DIVERSITY, ABUNDANCE, DISTRIBUTION, AND CONCORDANCE OF ANURAN SPECIES IN KINGWAL SWAMP AND NORTH NANDI FOREST RESERVE, KENYA

BY

JOSEPH MUSONDA KABANZE

A THESIS SUBMITTED TO THE SCHOOL OF ENVIRONMENTAL SCIENCES AND NATURAL RESOURCE MANAGEMENT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN WILDLIFE MANAGEMENT, UNIVERSITY OF ELDORET, KENYA

JANUARY, 2024

DECLARATION

Declaration by the candidate

This research project report is my original work and has not been presented to any other University or College for the award of a degree. No part should be reproduced without the express or written authority of the author and/ or Department of Wildlife Management, or University of Eldoret.

Joseph Musonda Kabanze

________________________________ ________________________

SNAT/WLM/M/008/21 **Date**

Declaration by the Supervisors

This thesis has been submitted for examination with our approval as the University Supervisors.

___________________________________ ____________________

Dr. Johnstone Kimanzi **Date**

University of Eldoret, Kenya


.... Date: 16th February 2024

Dr. Patrick Malonza

National Museums of Kenya, Kenya

DEDICATION

I dedicate this work to my mother Mrs. Kamwi Rosemary, my brothers (Mutulaa and Nyambe) and my sister (Vanessa). But the work is dedicated mostly to my lovely daughter Rachel for keeping me going through, and my late father Victor Kabanze, may his soul keep resting in peace.

ABSTRACT

Anuran species are one of the good environmental indicators of habitat quality in ecosystems due to their amphibious life modes and sensitivity to environmental change caused by a rapid expansion of anthropogenic activities and climate change. Therefore, understanding their biodiversity and distribution patterns is crucial for the development and implementation of conservation strategies. The study aimed at assessing and comparing diversity, abundance, distribution, and concordance of anurans between a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal swamp), which are among the underexplored areas in Kenya. Data was gathered both in the dry and wet season between October 2022 and June 2023 by employing standard sampling techniques for anurans (Visual encounter and pitfall traps with a drift fence). Three habitat types- farmland, intermediate, and forest were surveyed. A total of 1649 individuals from 21 different anuran species, belonging to nine genera and nine families were recorded. Ptychadenidae was the most abundant family from the recorded anurans, while Dicroglossidae, Arthroleptidae, Pyxicephalidae, and Ranidae were the least. Most species were found in the forest habitat (Protected), and least in the farmland (non-protected). The wet season had high species abundance, diversity, and richness compared to the dry season in all the habitats. Forest habitat had the highest values for Shannon diversity ($H' = 2.432$), and least in farmland habitat ($H' = 2.048$), even though species were evenly distributed. There was a significant difference ($p < 0.05$) in diversity between the habitats in the wet season, but no significant difference during dry season ($p > 0.05$) except for forest and farmland ($p = 0.014$). There was a significant difference in species abundance between seasons ($p = 0.001$), and between habitats ($p = 0.001$) in all seasons except for farmland and intermediate ($p = 0.826$), as well as farmland and forest ($p = 0.051$) during the wet season. Habitat type ($p = 0.223$) and season ($p = 0.157$) had no influence on anuran species richness. Most of the species encountered favored insects and frogs in their diet, occupied terrestrial and aquatic microhabitats, specifically stagnant water, and were predominately ground/wet terrestrial dwellers. The modest sampling indicates that Kingwal Swamp and North Nandi Forest Reserve are rich and support anuran species. However, the differences in anuran biodiversity and distribution in the 3-habitats demonstrate that conservation efforts continue to be a priority. Therefore, Nature-based organizations are recommended to engage communities along Kingwal Swamp and transform the wetland into a conserved protected area for the survival of anurans.

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LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance

ASA – Amphibian Survival Alliance

BCSI – Bray-Curtis Similarity Index

DWMT – Department of Wildlife Management and Tourism Studies

FAO - Food and Agricultural Organization

GPS – Global Positioning System

IBM SPSS – Statistical Package for Social Sciences

IUCN – International Union for Conservation of Nature

JCSI – Jaccard Coefficient Similarity Index

KEFRI – Kenya Forestry Research Institute

KFS – Kenya Forest Service

KFW – Kreditanstalt für Wiederaufbau

KWS – Kenya Wildlife Services

LC – Least Concern

MS-Excel – Microsoft Excel

NACOSTI – National Commission for Science, Technology, and Innovation

NNF – Namibia Nature Foundation

PAST – Paleontological Statistical Software

PA – Protected Area

SCSI – Sorenson Coefficient Similarity Index

VU - Vulnerable

ACKNOWLEDGEMENTS

The successful completion of this thesis involved valuable contributions from many people and since it will not be possible to enumerate all of them, I will just name but a few. First and foremost, I would like to thank the Almighty God for giving me the health and a sound mind throughout my academic sessions that enabled me to attain my long awaited goals and objectives in academic circles.

A special vote of thanks goes to my two outstanding supervisors, Dr. Johnstone Kimanzi and Dr. Patrick Malonza, for their guidance and support from the initiation of the research topic to the final thesis write-up. Thank you for believing in me and granting me a milestone opportunity to work under your strict supervision, support, thoughtful comments and guidance in shaping the write-up of this thesis.

I would like also to thank the KFW/DWMT for funding this study, spearheaded by the Namibian Nature Foundation (NNF) in the Zambezi Region. Thank you, Dr. Lucas Rutina from the University of Namibia, Department of Wildlife Management and Tourism Studies, for encouragement in pursuing this study.

Lastly, am grateful to my research assistant who aided in data collection (Charles), classmates Vivian, Betty, and Samson, as well as the entire department fraternity including the library staff who issued me with books, articles and journals.

To my family and friends, thank you for your consistent support during my studies far from home.

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Amphibians are a class of ectothermic vertebrate animals and consist of orders; Anura (frogs and toads), Urodela (Salamanders and newts), and order Gymnophiona or Apoda (which are the legless caecilians). These small quadrupedal vertebrates have two occipital condyles on top of their skull and their moist smooth skins without scales make them so vulnerable to any natural catastrophe (Frost, 2023). The fact that they are the first vertebrates to shift their capabilities of survival from water to land enlightens that they can survive both on land and in water, and they are believed to be the ones that gave rise to all other terrestrial vertebrates like birds, mammals, and of course reptiles (Malonza *et al*., 2018).

All members of this class are ectotherms meaning that they generate heat from the outside environment to perform their life processes. The presence or absence of amphibians, specifically frogs may be a guide or an excellent indication of the healthiness of an environment or ecosystem. In addition, semi-permeable skin makes them vulnerable and highly sensitive to environmental conditions and anthropogenic activities (pollution). Thus, in this case, healthy water bodies (wetlands) possess healthy populations of amphibian species (Malonza et al., 2011).

In terms of amphibian activity patterns, they are dependent, regulated, or even affected by environmental factors such as climatic change and seasonality, as well as the type of habitat with activities occurring in it whether disturbed or non-disturbed (Howell, 2004). Some pieces of literature stated that breeding activities in amphibians are initiated by rainfall (Duelllman & Treub, 1986), resulting in more active individuals during the wet periods and warm seasons (Howell, 2004), going into hibernation (in temperate areas) or aestivation (in the tropics) when conditions are not favorable for them (Hill, 2005).

Studies elaborate that the diversity of prey species and variation in the type and quality of habitats influences the distribution and feeding preferences of some anurans (Sousa & Ávila, 2015). Anuran species are distributed in different microhabitats found in major terrestrial and aquatic habitat types, these differences in distributions of anurans are influenced by many different factors such as the availability of breeding sites in favorable microhabitats (Oda *et al.*, 2016).

For instance, the environmental structure has been observed that it is linked to the distribution patterns of anuran species in the same habitat (Menin *et al.*, 2005; Ficetola *et al.*, 2014). In addition, diet and prey availability has been observed in feeding ecology studies to influence the diversity and distribution patterns of coexisting anuran species, for example, the leaf litter frogs (Fernanda et al., 2022; Allmo, 1991; Donnelly, 1991; Junca & Eterovic, 2007). Moreover, variations on how species utilize microhabitats and the foraging strategies they impose are also associated with their distribution patterns (Franca *et al*., 2004).

Freshwater and terrestrial ecosystems house abundant and diverse anuran species, as a result, they are components of these two ecosystems. In this case, they link the former and latter ecosystems by playing critical roles as part of the trophic level in food webs (Pradhan *et al*., 2014). Dedication efforts to understanding these ecological roles of anurans within ecosystems have been boosted by the current and rapid global reduction in their (anurans) species richness (Connely *et al.*, 2011). These rapid declines are consequences of human population expansions, who are heavily involved in the fragmentation and degradation of anuran microhabitats or forests for agricultural activities and urban developments, and this is particularly evident in East Africa's Coastal regions, specifically the Eastern Arc Mountains and Coastal Forests of Kenya and Tanzania (Barratt *et al.*, 2014).

Given that the proposed study area is in Kenya, it is important to know the most important conservation areas for amphibians, specifically Anurans (frogs and toads). The key amphibian and/or reptile important areas include the Arabuko-Sokoke Forest, Shimba Hills National Reserve and its environments, Tsavo ecosystem (Taita Hills, Kitobo forest, Taveta forest, and Kibwezi forest), Kakamega Forest, Mt Elgon National Park, Nandi Hills forests, Yala Swamp, Saiwa Swamp, Kingwal swamp, Cherangany Hills, Mt Kenya and Aberdare forests and National Park, Lower Tana River Forests, Mau Hills (Malonza *et al*., 2018). Despite being known to be an amphibian haven, little is known about the conservation status, distribution, and abundance of its anuran species.

