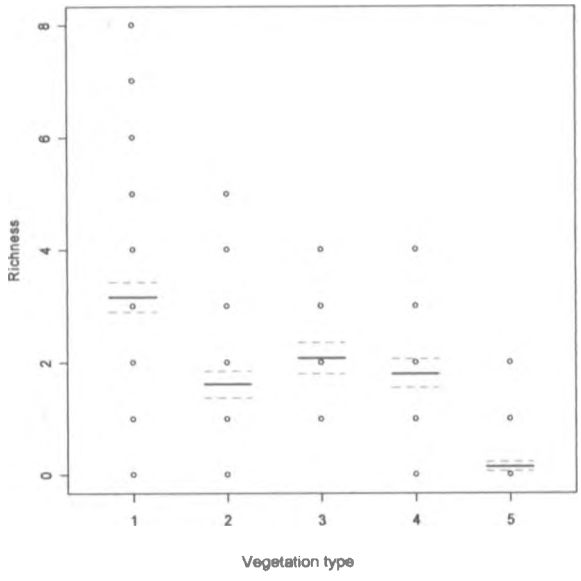


Figure 8b

1-Indigenous forest; 2-Grassland/scrub; 3-Scrub; 4-Plantation forest; 5-Grassland

Figure 8 a & b: Association between snail abundance and richness with the vegetation types respectively

4.2 The environmental variables that influence the distribution of land snails

4.2.1 Soil results

Results of soil parameters analyzed from soil samples collected from the field are shown in Table 5. The pH in water varied from 5.44 to 6.30. These values were rated as moderate to slightly acid where the optimum range was 5.6 – 7.5; the lowest value was in

grassland/scrub implying that the area was slightly acidic while that of the indigenous forest and plantation forest ranged from 5.44-5.79 and 5.97-6.06 respectively implying that both were moderately acidic. Electrical conductivity (EC) identifies soils that are saline and the test is normally done after pH tests. Since salinity is associated with alkalinity, and since all the soil samples were acidic, electro conductivity tests would be negligible. The results show EC levels of less than 1.2 dS/m, indicating that the soils were non-saline, with the indigenous recording higher electroconductivity levels than other habitats.

Grassland/ scrub was deficient in calcium (Ca), while the rest were sufficient in Ca levels with values ranging between 2.0 – 10.0 (Table 5). Indigenous forest (site 1) had the highest Ca levels followed by the plantation forest (site 2). Soil texture varied from clay (C), sandy clay (SC) to sandy clay loam (SCL) with some sites in the indigenous forest, plantation forest having higher percentage clay (C) which has been found to be adequate for water holding capacity.

4.2.2 Correlation results

The observed snail diversity patterns were correlated with the environmental variables using Pearson correlation analysis to identify factors that are closely associated with snails' distribution. Land snail metrics were correlated on environmental variables as shown in Table 6. Litter mass and relative humidity were found to have positive and significant association with snail abundance and richness. For instance, increasing litter mass increases the abundance of snails. Whereas canopy cover had a positive influence

on snail richness, it had a negative influence on snail abundance. Temperature had a negative influence on both snail abundance and richness, with the highest significance on snail richness.

Table 5: Summary of soil parameters analyzed

Habitat	Soil pH	EC 25^0C dS/m	cmol/Kg Ca	Soil Texture			
				% Sand	% Silt	% Clay	Texture class
Indigenous forest site 3	5.75	0.02	4.50	63	5	32	SCL
Indigenous forest site 2	5.44	0.50	5.65	59	5	36	SC
Indigenous forest site 1	5.79	0.30	9.50	37	6	57	C
Plantation forest site 2	5.97	0.20	8.00	39	5	56	C
Plantation forest site 1	6.06	0.02	4.95	69	7	24	SCL
Scrub site 2	6.01	0.20	4.60	59	5	36	SC
Scrub site 1	6.13	0.02	2.55	66	6	29	SCL
Grassland/ scrub site 2	6.30	0.20	1.95	65	5	30	SCL

EC- Electroconductivity; dS/m- deciSiemens per metre; cmol- centimole per kilogram

C- Clay; SC- Sandy clay; and SCL- Sandy clay loam

Table 6: Correlation coefficients of land snail metrics on environmental variables

	Temperature	Rel. Humidity	% Canopy	% Litter
Rel. Humidity	-.612* n = 40			
% Canopy	.107* n = 40	.371** n = 40		
% Litter	-.005 n = 40	.547** n = 40	.656** n = 40	
Abundance	-.097 n = 40	.112* n = 40	-.010 n = 40	.183** n = 40
Richness	-0167** n = 40	.198** n = 40	.136** n = 40	.293** n = 40

* Correlation is significant at the 0.05 level (1-tailed)

In Table 7, the snail parameters were correlated with soil parameters. Soil calcium and conductivity had a positive relationship with snail richness but this was not significant while, on the contrary, the two had a negative correlation with abundance. Soil pH had no influence on both snail abundance and richness but had a significant negative relationship with soil conductivity and calcium. It was also observed that none of the above soil parameters had a significant influence on snail richness and abundance.

Table 7: Correlation coefficients of land snail metrics and soil parameters

	Snail richness	Snail abundance	Soil pH	Soil conductivity
Soil pH	-0.178 n = 40	0.023 n = 40		
Soil conductivity	0.045 n = 40	-0.066 n = 40	-0.620** n = 40	
Soil calcium	0.004 n = 40	-0.006 n = 40	-0.507** n = 40	0.399** n = 40

** Correlation is significant at the 0.01 level (1-tailed)

Generalised linear models were fitted to compare species abundance with soil texture as shown in Figure 9. The short horizontal lines in the diagrams represent the mean number of snail specimens while the dotted lines surrounding the line represent the standard deviation from the mean.The results indicate that soil texture does not explain abundance of snails significantly ($F_{(3,364)} = 1.5776$, $P > 0.05$).

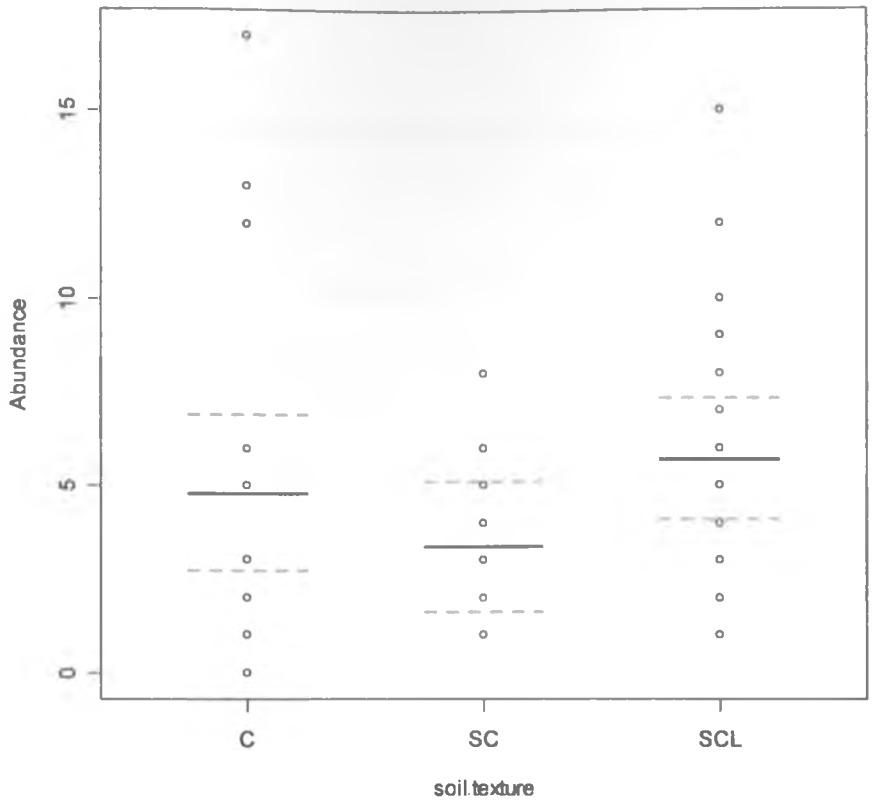


Figure 9: Generalized model for association between soil texture and abundance

4.2.3. Relationship between snail parameters and vegetation

Shannon-Weiner diversity index of plants was highest in Makadara forest (Table 8) which is a habitat with the highest diversity levels of land snails probably due to the highest densities of large trees like *Erythrophylum sp* and *Combretum schumannii*. Snail species *Achatina albopicta* was observed to occur mostly on these trees while most species found in the litter were members of the family Subulinidae. Makadara forest could be a region that has experienced more stability and complexity of structure unlike

the grasslands in the airstrip area where the index was lowest both in snails and vegetation.