1.2. Problem statement

For some decades, amphibians have been exhibiting decline and extirpation in their population worldwide (Stuart *et al*., 2004; Wake & Vredenburg, 2008). This results from interacting threats such as habitat degradation, chemical contaminations through indiscriminate usage of pesticides and fertilizers, alteration of habitats, climate change, and the spread of invasive species (Blaustein *et al*., 2011; Kiesecker *et al*., 2001).

Globally, understanding amphibian species diversity, abundance, status, and distribution is very crucial, especially in cases where the conservation of species and their habitats is to be realized. Yet, there is still little (underexplore) appropriate attention given to these species regarding the ecological roles they play in ecosystems (Valencia-Aguilar *et al.*, 2013). East Africa comprises of very complex terrestrial ecological habitats such as coastal forests, deserts, woodland, grasslands, and rainforest ecosystem, there is a need to look at some other habitats within the major ecosystems and the microhabitats mostly in wetland habitats. These diverse terrestrial habitats support the complex diversity of both floral and faunal species many of which are endemic. Studies on herpetofauna in East Africa focused mainly on coastal and terrestrial forested habitats (Kitobo and montane forests) with the inclusion of those that comprise hill ecosystems (Taita and Shimba hills). However, less (underexplore) is known specifically in wetlands and their microhabitats of protected and non-protected areas such as Kingwal swamp and North Nandi Forest Reserve).

With the exception of studies on comparing amphibian diversities in relation to elevation and habitat disturbance gradient differences (Malonza & Veith, 2012), zoogeographical affinities (Malonza *et al*, 2018), habitat edges affect in arid land forests (Malonza & Bwong, 2023; Malonza et al., 2011), Animal species diversity driven by habitat heterogeneity/diversity and the importance of keystone structures (Tews *et al.*, 2004). However, there is inadequate knowledge concerning diversity, abundance, distribution, concordance, conservation status and biology of different amphibian species in Kingwal Swamp and North Nandi Forest Reserve and their environments with regards to different land use and function of ecosystem, that's is between habitats in protected and agricultural areas.

This simply means that there have been some past herpetological studies done in North Nandi Forest Reserve and Kingwal Swamp, but the areas are still largely underexplored. Hence, less is known on the comparison of amphibian populations in different land uses within wetland habitats in protected and agricultural practiced areas. For this reason, this research sought to assess and compare the diversity, abundance, distribution, and concordance of anuran species between protected and non-protected areas, the case of Kingwal swamp and North Nandi Forest Reserve.

1.3. Justification and Significance of the study

Information on amphibian distribution is essential in understanding where species occur and to be able to determine sound management and conservation strategies for the species (Dodd, 2010). Since the focus of this study was mainly on investigating and comparing the diversity and distribution of frogs anurans both in protected and agricultural areas of Western Kenya (Kingwal swamp and North Nandi Forest Reserve) during dry and wet seasons, with the inclusion of their concordance response to environmental factors in the case of habitat and level of protection and their functional traits, results enlightens conservationist on the diversity, abundance, and distribution of frogs and toads in protected and agricultural areas by specifying which area inhabits more anurans and which season is mostly preferred by these organisms.

Furthermore, results give more emphasis on their functional roles (biological indicators) and traits which enables wildlife conservationists in determining functioning and nonfunctioning ecosystems, understanding whether anthropogenic activities has an influence on population sizes, so that they can design targeted and location-specific conservation interventions to ecologically and sustainably balance wetland and terrestrial ecosystems in both protected and non-protected area. Lastly, the result generates checklists for these areas which can be useful in the future for tourism and research purposes.

1.4. Research objectives

1.4.1. Main objective

To assess and compare diversity, abundance, distribution, and concordance of anuran species between a protected and a non-protected area (North Nandi Forest Reserve and Kingwal Swamp) respectively.

1.4.2. Specific objectives

i. To assess the diversity of anurans in a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal Swamp) between seasons.
ii. To determine the abundance of anurans in a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal Swamp) between seasons.
iii. To examine the distribution of anurans in a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal Swamp) between seasons.
iv. To compare the concordance of anurans in a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal Swamp).
v. To compile checklists of anurans for Kingwal swamp and Nandi North Forest Reserve.

1.5. Statistical hypotheses

i. $H_0: 1,$ Anuran species diversity is not a function of habitat quality or diversity and season.

ii. $H_0: 2,$ Anuran species abundance is not a function of habitat quality or diversity and season.

iii. $H_0: 3,$ Anuran species distribution is not a function of habitat quality or diversity and season.

iv. $H_0: 4,$ Anuran species concordance is not a function of habitat quality or diversity.

1.6. Research question

i. Which are the Anuran species found in Kingwal Swamp and North Nandi Forest Reserve?

1.7. Limitations of the study

Sometimes researchers tend to do whatever it takes to collect sufficient data in order to find solutions to their research questions, there are some drawbacks that limit the capacity to collect, analyze, and of course present their results. When it comes to sampling sites, accessibility to additional sampling sites in the study area was not guaranteed. Secondly, nocturnal sampling was always a challenge. Thirdly, North Nandi Forest Reserve and its environment is under the care of the Kenyan government (i.e. Kenya Wildlife Services, National Commission of Science, Technology, and Innovation, Kenya Forest Services) and the local communities, therefore there was a need to get permits in order to have access into the reserve, which required and followed time consuming procedures especially for international students. In addition, there was also a need to get permission from local communities to sample within their farms.

CHAPTER TWO

LITERATURE REVIEW

2.1. Overview and history of amphibians

Contextually, amphibian diversity and distribution is a key element to consider in science as it shows how vulnerable these species of concern are in ecosystems. However, their existence and origin worldwide have been given little attention (Hocking & Babbitt, 2014). Due to the fact that amphibians' origin dates back to 350 million years ago, they are considered to be the oldest tetrapod in the universe (Biodiversity Group Organization, 2022). Amphibians are found across the globe on every continent except Antarctica, reason being that the salamander-like creatures could be traced back to fishes that developed bones in their fins to adapt to navigation beyond water bodies and underwater obstacles according to evolution (Biodiversity Group Organization, 2022). Currently, three orders of class Amphibia exist and have been used to assess their survival and diversity in scientific valuation (Hocking & Babbitt, 2014). It is estimated that there are about 6,800 described amphibian species across all orders where 5,870 are frogs and toads (classified under order Anurans), 585 are salamanders and newts (classified under order Urodela), and 185 species of wormlike caecilians (classified under order Gymnophiona). Although some species are becoming extinct due to anthropogenic and natural disturbances (threats), class amphibians remain widely distributed across the globe based on the underpinning environments in ecosystems.

Amphibians’ uniqueness could further be explored when a focus is inclined towards the tropics between 23.4 latitudes on both sides of the equator, therefore, countries within this region have a high number of amphibian species in relation to those lying far from the equator. Ecologically, amphibians poses a two-fold feature due to their highly permeable skin (Biodiversity Group Organization, 2022), which enhances their ability to survive in various settings. However, the same feature makes them highly susceptible to environmental toxins and stressors. The nature of the permeable skin allow creatures under class Amphibia to live both in water and on land, which describes the Latin origin of the word amphibian denoting two lives (Hocking & Babbitt, 2014). The onset of the amphibian lifecycle is with the development of eggs that hatch into larvae (or tadpoles in the case of frogs), which later undergo a series of developments into adult forms, and once they are fully formed or developed, they can live independently of water for an extended period. Some can even spend a whole year underground without water i.e. the spadefoot species. Although that is the case, when it comes to breeding, water masses is a necessity (Biodiversity Group Organization, 2022). The various adaptations of individuals under class Amphibia have contributed to their survival regardless of their high level of vulnerability to environmental toxins, stressors, as well as predators (Hocking & Babbitt, 2014).

2.2. Importance of amphibians

Amphibians are considered one of the important group of animals that play numerous roles that directly and indirectly impact the ecosystem and human existence. Creatures under orders of class Amphibia assist in the maintenance of the desired ecosystem balance, resilience, and stability. The amphibians shape the food web and energy dynamics because of their biphasic life cycle, which is spent in aquatic, terrestrial, and wetland settings (Wells, 2007; Dodd, 2010). For example, when specific sources of food becomes scarce, ecosystems become imbalanced, but due to the availability of amphibians, they solve the above issue by having multiple habitats (both macro and micro habitats) and reproducing massively.

The fact that amphibian body temperature is not determined by metabolic activities but by their adaptation, they use a low amount of energy compared to other species of their size and classification, by so doing, they ecologically guarantee the required poikilothermic and efficient transformation of available energy to biomass in different ecosystems (Hocking & Babbitt, 2014) i.e. the food they consume or devour is converted into biomass using limited energy. In addition, the high levels of proteins in individuals under class Amphibia guarantee access to the high-energy predators. When they shift from land to aquatic settings, amphibians contribute to nutrient transfer across the two ecosystems (Earl *et al.*, 2011; Semlitsch *et al.*, 2014). Amphibians likewise play a significant role in terms of mineral dynamics across ecosystems. For example, phosphorus, omega-3, magnesium, nitrogen, carbon, calcium, and iron are abundantly available in amphibians meaning their biomass is crammed with rare nutrients and minerals.

Moreover, amphibians are linked to the burrowing benefits for soil quality and aeration. Since most species of amphibians have a burrowing lifestyle, they contribute to the aeration of the soil and in turn, optimize its quality. When they prey on invertebrates such as insects, they assist in controlling their population (Wells, 2007). Such a move results in balanced intra-species and interspecies competition in the ecosystem. Failure to control this essential balance could lead to an increase in predatory insects and other invertebrates, which in turn could change the ecosystem and lead to adverse implications (Lowe & Bolger, 2002; Wallace & Tronstad, 2019). By controlling the predatory invertebrates, amphibians reduce the rate of the use of pesticides and in turn, indirectly reduce the accumulation of toxins in the soil guaranteeing its quality in the long run (Relyea *et al*., 2005; Wallace & Tronstad, 2019).

At the same time, amphibians have a direct influence on human life based on the nature of their life-related behavior and development. In line with the five dimensions of evaluating the impact of diversity as defined in Groom *et al.* (2006), amphibians meet the depicted elements. First, amphibians assist humans directly by being biological control agents for pest control and the spread of diseases. Amphibians feed on pests and vectors that cause human diseases. Durant and Hopkins (2008) estimated that amphibians feed an average of 6 billion mosquitoes and their larvae in a month within a confine of one hectare. At the same time, insect-borne pathogens are significantly reduced because of the feeding patterns of amphibians in aquatic, wetlands, and terrestrial habitats. Amphibians are direct sources of food for humans both at subsistence and commercial levels. Selective butt spontaneous breeding patterns guarantee a high rate of population increase offering easy access to food to humans across the globe. Almost more than half a billion United States dollars are accumulated from the exportation of frog legs and this value has been increasing significantly (Groom *et al.,* 2006). Indonesia and Belgium have been on the top of the exporters with France and the United States leading in importation.

Besides, amphibians shape environments as indicators that in turn improve the health and quality of the ecosystem. Amphibians have been used over the years to provide insights regarding the environmental dimensions such as whether the habitat is thriving or undergoing degradation (Hocking & Babbitt, 2014). The permeability of the amphibian skin facilitates the intake of nutrients and toxins at the same time. This implies that as the population of amphibians' increases in a particular setting, there is a high probability of the habitat being healthy and of high quality. The converse of this is equally true and could be used to interpret environmental patterns (Quaranta *et al*., 2009). Furthermore, amphibians play a significant role in medicine and pharmaceutical advancements including the development of antibacterial, antifungal, antiviral, and anticancer compounds (Govender *et al*., 2012). The high degree of tissue regeneration in amphibians has been used to advance and foster optimized inflammation and tissue formation interventions (Godwin & Rosenthal, 2014). Additionally, amphibians also have several indirect values to humans. For example, improved ecotourism over the years focusing on amphibians has contributed to increased revenue among countries with diverse species (Melillo *et al.*, 2016).

2.3. Species diversity, abundance, and distribution of amphibians

Although the most known amphibians are Anurans compared to Gymnophiona and Caudata (Howell, 2004), species of this class ecologically only inhabit areas with fresh water and cannot be found in areas with marine or seawater, due to inability to tolerate harsh arid conditions (sea water) (Roth-Monzón, 2018) which may impact their survival due to having a permable skin (Channing & Howell, 2006). Since tropical areas are mostly encompassed with fresh water, this enlightens that there is a high diversity of amphibian species in such areas (Malonza & Bwong, 2023). Worldwide, the Amazon is believed to be the area with the highest diversity of amphibian species inhabiting about close to 800 species (IUCN, 2018), compared to East Africa reported having over 200 amphibian species (Howell, 2004; Channing and Howell, 2006). However, the global living amphibians are estimated to be 6,800 species variations that are classified as frogs and toads (Anura), salamanders (Caudata), and caecilians (Gymnophiona). The location and availability of a specific species depend on the ecosystem and habitat characteristics that are unique to that setting.

Salamanders and caecilians, which are considered to be equally diverse, have a limited number of species. For this reason, they are occasionally more restricted in distribution compared to the other species (Whittaker *et al.*, 2013). However, they are widely spread across the globe with more than 600 species of salamander and about 200 species of caecilians available worldwide as documented in the biodiversity database (Whittaker *et al.*, 2013). Studies have ascertained how most of the global amphibian diversity is available in the tropics. The distribution therefore points out that amphibians are highly distributed in Central and South America while the other region with significant populations of various species include sub-Saharan Africa, New Guinea, Sri Lanka, SE Asia, Madagascar, and Australia (Whittaker *et al.*, 2013).

The diversity and abundance of amphibians depend on many factors. Concerning elevation, amphibian species richness tends to decrease with an increasing elevation in the southern slopes of Chitwan, Nepal (Khatiwada & Haugaasen, 2015), this was due to warm effects and favorable climatic conditions such as higher or average annual temperatures, evapotranspiration, precipitation, and productivity. On the other hand, Malonza & Veith (2012), stated that the species richness of anurans increases with increased habitat disturbances from forests to streams but it tends to decrease with increasing elevation. However, the abundance of those amphibian species having a direct developing mode of reproduction and/or habitat specialists decreased with an increasing habitat modification in Taita Hills. Thus, not only elevation changes species composition and distribution worldwide but also human disturbances of habitats or anthropogenic activities (Malonza and Bwong, 2023).

Amphibian species diversity and abundance dominated by habitat generalists may be high in farmlands but lack forest or habitat specialist species. Within tropical regions, where remnants of forests exist within agricultural practiced landscapes it has been observed that they (forest patches) support the inhabitation of increasingly isolated individuals of forest-dependent amphibian species (Benedick, 2006) compared to areas where agricultural activities are occurring (Hillers *et al.*, 2009). Studies have ascertained how amphibians are classified as tetrapods, where they have aquatic larvae and terrestrial adults. However, this does not imply that alternative life histories are not available since evidence exists (Whittaker *et al*., 2013). For example, some of the amphibian clades are permanently aquatic while the others are entirely terrestrial and do not have aquatic larvae. Those without aquatic larvae lay eggs that are provisioned with a yolk that eventually develop spontaneously into miniatures of adults. Species assessment also shows that some of the amphibian clades give birth to metamorphosed young ones (Whittaker *et al*., 2013).

2.4. Factors influencing amphibian species diversity and distributions

Different factors influence the distribution and diversity of amphibians. An understanding of these factors paves the way for comprehensive conversation and protection of the numerous species of amphibians. When evaluating and assessing these factors, it is necessary to consider the ecosystem elements that favor and support the thriving of amphibians over an extended period bearing in mind the duality of their lifestyle as an adaptation.

In terms of water and habitat quality, amphibians are selective when it comes to aquatic habitats and this depends on the season and the activity they are undertaking. For example, Boreal toads are known to effectively breed in wetlands characterized by a high conductivity capacity because of the guaranteed resistance to potential infections (Klaver *et al.,* 2013). Wetlands with dissolved minerals, therefore provide a favorable setting for amphibians to breed. Warmer water temperatures abundant in chloride errand some amphibians (Brodman *et al*., 2003; Wallace & Tronstad, 2019). For this reason, interference with the wetland habitats could adversely alter the distribution and diversity of amphibians in that ecosystem.

In addition, vegetation and the topography of the land determine the occupancy of amphibians. Wetlands with greater forest cover have been associated with a higher population of amphibians compared to those with limited coverage. Valleys and depressions are characterized by low amphibian populations compared to relatively flat topography or mid-slope habitats (Malonza and Bwong, 2023). Canopy covers in forests located within wetlands have been linked to support mechanisms for enhanced breeding and survival of amphibians (Browne *et al.,* 2009; Wallace & Tronstad, 2019). Lower elevated settings that provide oxbows, hiding covers, pools, and ponds have been occupied by a high population of amphibians when compared to steep and exposed mountainous habitats (Gould *et al*., 2012).

In terms of wetland habitat, specific species of amphibians occupy a particular habitat and this influences diversity and distribution. The nature of the wetland determines the species that will be dominant in that setting. For example, the Columbia spotted frog and the boreal chorus frog occupy unique wetlands in line with their natural characteristics (Klaver *et al.,* 2013; Maurer *et al.,* 2014). The boreal chorus frogs avoid wetlands occupied by fish while the Columbia spotted frog dominate wetlands with high precipitation during the warning quarter of the year. The pattern in distribution and diversity is associated with the adaptation and lifestyle of the particular amphibian species (Maurer *et al.*, 2014). The tendency of avoiding predation and being guaranteed a permanent wetland determines the species that will dominate a specific wetland habitat.

Human activities also influences the distribution and diversity of amphibians, specifically focusing on climate change and human behavior. Different activities including industrialization and the clearing of wetlands and other aquatic settings to create settlements have adverse implications for the biodiversity of various species including amphibians (Mi *et al*., 2022). Climate change has affected the distribution of plants and animals and amphibians are no exception. The changes have shifted the distribution and diversity of amphibians, especially along the equatorial regions. The increased emission of toxins has become a threat to amphibians because of the high degree of their skin permeability (Mi *et al*., 2022).