Table 8: Shannon-Weiner diversity index for snails and plants

Habitat	Site	Snails	Plants
Forest	Makadara	2.302	2.329
Forest	Mwele	2.249	1.847
Forest	Main gate	1.651	2.226
Grassland	Marere	1.767	1.511
Scrub	Kivumoni	1.828	1.934
Plantation	Kivumoni	1.689	1.509
Grassland/scrub	Airstrip	1.743	0.451

There was positive correlation between land snail metrics and vegetation metrics as shown in Table 9. Significant correlation was between snail richness and vegetation richness though there was positive but no significance association between snails' Shannon-Weiner index and plant index. This means that one expects high diversity of snails in places with high diversities of plants though in this case, it was not significant. Abundance of land snails positively correlated with that of vegetation. This suggests that an increase in abundance of vegetation is associated with an increase in the abundance of snails.

Table 9: Correlation between land snails and vegetation

	Vegetation richness	Vegetation abundance	Vegetation Shannon
Snail richness	.851* n = 40	.739 n = 40	.621 n = 40
Snail abundance	.711 n = 40	.360 n = 40	.385 n = 40
Snail Shannon	.724 n = 40	.773* n = 40	.609 n = 40

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

4.3 Influence of season on diversity and abundance of land snails

Coastal forests are in an area of predictable seasonal changes. During the study period, Shimba Hills forest received minimum rainfall between January and March; substantial amount of rainfall between November and December while highest rainfall was observed between April and June. There were changes in richness and abundance of land snails in the different seasons. The highest number of species was recorded in the wet season while the least was in the dry/wet season. For abundance, the highest was in the wet season as expected with 703 individuals and the least in the dry season with 466. Shannon-Weiner diversity index for snails was highest in the wet season having 0.677 followed by the dry season, 0.497, and the least in the dry/wet season with 0.478. This observation implies that even though the dry/wet season was more abundant in snails than the dry season, it had the least species richness. ANOVA for the Shannon-Weiner Index showed a difference in the diversity of land snails in the three seasons ($F_{(2,407)}$

=6.324, P <0.05) with the wet season having a significantly influence on land snail diversity than the other seasons.

Figure 10 shows snail abundance in the different vegetation types within the three seasons. As said before, the trend was an increase in total number of individuals from the dry season to the wet season. For each vegetation type considered separately, the number of individuals also showed a similar pattern to that of the totals. For example, in the indigenous forest, there was an increase in the number of individuals from the dry season through the dry/wet season to the wet season with 229, 272 and 352, respectively. Results of ANOVA showed a significant difference in the abundance of land snails in the seasons ($F_{(2,407)} = 6.6095$, $P < 0.05$). The wet season had the highest mean density and variation while the dry season was found to be significantly different from the other two seasons.