Some studies elaborates that geology has limited influence on the distribution and diversity of amphibians. The reason for this is that its effect is minimal compared to the other factors. However, there is a need to understand how geology shapes amphibian habitats. The primary element is the nature of the bedrock in a particular wetland (Russell *et al*., 2004). The nature and characteristic of the bedrock determines the types of minerals released into the wetland. For example, boreal toads occupy wetlands with low levels of limestone-dolomite bedrock since this interferes with the quality of the habitat. At the same time, sandstone bedrocks contribute to increased dissolved calcium in aquatic habitats (Russell *et al*., 2004). Such settings favor boreal toads and other species that reproduce in water with high conductivity.

2.5. Concordance and feeding ecology of amphibians

The understanding of a species' ecosystem dynamics includes the feeding patterns and how this shapes their survival in a particular habitat. Amphibians have an invertebrate-based diet, which is characterized by unique foraging and limited dispersal tendencies (Almeida-Santos *et al.*, 2017). The feature has been used to analyze comparative feeding characteristics across species under the amphibians' umbrella (Herrel *et al*., 2019).

The sympatric species of amphibians feed on the same category of potential prey. On the other hand, anurans have similar diets, which explains why they could thrive in related habitats regardless of the species. When amphibians share the same ecological, behavioral, and morphological features, they equally have related refined resource-sharing characteristics. From the anatomical perspective, each species is adapted to specific feeding behaviors (Herrel *et al.*, 2019; Almeida-Santos *et al.*, 2017). However, popular feeding habits depict that amphibians prey on insects, earthworms, snails, spiders, and slugs. Some larger amphibians prey on bigger animals as seen with the ability of the ornate horned toad to eat sizable mice. Since the digestive system is short, acidic, and without a cecum, it is enzyme-based and integrates peristalsis as well as ciliary action. Suction feeding is dominant among the young amphibians but this changes as they grow and develop strong jaws and long tongues for advanced predation and protection (Herrel *et al.,* 2019; Almeida-Santos *et al.,* 2017).

Furthermore, it is necessary to point out how various factors could influence the diet of an amphibian. Genus-related differences shape how amphibians feed to survive. Each species is adapted to its nutritional needs and aligns with the size and the stage of growth (De-Oliveira & Haddad, 2015). Another key consideration is seasonality, which implies that the preying behavior of amphibians depends on the availability of a specific type of prey in their habitats. Each season is characterized by a specific group of prey in an amphibian-dominated habitat. Ontogeny has also been considered another key factor that influences the diet of amphibians.

The study by Luria-Manzano and Ramirez-Bautista (2019) showed that amphibians feed on a specific diet based on the stage of development. At a younger age, they depend on simple nutrition and advance as they grow to adulthood. The size of the amphibians also shapes the nutrition characteristics and feeding behavior as depicted in a study by Santos-Pereira *et al*. (2015). The findings have also been echoed by other scholars who proved how the size of amphibians determined the size of the prey they eat in a particular habitat (Almeida-Santos *et al*., 2017).

2.6. Threats to amphibian and population decline

Globally, herpetofauna (reptiles and amphibians) are believed to be among the most terrestrial vertebrates high in species richness, such that hundreds of new species are being discovered yearly (Pincheira-Donoso *et al*., 2013; Uetz & Hošek, 2015).

Amphibians and reptiles are essential components of both aquatic and terrestrial environments, in the sense that they act as ecosystem indicators and occupy a major role as secondary consumers, and play an important role as food for many tertiary and quaternary consumers in ecosystem food chains and food webs (Raxworthy, *et al*., 2008; Böhm, *et al*., 2013). In this case, these species are also classified as among the world's most threatened vertebrates (Stuart *et al*., 2004).

Habitat loss and degradation resulting from agricultural activities, pollution, and climate change, have indeed resulted in massive declines in herpetofauna species (Ribeiro et al., 2018; Thompson & Donnelly, 2018; Runting et al., 2017; Pounds et al., 2006). Not only in terrestrial habitats but also in rapid loss and degradation of tropical wetlands threatens the survival and maintenance of biodiversity, such that it has been implicated in the declines of species diversity and abundance (Nowakowski *et al*., 2018).

Moreover, in the last decades, it has been observed that amphibians as vertebrates experience the highest increase with the IUCN Red List Status (Stuart *et al.*, 2004), and currently, at least more than 25 to 30 % of all the amphibian species are categorized either being threatened or critically endangered species on the IUCN Red List (Leduc *et al.*, 2012; Musah *et al.*, 2019). Thus, this enlightens the need to conserve all species at both local and regional levels because they are habitat and microclimate specific to perform activities such as metabolism and reproduction, and their sensitivity to change in the environment (Meiri *et al.*, 2013). The critical side of this occurrence is that there is no direct solution to the problem, which implies that a comprehensive approach to the restoration of the amphibian population is required. Since this issue is a global problem, a multidimensional need assessment is needed to ensure that the underpinning problems and causes are tabled for analysis to inform the development and implementation of targeted interventions (Whittaker *et al.*, 2013). It is essential to understand the dynamic nature of the amphibians' lifestyle, distribution, and diversity, which in turn shapes the degree of vulnerability as well as the approach to conservation.

In addition, diseases, road kills, and illegal hunting as a source of food also tend to reduce amphibian populations. Many amphibian's declines have been considered an early warning to human welfare and other wildlife species. Measey *et al.,* (2009), Malonza *et al.,* (2010) stated that niche overlap competition between toads and frogs leads to the exclusion of one taxon from the ideal habitat hence affecting its population dynamics, such that toads end up feeding on frogs in some cases.

According to different studies, the causes of the declining amphibian population are diverse and fall under the direct and indirect categories. The declining amphibian population is caused by a reduction in the freshwater and wetlands resources across favorable terrestrial landscapes (Briggs *et al*., 2010; Crawford *et al*., 2010). The habitats offer a reliable environment for the breeding and growth of amphibians whereas encroachment of unfavorable resources poses a threat to various species (Whittaker *et al*., 2013). Climate change, the loss of biodiversity, and other changes in the environment have been associated with the witnessed habitat stressors that have led to the decline in the amphibian population. Infectious diseases and exposure to numerous environmental toxins and contaminations have adversely affected the already vulnerable species of amphibians (Whittaker *et al*., 2013; Briggs *et al.,* 2010).

The high skin permeability is susceptible to environmental contaminants and toxins. Furthermore, human activities have significantly contributed to the witnessed decline in amphibian diversity and distribution in terms of local, regional, and global scales. Activities such as the encroachment into wetlands, modification of habitats, clearing of favorable terrestrial settings, and escalated emission of greenhouse gases have cumulatively affected the survival and breeding patterns of amphibians (Whittaker *et al*., 2013; Crawford *et al.,* 2010). For this reason, it is necessary to consider a multidimensional approach to the conservation of amphibians in line with the identified and habitat-specific causes of population decline across various amphibian species.

2.7. Conservation of amphibians

The subject of the conservation of amphibians has become one of the critical global concerns because of the recently witnessed decline in population and the threat to a variety of amphibian species (Bland *et al.,* 2014). The reason for this is the role that amphibians play in ecosystems as well as the direct and indirect benefits to the human population (Meredith *et al*., 2016; Wallace & Tronstad, 2019).

Different interventions are being implemented across different habitats locally, regionally, and globally to conserve amphibians. Conservation measures begin with the designing of a network of sites in line with the presented distribution and diversity patterns (Bishop *et al.,* 2012; Fig & Wederkinch, 2016). This move is only achieved once there is a deeper understanding of the existing threats and environmental issues affecting amphibians. Effective conservation of amphibians also integrates the assessment of freshwater or wetland resources and how this relates to terrestrial landscapes (Meredith *et* *al.*, 2016). Professionals have raised concerns regarding how environmental dimensions such as climate change and biodiversity loss affect the distribution and population changes in various amphibian species.

Moreover, conservation measures seeking to restore the biodiversity and distribution of amphibians have included the need to optimize the prevention of infectious diseases and overharvesting of edible species (Bland *et al.*, 2014; Fig & Wederkinch, 2016). Environmental contamination has adversely affected the population of amphibians and in turn, escalated the infection risk factors. Captive programs as well as genome resource banking have proved to be effective in informing amphibian conservation interventions and measures (Meredith *et al.*, 2016). Reintroduction measures have also proved to be effective where the declining species have been replenished in specific habitats to improve reproduction to enhance distribution and diversity. When it comes to reintroduction, numerous factors associated with the ecosystem need to be guaranteed for this approach to guarantee sustainable outcomes (Bergeron *et al.*, 2010; Fig & Wederkinch, 2016). Encouraging the continuous assessment of the existing and emerging conservation intervention ensures that the exhibited trends have been accommodated to optimize the impact of the implemented measures. Nevertheless, there is a need for more advanced and targeted conservation strategies to ensure that the desired milestones in terms of population stability have been attained (Meredith *et al.*, 2016). The reason for this is that the existing threats are critical to the distribution and biodiversity of amphibians in the long run.

CHAPTER THREE

METHODOLOGY

3.1. Study area

The study focused on both protected and non-protected areas for comparison purposes: these includes Kingwal Swamp (non-protected) and North Nandi Forest Reserve (Protected area), both in Nandi County. The area around the Forest and the swamp is largely inhabited by Nandi (sub tribe of the large Kalenjin tribe).

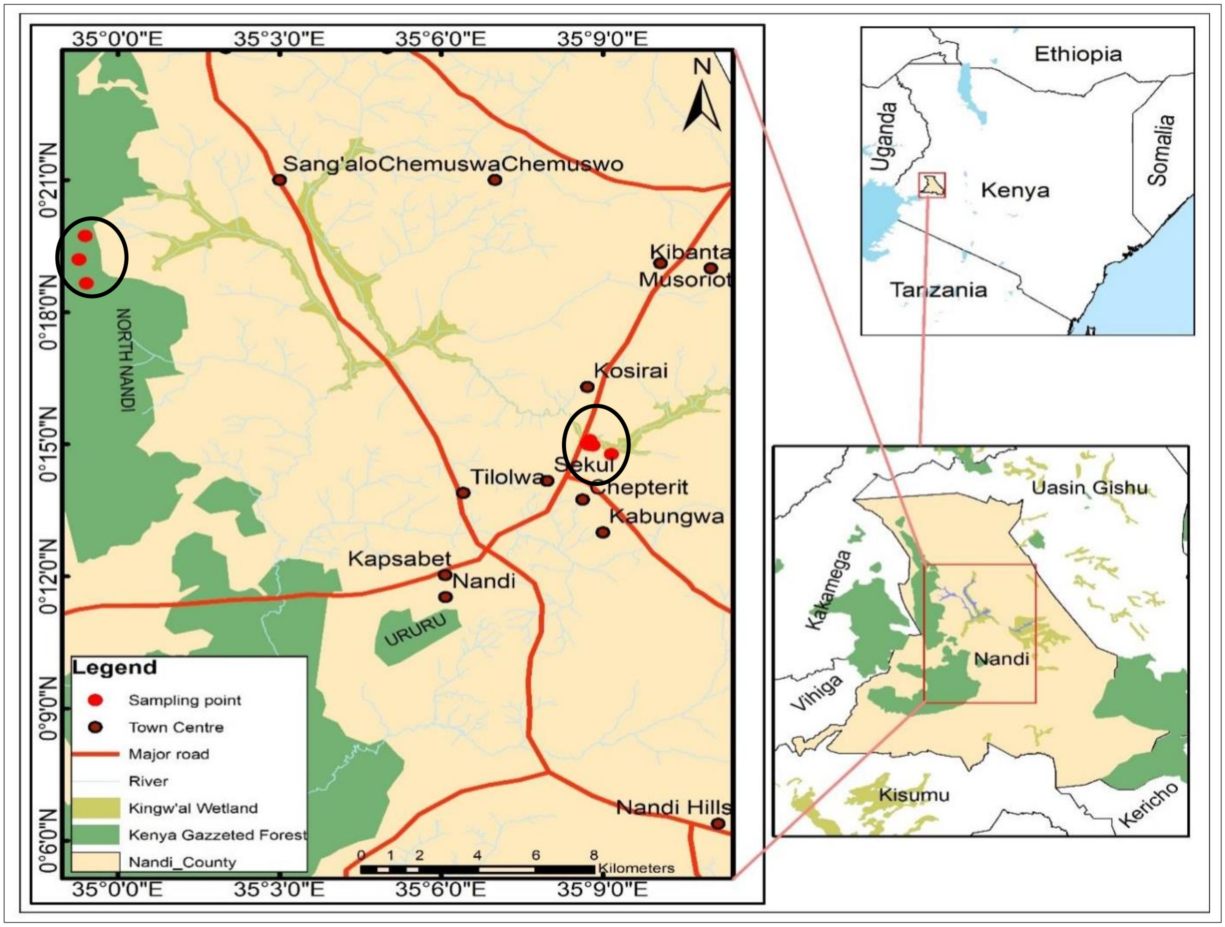

Figure 1: Map of study area showing Kingwal Swamp and North Nandi Forest Reserve in Nandi County (circled red dots as sampling points) (Author, 2023)

3.1.1. Kingwal Swamp

As stated earlier that the expansive non-protected swamp is located in Nandi County (within 0° and 0° 34” N and 34° 44” and 35° 25’”E), derives its main catchment from Uasin Gishu County near Kesses. It encompasses the Kesses River, streams, and interconnected swamps stretching from Lolminingai to Kombe locations (World Bank, 2014). It receives water mainly from the above mentioned water bodies flowing from the east and drains into the Kingwal (Kimondi) river while flowing to the west of the wetland. Positioned approximately 25 kilometers from Eldoret towards Kapsabet and about 400 kilometers from Nairobi, the vast swamp covers an area of 2.73 square kilometers.

The swamp experiences varying rainfall patterns vary, with the northern parts receiving an average annual ranging from 1200 mm to 1600 mm. The southern half is influenced by Lake Basin atmospheric conditions, resulting in higher rainfall levels of up to 2000 mm per annum (World Bank, 2014). Overall, the wetland and its surrounding receive rainfall between 1200-2000 mm per year. Although rainfall occurs throughout the year, there is a dry spell typically experienced from the end of December to mid-March (World Bank, 2014). The reliable rainfall in Nandi County provides ample opportunities for diverse crops, including tree crops, horticultural crops, and pyrethrum, cereals, and fruit trees.

The wetland ‘s temperature vary in terms of seasons, it range from 15°C to 20°C during the dry season which occurs from October to March and it peaks up to 24°C during the wet season which is April to September.

In terms of fauna and flora species within the wetland, various vegetation types thrive, including forests, grasslands, shrubs, Reeds, Papyrus *(Cyperus papyrus)*, and Water lilies. Grass species like *Andropogon gayanus, Heteropogon contortus, Panicum maximum,* and *Sporobolus pyramidalis* dominate the area. However, around 40% of the wetland has been converted into *Eucalyptus*, *Azadirachta indica* (neem), and tea plantations, while certain sections have been designated as forest reserves (Achieng *et al.*, 2014;Sitienei *et al.*, 2012). On the other hand, it is home for the endangered Sitatunga antelope (*Tragelaphus spekei*). In addition, it is a habitat for different species of mammals, birds, and fish. That is, mongoose, foxes, cranes, snakes, and frogs among others (World Bank, 2014).

Human activities in the wetland primarily consist of extensive crop farming of maize, vegetable cultivation, tea plantation, livestock keeping, agro-forest (Eucalyptus cultivation), and brick-making among other (World Bank, 2014). Sitatunga antelopes have been introduced to Kingwal wetlands since 1995, enhancing the potential for eco-tourism in the county (World Bank, 2014). However, emerging environmental issues, including wetland degradation, unsustainable conservation and management, and climate change, pose significant challenges to the wetland's sustainability (Ambasa, 2005).

3.1.2. North Nandi Forest Reserve

This strip of high canopy forest (between 00°12.38' to 00°25.10'N and 34°57.58' to 35°01.05'E) located North of Kapsabet town, lies on the edge of Nandi escarpment, above and east of Kakamega Forest. It is one of the several forest blocks in Nandi Forest Ecosystems, situated in Kabiyet and Central Nandi sub-counties, covering a gazetted forest area of 10,500 hectares (KEFRI, 2015), of which 8000 ha is indigenous closed canopy forest while the remaining portion consists of shrubs, grassland, cultivation, plantations, and tea zone (410 ha) among others.

It stretches over 30 kilometers from north to south and has a width of 3-5 kilometers for most of its length. The forest was gazetted in 1936 as a Trust Forest and later became the North Nandi Nature Reserve in 1968, with a total area of 3,434 hectares. Some areas have been excised since then, including parts of the nature reserve. It drains water mainly eastwards into the Kimondi and Kingwal River systems, which flow through the Southern part of Nandi Forest and Westwards into Lake Victoria and Yala River. This forest is believed to be a transitional between the montane forests of the central Kenya highlands and the West and Central Africa. Although it is higher in altitudes compared to forests like Kakamega, it is floristically less diverse

The forest experiences a tropical monsoon climate, therefore it receives an average annual rainfall ranging from 1600 to 2000 mm with peaks in April/May and August/September (Melly *et al*., 2020), making it a 'moist' forest according to the guidelines of the Food and Agricultural Organization (FAO) of the United Nations (Agwanda *et al*., 2009). Overall, the region experiences rainfall throughout the year with infrequent dry seasons. North Nandi Forest has an annual mean temperature ranging between 17 °C and 20 °C, with the mean minimum and maximum of 11 °C and 25 °C, respectively.

North Nandi Forest Reserve is rich in biodiversity, with over 628 plant species representing 118 families and 392 genera. There are 61 species of ferns and fern allies, as well as 567 species of seed plants, accounting for nearly 10% of Kenya's total plant species. The majority of plants in the forest are herbs, followed by shrubs (Melly *et al*., 2020). The forest is also home to a variety of bird species, amphibians, and primates among others. Over 600 birds have been ringed, and 117 bird species have been recorded in the forest (Schifter *et al.,* 1998; Kapkiai, 2006).

Human activities surrounding the forest primarily consists of cultivation, tea zone plantation, and livestock farming. Although there are challenges to the forest such as encroachment, population pressure resulting in unsustainable removal of forest products (firewood, illegal timber extraction, honey and medicinal plants), poor livestock husbandry practices (forest grazing of livestock), and forest fires (charcoal burning), conversion of the forest to plantations has fortunately not taken place due to the implementation of conservation interventions to protect biodiversity (KEFRI, 2015).