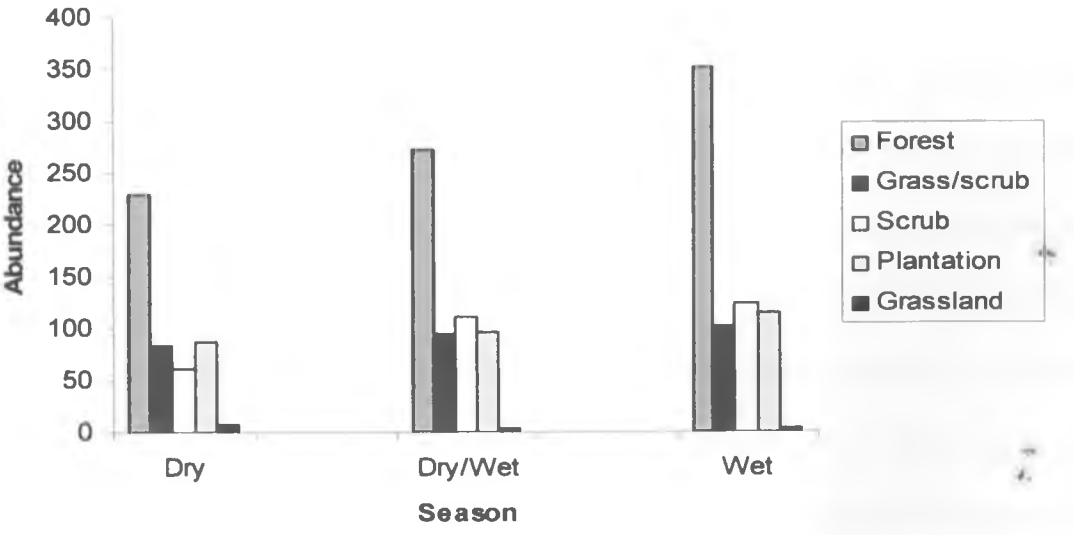


Figure 10: Snail abundance in the different vegetation types within the different seasons

CHAPTER FIVE

DISCUSSION

5.0 Diversity and abundance of land snails in the study area

A total of 28 species were recorded during the study (Table 1 & Figure 7), confirming that Shimba Hills forest is the richest coastal forest in terrestrial snails in Kenya. A large proportion of species recorded were members of the family Streptaxidae. Out of the 28 species reported in this study, 9 species belonged to this family and had the highest number of specimens with 463 compared to other families that included Urocyclidae, Subulinidae and Endodontidae which had 383, 412 and 36 individuals respectively (Table 1). This observation has been made in other molluscan studies in East Africa (Emberton *et al.*, 1997, Tattersfield *et al.*, 1998) where Streptaxidae represents 23% of the whole East African terrestrial mollusc fauna. This confirms that the high streptaxid diversity is common in most Eastern Arc and coastal forests.

Although there was no differentiation between arboreal snails and litter dwellers during field work, there was, from personal observation, considerable ecological specialization. As indicated in Table 8, Makadara forest had the highest tree and snail densities with snail species such as *Achatina albopicta* being found to occur on trees that included *Combretum schumannii*. The trees are favoured by the adult snail probably because their foliage is food to the snails or they are refuge sites for the snails while their young ones occured in soil litter. This probably means that the snails lay their eggs on the ground, the eggs hatch and live on the ground until they mature. On the other hand, most snail species were litter dwelling and included some species of the family Subulinidae which were

mostly seen alive in soil litter. This observation agrees with those of Schilthuizens & Rutjes (2001) where they observed ecological specialization of snails. Therefore more studies are required to have an understanding of the ecological niches and the degree of overlap of snails.

5.1 The diversity and abundance of land snails in the various habitat types

The reserve has a heterogeneous mosaic of vegetation types, including indigenous forest, scrub, grassland, grassland/scrub and pine plantations (Figure 3). The indigenous forest occupies the largest area of the reserve followed by scrub. Grassland and grassland/scrub occupy a considerable size while plantations take up the least area. These vegetation types have different characteristics that make them distinct in terms of rainfall infiltration, moisture content, complexity of the vegetation structure, amount of litter, canopy cover and soil fertility among other parameters.

From the findings, indigenous forests support higher snail diversity levels and abundance than the other habitats (Tables 2, 3 & 4). This high diversity level in the indigenous forests agrees with work done by Emberton *et al.* (1997) and Tattersfield (1996). This could be explained by the forests having the highest rainfall and complex vegetation structure with respect to their heterogeneity in plant species. This results in more microhabitats, a wide range of microclimate and an expanded resource spectrum. Most land snails occur in forest litter which provides aestivation, egg-laying and refuge sites for them. Other factors that account for the observed distribution patterns of snails in indigenous forests are that forests are characterized by stability of community through

time, environmental heterogeneity and less severe induced perturbations (Lange & Mwinzi, 2003). These factors permit continued survival of a relatively more complex malacofauna community. Forests have higher humidity levels relative to other vegetation types thus an important recipe for the survival of the malacofauna. Grasslands had the least abundance and diversity which might be explained by high soil compaction limiting the survival of land snails.