3.2. Sampling design and layout

Field surveys were carried out during both the dry and wet seasons from October 2022 to June 2023 progressively. The study area was stratified (based on intensity of agricultural activities, distance of homesteads from the habitats, biodiversity, human activities, and other drivers of change) into three habitats: 3.2.1. Farmland/agricultural habitat, 3.2.2. Intermediate habitat, and 3.2.3. Forest habitat. Of those three habitats, 3.2.1 and 3.2.2 were from Kingwal swamp while habitat 3.2.3 was from North Nandi Forest Reserve (Figure 1). The three habitats were later stratified into Nine sampling points/transects, meaning three uniform (to facilitate random sampling) transects/sampling points per habitat were randomly selected for data collection. In each sampling point, a line transect (200 m by 10 m) was designed starting at any random point (Rödel & Ernst, 2004).

Therefore, nine transects in the study area, i.e., three transects from each study habitat (Farmland, Intermediate, and Forest).

The sample size was determined based on the sampling days per habitat. For example, a visit to a single site both morning and afternoon in a single habitat was regarded as a single sample, a visit in a single day to two sites in the same habitat was regarded as two samples for that habitat in a day, and a visit to three sites within the same habitat in a single day was regarded as three samples in a single day for that particular habitat.

3.2.1 Farmland habitat type

This was known as an agricultural land, described as a portion of land where crops are grown and livestock's are reared. In this study, the habitat was classified based on the intensity of agricultural activities, the distance of homesteads from the swamp, proportion crop land, and other drivers of change. It was classified as an area where there is high intensity of agricultural production on a small piece of land but with high production resulting from the use of agrochemicals such as fertilizers and pesticides which wreak havoc on ecosystems, polluting water and killing off important native species (although increased productivity or yield). In addition, the working personnel is high. Human activities in the sites of this habitat consisted of maize farming, tea/coffee plantations, nursery for plants, orchards, fish pond, as well as horticulture gardens on a small piece of land.

The homesteads were constructed approximately less than a 100 m from the swamp, thus they drain water for crops (horticulture/nursery) irrigation. Biodiversity along the swamp is limited meaning only few bird species and natural species were observed. For example

Cyprus is harvested for provisional services and most of the area which was occupied by grass, trees, or herbaceous plants was cleared for plant production along the swamp. Highly vegetated stagnant water bodies (pond and pools) with shallow water exist in addition to the swamp.

Figure 2: Farmland habitat; stagnant pool of water, an orchard and fish pond, and a nursery few meters from the swamp (Author, 2023).

3.2.2 Intermediate land habitat type

Regardless of it being an agricultural land, this habitat had two most common features of farming which are riparian buffer zones and habitat islets. The former are areas along the margins of waterways (the swamp in this case) which are not used for grazing, and they take many natural forms of plants. They often involve having up to 10 m of native plants along the swamp providing habitat for terrestrial species, reducing soil erosion, shading the waterways, and improving the water quality for aquatic species. The latter refers to patches of native habitat in a sea of pasture that improve surrounding soil quality by depositing leaf litter, and provide shade for livestock created by riparian buffer zones. In addition, this habitat was classified as an area where agricultural activities are practiced on a low intensity, in the sense that it was a mixture of natural plants (sedge/Cyprus) along the swamp with a huge portion of open (mosaic landscape with high biodiversity) semi-natural graze land (traditionally managed pastures and their associated biodiversity) associated with native species of grass (some areas enclosed in barbed wires).

Homesteads are approximately 1000m away from the swamp. Although crop production is not practiced that much, there are other water bodies such as ditches designed from the swamp into near eucalyptus plantations (agroforest) which are grown for timber production. Apart from eucalyptus plantations, some sites consisted of semi-natural forests and graze-land along the swamp, thus locals valued the option to keep small stocks of sheep or beef cows, therefore farming largely relies on the natural fertility of the land and the natural behaviors of the animals. Road networks in this habitat were not easily accessible compared to those of farmland although the variation in land cover types along the roads was similar. In terms of bird and plant diversity, wetland/forest-associated species (cranes) were many compared to farmland habitats where many bird species which are associated with agricultural lands were absent in spite of the presence of agricultural fields. All in one, semi-natural habitats, which were highly appreciated for both their biological and cultural values denoted this habitat type. Thus, it was more of a mixture of natural and agricultural habitats.

Figure 3: Intermediate habitat; a riparian buffer zone, habitat islet, and semi-natural grazing land (Author, 2023).

3.2.3 Forest habitat

Ecologically defined as a subset or component of a terrestrial ecosystem in which living things such as plants (trees), insects, amphibians, other animals, and people interact. Can be considered the smaller classification of the ecosystem as a whole, which is the biggest functional unit comprising all the geographical features and living organisms on Earth. As stated earlier, this type of habitat comprised of different microhabitats mainly suitable as in addition to the montane forest itself i.e. native grass, shrubs, high closed canopy trees, herbaceous plants, water bodies (swamp, river, rock swamp) among others. Rich in biodiversity, with over 628 plant species of which 61 species are native ferns and fern allies, as well as 567 species of seed plants, accounting for nearly 10% of Kenya's total plant species (KEFRI, 2015). The majority of plants in the forest are herbs, followed by shrubs. The forest is also home to a variety of bird species (600 birds), amphibians, and primates among others, this is attributed to the fact that it's under KFS and KWS conservation innervations and implementation guidelines (KEFRI, 2015).

Human settlements are located some few kilometers away from the sampling points, however there are some few (low intensity) anthropogenic disturbances surrounding the habitat primarily cultivation, tea zone plantation, and livestock farming (poor livestock husbandry practices), forest encroachment (removal of forest products i.e. firewood, illegal timber extraction, honey and medicinal plants), and forest fires (charcoal burning), but conversion of the forest to plantations has fortunately not taken place.

Figure 4: Forest habitats; the understory and high canopy cover, wetlands inside as breeding sites, and the evergreen herbaceous plants (Author, 2023).

3.3. Data collection

Visual encounter and pitfall traps with X-drift fence sampling methods were used to collect data on anuran species diversity and distribution in each study habitat (Rödel & Ernst, 2004; Veith *et al.*, 2004; Malonza *et al*., 2011), from October to December 2022 and from March to June 2023. Regarding the visual encounter method, each transect was searched for four to six hours a day, six days per week both in wet and dry seasons. Two people walked along transects twice a day at a constant speed from 06:00 to 09:00 am (diurnal) and from 5:00 to 8:00 pm (nocturnal) to maximize species numbers and abundance (Heyer *et al*., 1994). As stated earlier regarding sample size in the sampling design and layout, during dry season, we sampled the farmland and the intermediate habitat each for a period of 28 days (3 samples from 3 sites per day and per habitat), which resulted to 84 samples in farmland habitat and 84 samples in the intermediate habitat. On the other hand, the forest habitat was sampled for a period of 5 days due to some limitations regarding permits to collect data in protected areas and was only obtained when wet season was approaching. The 5 sampling days resulted in 15 samples (3 samples per day and per habitat) in the forest habitat during dry season i.e. 84 samples in the farmland, 84 samples in the intermediate, and 15 samples in the forest habitat. In the wet season, a total of 20 sampling days was conducted in each habitat, therefore, this resulted to 60 samples in the farmland, 60 samples in the intermediate, and 60 samples in the forest habitat. Thus, all together resulted to 363 samples with 183 samples (84 samples from farmland, 84 from intermediate, and 15 samples from forest) during the dry season and 180 samples (60 samples from each habitat) during the wet season.

At least two pitfall traps with X-drift fence comprising of 10L plastic buckets flushed to the ground, with every trap array comprising of five buckets in total for sufficient capture, 5 M long segments, with 30 cm high drift fence, stapled vertically onto wooden stakes or pegs were set along each transect to capture or detect some species which may not be easily found physically or through other methods, such that they are small, primarily nocturnal, or crawling herpetofauna, for example Puddle frogs, *Xenopus* species, and Leaf-litter frogs. They were checked twice a day, early in the morning and late afternoons before sunset (Malonza et al., 2018; Malonza and Bwong, 2023).

In order to justify that sampling effort and sample size was adequate, species accumulation curves were prepared for all the seasons and per habitat. The species accumulation curves of anurans for dry and wet seasons for all the habitats were plotted against survey effort (number of samples plotted against species richness). On the other hand, species rarefaction curves were designed to show differences in species diversity and richness per habitat and per season in the study area.

In addition to maximize the sample, an standard active search (30 minutes per sampling day, per site, and per habitat) for anurans was conducted at random in locations few meters away from the transect lines, which included under logs, under leaves or leaf litter, tree holes, under rocks, as well as potential hiding places. The search had a specific starting point and finishing end i.e. specific locations (10 m away from the transect) were searched every sampling day constantly.

For Specific objective (iv) regarding concordance, data was gathered from existing literature using five functional and ecological attributes considered important for assessing the effects and response of anuran species to habitat variations and seasonality. The traits used included (1) Feeding guild (dietary) and major food item as it influence foraging behavior and response to anthropogenic activities that change their main diet; (2) Ecological guild (basically involving their niche, are they arboreal, puddle frogs on leaf litter, aquatic, or terrestrial dwellers; (3) Major habitats dependability (do they occupy terrestrial habitats, aquatic habitats, or both during their survival); (4) Micro-habitats dependability (where the breeding occurs, availability of stagnant water, flowing water, or both influencing their reproductive cycle); (5) Breeding behavior (location and seasonality of breeding) as anurans during breeding can relocate either to agricultural fields or nearby terrestrial ecosystems, as unsustainable of wetland resources can negatively affect breeding sites of anurans, breeding of these species are normally synchronized based on seasonality influencing survival rates and resilience to environmental condition (since variability of anthropogenic activities may change the physical characteristics of the river). Species functional attributes were obtained from African Amphibian scratchpad (Amphibia web, 2023; Appendix III).

For specific objective v regarding species checklist, data was gathered using existing literature (Amphibiaweb, 2023), specifically on common names, scientific names, and their distribution/where they are found in Africa.

All observed and detected species were identified using guide books such as Field Guide to the Amphibians of Kenya (Channing & Howell, 2006). Unidentified species were later identified by supervisors through photographs (IPhone S8 Plus), and the Geographic coordinates of the sites were taken using a Geographic Positioning System device.

3.4. Data analysis

The collected data was curated in MS-Excel version 2013 for further analysis. Then Paleontological Statistics Software (PAST) version 4.12 was used to determine the biodiversity indices (Hammer *et al.*, 2001). That is, species richness, alpha and beta diversity, relative abundance, evenness, distribution, and dominance in the 3-different habitats per season (Delatore & Nuneza, 2021).

Shannon-Weaver index (H') and inverse Simpson index (D) were computed across each habitat per season to analyze frog species diversity as follows;

$$\text{Shannon-Weaver index } (\boldsymbol{H'}) = -\sum(\boldsymbol{Pi ln Pi}) ,$$

where Pi is the proportional abundance of the i^{th} species, *ln* is a natural logarithm, and $Pi = \frac{ni}{N}, where\ i = 1,2,3, \ldots\ S$, where ni is the abundance of the i^{th} species, N is the total number of individuals, and S is the species richness (total species in the community) (Teme, 2016; Magurran, 1988; Shannon & Weiner, 1949).

According to Magurran (1988), this index is one of the heterogeneity theory of indices. It assumes that individuals are randomly sampled from continuous large population and that all species are represented in the sample. The index (H') is maximum (H_{max}) when all S species are represented by the same number of individuals (evenly distributed) (Krebs, 1989).

Simpson's index was used to measure the probability that any two individuals drawn at random from infinitely large community belong to different species, and also to reflect how many different types of species are in a community and how evenly distributed the population of each species and the formula is given as follow; $\text{simpson diversity index} = (\mathbf{1} - \boldsymbol{D})$

Where $D = \frac{\sum ni(ni-1)}{N(N-1)}$, while *ni* is the number of individuals in the *i-th* species; and *N* is the total number of individuals in the community. Therefore the inverse was calculated as Simpson's reciprocal index = **(1/D)** (Singh *et al*., 2023).

Regarding the calculation to separate additional measure of evenness, in this study Shannon's evenness index (E) was employed, of which it is the ratio of observed diversity to maximum diversity and abundance, and it is given as follow**;** $\boldsymbol{E} = \boldsymbol{H'}/\boldsymbol{H_{max}}$

Where H_{max} is $\ln(s)$ which is denoted as the natural logarithm of species richness, and H' is Shannon's diversity index. The evenness index has a range of values from 0 to 1; when values are close to 1, the species are evenly distributed and vice versa (Shannon & Weiner, 1949).

Beta diversity for anuran species composition and turnover, better described as the measure of the degree of variation and similarities in species diversity or absence and presence of species from two habitats or communities (and season) was analyzed using similarity indices i.e. Bray-Curtis, Sorenson, and Jacquard's Coefficient Similarity Index, calculated as;

$$\boldsymbol{B_c} = \boldsymbol{b} + \frac{\boldsymbol{c}}{\boldsymbol{2a}} + \boldsymbol{b} + \boldsymbol{c};\ \textbf{SCSI} = \boldsymbol{2a}/(\boldsymbol{2a} + \boldsymbol{b} + \boldsymbol{c});\ \text{And}\ \textbf{JCSI} = \boldsymbol{a}/(\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c}),$$

Where a is the species common to both sites A and B, then b is the species unique to site A, and c is the species unique to site B. A low degree of similarity indicates a high rate of turnover based on the range of values provided by the index from 0 (there are no species shared by the two habitats) to 1 (there are a completely identical set of species shared by the habitats) (Bray & Curtis, 1957; Sørensen, 1948; Jaccard, 1912).

On the other hand, for Beta diversity is generated through a formula: Dissimilarity = 1 – Similarity index value and that is (Sorensen or Bray-Curtis) dissimilarity is equal to 1 minus (Sorensen or Bray-Curtis) similarity. All the indices take values from 0 to 1. If we are using the dissimilarity or distance indices, then a value 0 means that the communities are 100 % similar and 1 means that they are not similar at all (that is, they don't share any species).

To assess sampling effort and sample size adequacy of Anurans per habitat type and seasonality, sample size/species cumulative curves were generated using Microsoft Excel version 2013, with species richness plotted against number of samples.

As for testing or estimating anuran species diversity and richness per habitat type and season, sample based rarefaction curves as described by Chao (2012), were generated using Hill numbers developed by Chao *et al.* (2014), where we considered q = 0 (anuran species richness), and q = 1(exponential of Shannon’s entropy index), while q representing the effective number of species. These were performed using the simplest iNEXT online as it allows comparison of species richness despite differences in sampling effort (Hsieh *et al.,* 2006). Furthermore, because it allows the extrapolation and comparison of species richness at equal sample coverage even with the smallest samples (Chao, *et al.*, 2014). Thus, we generated generate rarefaction curves with the default bootstraps to estimate 95% confidence limits (CL) (Hsieh *et al*., 2006).

For specific objective (iv), Concordance using functional and ecological attributes was analyzed through Ecological Guild Analysis, where guild classification was used to gain a greater understanding of spatial patterns of species richness as well as assemblage structure (Williams, 1997), hence anurans were classified into guilds on the basis of possible variables describing their functional ecology from order to species level. All detected anuran species' taxonomic nomenclature were determined using published taxonomic key field guide books for amphibians (Channing & Howell, 2006), with taxonomy for amphibians following Frost (2023).

All statistical analysis such as diversity t-tests (for testing differences in species diversity), One-way ANOVA (for testing differences in species abundance between habitats), Independent sample t-test (for testing differences in species abundance between seasons) , and cross tabulation Chi-square (for testing differences in species richness) were computed using PAST version 4.12 software and IBM SPSS statistics 20, to test the significant difference or dependability between and within habitats and seasons, an exact significance p values (written in full as generated in the statistical software) was used, but the decision focused on whether $p > 0.05$ or $p < 0.05$. The diversity t-test is denoted as follows through the Hutcheson t-test developed as a method to compare the diversity of two community samples using the Shannon diversity index (Hutcheson, 1970),

$$\boldsymbol{t = \frac{H_a - H_b}{\sqrt{S_{H_a}^2} + S_{H_b}^2}}$$

Where, H represents the Shannon diversity index for each of the two samples (subscripted a and b). The bottom of the formula refers to the variance of each of the samples, which is denoted by the formula; $\boldsymbol{S_H^2} = \frac{\sum \boldsymbol{p}.(\boldsymbol{lnp})^2 - (\sum \boldsymbol{p}.(\boldsymbol{p}.\boldsymbol{lnp})^2}{\boldsymbol{N}} + \frac{\boldsymbol{S-1}}{\boldsymbol{2N^2}}$

Where; S is the species richness, N is the total number of individuals, and p is the proportion that each species makes towards the total.

Additional to the diversity t-test (Hutcheson), one has to compute the degree of freedom through the formula; $\boldsymbol{df} = \frac{(\boldsymbol{S_{H_a}^2} + \boldsymbol{S_{H_b}^2})^2}{(\frac{(\boldsymbol{S_{H_a}^2})^2}{\boldsymbol{N_a}} + \frac{(\boldsymbol{S_{H_b}^2})^2}{\boldsymbol{N_b}})}$

Whereby in the formula you need the variance for each sample and the total abundance for each sample. The final value is close to the total abundance for the two samples added together. Therefore degree of freedom when it comes to diversity t-test always has a decimal place compared to other t-tests (Hutcheson, 1970).

CHAPTER FOUR

RESULTS

4.1. Species diversity per habitat and per season

Shannon-wiener indices were determined to represent the diversity of frogs and toads in farmland, intermediate land, and forest habitats within Kingwal swamp and North Nandi Forest Reserve. Overall, the highest species diversity was calculated in the forest habitat (H' = 2.432), followed by the Intermediate habitat (H'=2.244), and the least was in the farmland (H'=2.048). Similarly, the Simpson index value was high in the forest (D = 0.871) and least in the farmland (D = 0.810) (Table 1). In addition, the farmland (E = 0.547), intermediate (E = 0.629), and forest habitats (E= 0.569) were all evenly distributed in all the habitats both in dry and wet season regardless of forest having the highest species diversity compared to other habitats (Table 1). Regarding species evenness, in contrast to the forest, the species were more uniformly dispersed in farmland and intermediate land habitats in both seasons (Table 1).