The presence or absence of snail species is influenced by the interaction of several environmental factors that include leaf moisture, calcium levels, canopy cover and degree of compaction among other factors (Tattersfield *et al.*, 2001; Lange & Mwinzi, 2003). The ecotones and grasslands had the least number of specimens and diversity and this could be because these areas have little or no ground litter therefore offering few microhabitats. They had dry, compacted soils and were more open compared to other habitats that had canopy. The calcium levels in the soils were higher in the indigenous forests than in the other vegetation types.

For the pine plantation forest, there was a relatively high level of snail abundance compared to the grasslands and ecotones. Despite plantations having less complex vegetation structure (they are mostly made up of monospecies), an interesting phenomenon existed, where regeneration of indigenous trees was observed, bringing about more vegetation (through increase in canopy cover), and plant diversity as opposed to domination of single species therefore enabling high abundance and richness of snails.

A number of species that were found in the indigenous forest included *Gonaxis enneoides, Curvella calorhaphe, Rhachidina chiradzuluensis, Rhachidina picturata, Edouardia alycaeoides, Edentulina ovoidea* while others were not found in forest ecosystems notably *Gulella vicina* and *Gulella radius* (Table 4). The species that have particular affinities with the forest have the potential of being used as indicator species of indigenous forests. Past studies have shown that snails are good indicators of the health of the environment (Seddon *et al.*, 1996). There was a high concentration of *Pseudoglessula spp.* in the *Pinus* plantation and this is probably due to the species having a high tolerance to acid soil conditions associated with the plantations.

5.2 The environmental variables that influence the distribution of land snails

From the findings, it was observed that environmental variables influence snail ecology among them temperature, relative humidity, soil and vegetation; these parameters determine snail distributions and abundance. A combination of high canopy cover, litter mass, tree density among other parameters were found to influence the humidity of the habitat thereby providing suitable conditions for these sensitive range-restricted snails. Studies have shown that some mollusc species may prefer habitats with calcium but little moisture and in turn develop ways of coping with moisture stress (Warui, 1998). Therefore molluscs can be found in a range of moisture levels with some species inhabiting dry environments by confining themselves to more sheltered, moist habitats beneath logs and in deep leaf litter (Evans, 1972) while others are known to obtain sufficient water from food (Blinn, 1963). Some species exist in a semidormant state for a

period of a few years (Baker, 1958) while others develop structural modification of the shell (Jacot, 1935).

The results show that relative humidity influences both abundance and richness of snails (Table 6). This is expected since the snails are sensitive to changes in moisture levels and any reduction in the atmosphere may cause dehydration and subsequent mortality. These findings agree with studies done by Čejka *et al.* (2008) who found that humidity influenced the variation of snail species composition among different Danubian floodplain forest types. Snails have however developed strategies to cope with moisture stress. They are found in a range of different moisture levels while others secrete a mucus epiphragm over the shell apertures and remain in a dormant stage to prevent desiccation (Machin, 1975).

Litter has a significant influence on snail abundance too where the more abundant the litter, the more food for the litter-dwelling snails, the more refuge sites to avoid predation and desiccation, and the more substrate for egg laying. In contrast, temperature and canopy cover have negative influence on snail abundance. These results deviated from the expected results in which a high canopy cover and the more stratified the canopy is, the higher the snail abundance. For grasslands, the abundance is expected to be less since short vegetation permits high soil temperatures which, in turn, increase soil moisture loss thus having a negative effect on many snails.

Canopy cover and litter mass have a significant influence on snail richness, while temperature significantly and negatively affects land snail richness (Table 6). This shows the importance of some of these variables in determining the distribution and diversity of land snails. Temperature significantly influences land snail ecology so much so that any increase affects their survival (Martin, 2000). These terrestrial snails face limitations of temperature regulation and water balance when their moist bodies are exposed during activity hence they have developed behavioural adaptation of burrowing and the subsequent inactivity (aestivation with lowered metabolism) as a strategy to overcome them (Burky *et al.*, 1972).

Soil is important since most important nutrients are obtained from it and determines the kind of plants that the ecosystem will support, hence the type of animals. Soil Calcium plays a major role in shell formation; therefore areas with little calcium are expected to have low abundance of land snails. The pH of the soil solution controls the form and solubility of many plant nutrients (Okalebo, 2002) while electroconductivity measurement identifies soils which are potentially saline. Areas with moderate acidity levels were found to be in the indigenous forest which also happened to have the highest land snail diversities. Except for a few sites in the indigenous forest, soil Calcium levels were low; this justifies previous studies in the area that have shown that the soils are deficient in Calcium (Makin, 1968).

The results of this study demonstrate that richness was associated with soil calcium but had a negative association with pH (Table 7). This observation is in agreement with

studies done by Hotopp (2002) Valovirta (1968); and Wareborn (1992). This observation is attributed to a number of factors. Most species of land snails use calcium to make their shells and for reproduction. They obtain calcium from leaf litter, live vegetation, soil and rocks. It is expected that an increase in calcium increases the resource spectrum of the molluscs. However, despite snail richness was influenced by soil Calcium, snail abundance was not. This contradicts research done by other scientists (Burch, 1955, Wareborn, 1969 & Warui, 1998) who found a high association between soil Calcium and snail richness. Therefore, studies have shown that if soil Calcium does not influence the abundance of snails, then other factors such as moisture may have been more important (Warui, 1998).

When correlating pH and calcium, both were found to be negatively and significantly associated with each other. This is unexpected and is in disagreement with other research studies done by, Hotopp (2002), Lange (1999) and Tattersfield *et al.* (2001) among others. Under normal circumstance, it is expected that an increase in the pH of the soil will result in an increase in calcium. Studies by Graveland *et al.* (1994) have shown that acid precipitation is believed to be the most probable cause of soil calcium declines in some parts of the world in Europe. In his study, a decrease in calcium subsequently results in decrease in snail biodiversity and in effect, ecosystem ripple effects may occur whereby bird predators of land snails may have reduced hatchings linked to land snail reductions in areas of Calcium-poor soils. The relative importance of snails as calcium source for these species needs more studies. Wareborn (1969) observed that amount of calcium contributed to high abundance of snails where pH was low. Lange (1999) reports

that leaf litter of *Pinus* sp. plantations causes low soil pH that is associated with decrease in available calcium.

There was positive association between soil conductivity and calcium implying that high conductivity is related to high calcium levels. High conductivity refers to a situation where soils are highly alkaline and in effect, high salt levels. Therefore a positive association between the two parameters is expected.

5.3 Influence of season on diversity and abundance of land snails

The seasons were clearly different from each other. There were some species that were found to occur or were more abundant in the wet season than in other seasons (Figure 10). They included *Trachycystis ariel* and Achatina *albopicta*. This could be as a result of increase in soil moisture which could have resulted in the species resurfacing from their hibernating sites. Thus in seasonally changing environment, different species may be suited to conditions at different times of the year (Chira, 1993). More species might exist in that kind of environment than in a completely constant one (Begon & Townsend, 1986). The data may have also been affected by differences in detectability of the various species in different seasons. Detectability may have been an issue in the wet season where there was more vegetation cover and in the dry season where snails may have hibernated from high temperatures.

The wet season was observed to be a time where the species richness and abundance reach higher levels. This observation is in agreement with other previous findings in Erko

et al. (2006); Cridland (1975) who found an increasing population of fresh water snails during and shortly after the rains. This is explained by a number of factors but the most important one being rainfall. Rainfall cycles are important in affecting life cycles of snails and influencing seasonal fluctuations in their density (Webbe, 1982). They have an influence on land snails both directly and indirectly: directly through availability of moisture which is essential for snail survival and indirectly through availability of vegetation that are habitats for snails, and provide calcium which is essential to the snails.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Despite a high diversity of snails in Shimba Hills National Reserve than in any other coastal forest in Kenya, having been compared with studies done in Arabuko Sokoke forest where 25 species were recorded (Lange & Mwinzi, 2003), there was a lower snail diversity compared to other Kenyan and Eastern African forests. For instance, a study in Kakamega forest by Lange (1999) yielded 47 species; in Mount Kenya forest (Tattersfield *et al.*, 2001) where 53, 49, 46 and 34 were observed on different sites of the forest. Other studies have found 29 species in Amboni caves in Tanzania, 46 species in Usambara Mountains, 45 species from the metamorphic limestone forest at Kimboza, Uluguru Mountains, 34 from the submontane forest at Uluguru North Forest Reserve and 36 from Mazumbai Forest in the West Usambara (Ngereza, 2005).

This low diversity could possibly be as a result of majority of them being large and conspicuous suggesting that many small ones could have been overlooked. It is therefore possible that not all species present in the plots were detected during the study. Another explanation could be that the snails that were sighted opportunistically outside the sampling plots were not included in sampling and therefore not recorded. Sampling methodology and intensity could be another reason. More specimens were collected from the indigenous forests since they form the largest area of the Reserve.

Land snails are as important as any other living organism and they have been observed to have a number of ecological roles. The results of this study clearly demonstrate that

majority of snail species were found in the indigenous forest thus emphasizing the role these forests play in determining land snail distribution and diversities. Despite the importance of the forest, a number of park activities threaten the survival of land snails and include:

- Road construction. During field work, there was extensive road construction at the park. This involved pruning tree branches, clearing grass and bushes and in many situations many snails' shells were sighted broken at the road side. These roads produce marked edge effects that may have negative consequences on the function and diversity of the forest ecosystem.

- The use of fire regimes to promote growth of fresh grass for the herbivores greatly affects snails since most of them are litter-dwelling and are also range-restricted suggesting that when caught up in the process, they will not survive.

Therefore, there is need for a change in priority so that not only are the megafauna considered for protection, but the macroinvertebrates too. The land snails depend on the existence of the forest and its proper management, therefore, proper management plan should be drawn to protect the forest and at the same time encourage the local community to be participants in forest management since even though forest under protection with an electric fence, there are a number of cases where illegal logging has occurred.

There is also a need to encourage research on the less-studied species that have not received enough attention. This therefore requires broad conservation strategies to

understand the impacts of various management practices on the survival of land snails. Any form of disturbance to the land snails will affect the ecosystem status since they have been reported to be indicator species of ecosystem health.

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APPENDICES

Appendix 1: Checklist of plant species identified in Shimba Hills National Reserve.

Compositae
Aspilia mossambicensis (Oliv.)Wild

Sapindaceae
Lepisanthes senegalensis (Poir.) Leenh.
Allophylus rubifolius (Hochst.) Engl.
Blighia unijugata Baker
Pancovia golugensis (Hiern) Exell &Mendoca

Rubiaceae
Leptactina platyphylla (Hiern)Wernh
Agathisathemum bojeri Klotzch Var.glabr
Canthium sp
Crossopteryx febrifuga (G. Don) Benth
Coffea pseudozanguebarica Bridson
Pachystigma loranthifolium (K.Schum.)
Polysphaeria parvifolia Hiern
Psychotria alsophila K. Schum.
Psychotria sp.
Psychotria tanganyicensis Verdc.
Pavetta stenosepala K. Schum. ssp. stenosepala
Pavetta sp.
Pentas bussei K. Krause
Tricalysia ovalifolia Hiern Var ovalifolia
Tricalysia sp.
Rytiginia sp.

Celastraceae
Maytenus heterophylla
Salacia madagascariensis (Lam.) DC

Sapotaceae
Pouteria alnifolia (Baker) Roberty var. alnifolia
Mimusops sp.

Icacinaceae
Apodytes dimidiata Arn.Var. acutifolia

Acqustaceae
Asystasia gangentica (L.) T. Anderson

Caesalpiniaceae
Bauhinia tomentosa L.
Hymenaea verrucosa Gaertn.

Euphorbiaceae
Alchornea laxiflora (Benth.) Pax & K. Hoffm.
Bridelia cathartica G. Bertol
Bridelia sp.
Phyllanthus sp.
Croton sylvaticus Hochst.
Suregada zanzibariensis Baill

Sterculiaceae
Cola minor Brenan

Combretaceae
Combretum schumannii Engl.
Quisqualis littorea (Engl.) Exell

Connaraceae
Connarus longistipitatus Gilg

Ebenaceae
Diospyros greenwayi F. White

Leguminosae
Erythrophylum suaveolens (Guill.& Perr.) Brenan

Melastomataceae
Memecylon verrucosum Brenan

Mimosaceae
Newtonia paucijuga (Harms) Brenan

Olacaceae
Olax obtusifolia De Wild
Strombosia scheffleri Engl.

Flacourtiaceae
Rawsonia lucida Harv. & Sond.

Anacardiaceae
Sorindeia madagascariensis DC.

Thymeleaceae
Synaptolepis kirkii Oliv.

Apocynaceae
Tabernaemontana elegans Stapf

Dilleniaceae
Tetracera litoralis Gilg

Meliaceae
Trichilia emetica Vahl
Trichilia sp.

Rutaceae
Vepris sp.

Verbenaceae
Vitex zanzibariensis Vatke

Pinaceae
Pinus caribea Morelet

Annonaceae
Xylopia parviflora (A. Rich) Benth
Isolona cauliflora Verdc.
Uvaria acuminata Oliv.

Graminae
Pennisetum polystachion L.Schult

Diheteropogon amplectens Clayton

Rhizophoraceae
Cassipourea euryoides Alston

Zingiberaceae
Costus afer Ker Gawl

Leguminosae
Crotolaria sp.

Bignoniaceae
Fernandoa magnifica Seem

Guttiferae
Garcinia livingstonei T. Anderson

Acanthaceae
Justicia sp

Appendix 2: A list of snail species in the study area

1 - *Gonaxis quadrilateralis*
2 - *Pseudoglessula boivini*
3 - *Trochonanina mozambicensis*
4 - *Achatina fulica*
5 - *Thapsia curratula*
6 - *Gulella vicina*
7 - *Opeas lamoense*
8 - *Achatina albopicta*
9 - *Rhachidina brownsii*
10 - *Gonaxis kibweziensis*
11 - *Maizania hildebrandtii*
12 - *Trochonanina shimbiense*
13 - *Trachycystis ariel*
14 - *Curvella calorphaphe*
15 - *Gonaxis gibbonsi*
16 - *Edouardia alycanides*
17 - *Pseudopeas sp*
18 - *Gonaxis enneoides*
19 - *Pseudoglessula inglosia*
20 - *Tropidophora letourneuxii*
21 - *Edentulina affinis*
22 - *Gonaxis sp*
23 - *Rhachidina chiradzuluensis*
24 - *Trochozonite sp*

25 - *Gulella radius*
26 - *Morphospecies 1*
27 - *Rhachidina picturata*
28 - *Morphospecies 2*

Appendix 3: Association between vegetation and snail parameters

Correlations

		Richness veg	Abundance veg	Shannon veg	Snails Richness	Snails Abundance	Snails Shannon
Richness veg	Pearson Correlation	1.000	.286	.794*	851*	.711	.724
	Sig. (2-tailed)	.	.533	.033	.015	.073	066
	N	7	7	7	7	7	7
Abundance veg	Pearson Correlation	.286	1.000	.077	.739	.360	.773*
	Sig. (2-tailed)	.533	.	.869	058	.428	.041
	N	7	7	7	7	7	7
Shannon veg	Pearson Correlation	.794*	.077	1.000	.621	.385	.609
	Sig. (2-tailed)	.033	.869	.	.136	.394	.147
	N	7	7	7	7	7	7
Snails Richness	Pearson Correlation	.851*	.739	.621	1.000	.679	.952*
	Sig. (2-tailed)	.015	.058	.136	.	.094	.001
	N	7	7	7	7	7	7
Snails Abundance	Pearson Correlation	.711	.360	.385	.679	1.000	.633
	Sig. (2-tailed)	.073	.428	.394	.094	.	.127
	N	7	7	7	7	7	7
Snails Shannon	Pearson Correlation	.724	.773*	.609	.952**	.633	1.000
	Sig. (2-tailed)	.066	.041	.147	.001	.127	.
	N	7	7	7	7	7	7

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

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