Table 1: Anuran biodiversity indices of three different habitats in Kingwal Swamp (Farmland and Intermediate land) and North Nandi Forest (Forest) per season

Habitat & Season	**Farmland**			**Intermediate**			**Forest**		
Diversity	Dry	Wet	Overall	Dry	Wet	Overall	Dry	Wet	Overall
Taxa_S	8	14	14	8	15	15	7	20	20
Individuals	180	347	527	118	314	432	211	479	690
Dominance	0.273	0.159	0.190	0.230	0.120	0.139	0.195	0.108	0.130
Shannon_H'	1.579	2.168	2.048	1.675	2.34	2.244	1.768	2.588	2.432
Evenness_e^H/S	0.606	0.625	0.547	0.667	0.692	0.629	0.837	0.665	0.569
Simpson_1-D	0.727	0.84	0.810	0.770	0.880	0.861	0.805	0.892	0.871

In terms of seasons, all the habitats had high diversities during the wet season compared to dry season. Although that was the case, forest had the highest species diversity in all the seasons (dry season; H= 1.768, D = 0.805 and wet season; H=2.588, D= 0.892) compared to other habitats (Table 1). Similarly, all the habitats were evenly distributed (values close to 1) in all seasons even though for farmland and intermediate the values were high in wet season compared to dry season while for the forest it was vice versa. Thus, increased evenness and diversity, means low dominance in all the habitats (Table 1).

The diversity t-test indicated that there was no significant difference between farmland and intermediate habitat (t = −0.855, df = 272.22, p = 0.393 for H'; t= 1.332, df=295.99, p = 0.184 for D), intermediate and forest (t = −1.295, df = 191.01, p = 0.197 for H'; t = 1.642, df= 203.98, p = 0.102 for D) but differed significantly between farmland and forest (t = -2.474, df = 301.83, *p* = 0.014 for H'; t = 3.058, df = 276.52, *p* = 0.02 for D) during the dry season respectively (Table 2).

Table 2: Diversity t-test variation of anuran species between habitats during dry seasons.

Index	Habitats		Diversity t-tests		
a)	**Farmland**	**Intermediate**	**t**	**df**	**P**
Simpson D	0.277	0.236	1.332	295.99	0.184
Shannon H'	1.56	1.645	-0.855	272.22	0.393
b)	**Farmland**	**Forest**	-	-	**-**
Simpson D	0.277	0.198	3.058	276.52	**0.002***
Shannon H'	1.56	1.754	-2.474	301.83	**0.014***
c)	**Intermediate**	**Forest**	-	-	**-**
Simpson D	0.236	0.198	1.642	203.98	0.102
Shannon H'	1.645	1.754	-1.295	191.01	0.197

*States that there is a significant difference

On the other hand, during the wet season, there was a highly significant difference in Shannon (H') diversity between farmland and intermediate habitat (t = -2.4998, df = 658.29., *p* = 0.0127), farmland and forest habitat (t = -6.5109, df = 748.06, *p* = 0.0001), and intermediate vs forest habitat (t = -4.2168, df = 743.54, *p* = 0.0001). However, with Simpson index there was a highly significant difference between farmland and intermediate habitat (t = 2.8935, df = 592.67, *p* = 0.0040), and farmland vs forest habitat (t = 4.0422, df = 608.92, *p* = 0.0001) only, whereas between intermediate and forest habitat (t = 1.4287, df = 743.17, *p* = 0.1535) there was no significant difference (Table 3).

Table 3: Diversity t-test variation of anuran species between habitats during wet season

Index	Habitats		Diversity t-tests		
a)	**Farmland**	**Intermediate**	**t**	**df**	**P**
Simpson D	0.161	0.123	2.8935	592.67	**0.0040***
Shannon H'	2.15	2.317	-2.4998	658.29	**0.0127***
b)	**Farmland**	**Forest**	-	-	**-**
Simpson D	0.161	0.108	4.0422	608.92	**0.0001***
Shannon H'	2.15	2.577	-6.5109	748.06	**0.0001***
c)	**Intermediate**	**Forest**	-	-	**-**
Simpson D	0.123	0.108	1.4287	743.17	0.1535
Shannon H'	2.317	2.577	-4.2168	743.54	**0.0001***

*States that there is a significant difference

The Diversity t-test also indicated that there was a highly significant difference between dry and wet season both in Shannon diversity index (t = -14.66, df = 1098.4, p = 0.0001) and Simpson diversity index (t = 9.1775, df = 764.95, p = 0.0004) of frog species in the study sites or habitats (Table 4).

Table 4: Diversity t-test variation of anuran species between dry and wet season

Index	**Dry season**	**Wet season**	Diversity t-test		
			T	**df**	**P**
Simpson D	0.225	0.123	9.1775	764.95	**0.0004***
Shannon H'	1.749	2.472	-14.66	1098.4	**0.0001***

*States that there is a significant difference

4.2. Species richness per habitat and per season

A total of 21 species of anurans from 9 families were recorded in the study area within the three habitats. Family Ptychadenidae had the highest dominant species (7 species), followed by family Phrynobatrachidae with 4 species, then family Bufonidae, Pipidae, and Hyperoliidae with each consisting of two species, and one specie in each of the families of Dicroglossidae, Arthroleptidae, Pyxicephalidae, and Ranidae (Table 5).

Of the 21 species recorded in the study area, in overall the forest had the highest species richness (20 species) while the farmland had the least species richness (14 species), whereas intermediate had 15 species regardless of the season.

During the dry season, the results indicate that farmland and intermediate had the highest species richness (Figure 5) due to less sampling days in the forest during the dry season, Farmland and Intermediate both exhibited 8 species from family Bufonidae (2 species each), Pipidae (1 specie each), Pyxicephalidae (1 specie each), Phrynobatrachidae (1 specie each), and Ptychadenidae (2 species each), while the forest consisted of only 7 species from family Pyxicephalidae (1 specie), Phrynobatrachidae (2 species), Hyperoliidae (1 specie), and Ptychadenidae (3 species), on the other hand, forest exhibited high species richness during wet season (2species), with intermediate having 15 species and farmland with 14 species (Table 5). More species were observed during wet season compared to dry season in all the habitats (Figure 5).

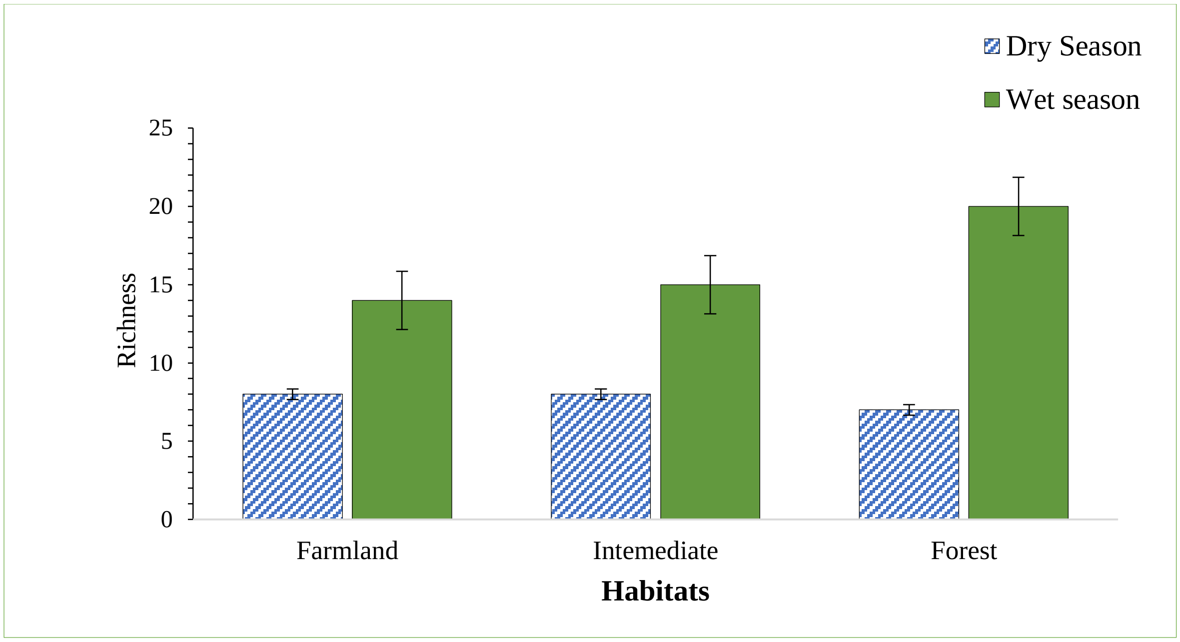

Figure 5: Seasonal variation of anuran species richness between the habitat types in Kingwal Swamp and North Nandi Forest Reserve.

Chi-square tests indicated that there was no significant association between species richness and seasons ($X^2([1], N = [2]) = [2.00], p = 0.157$), meaning season had no influence on the number of species detected. Similarly, there was no significant association between species richness and habitat type both during the dry season ($X^2([2], N = [3]) = [3.00], p = 0.223$) and the wet season ($X^2([4], N = [3]) = [6.00], p = 0.199$), hence habitat type had no influence on anuran species richness.

4.3. Species abundance per habitat and per season

Abundance as the total number of individual of all the species in the study area. Altogether, this study identified and recorded a total number of 1649 individuals from 21 different species within 9 different families in the study area (Table 5). Forest habitat had the highest abundance totaling to 690 individuals, of which 211 individuals were observed during the dry season, and 479 during the wet season (Figure 6). The least number of individuals were observed in the intermediate land (432 individuals, 118 during dry season and 314 in wet season), whereas the farmland consisted of 527 individuals (180 in dry season and 347 during wet season) (Figure 6). The results generally indicated that all the habitats were highly abundant in wet season (1140 individuals) compared to dry season (509 individuals) (Figure 6).

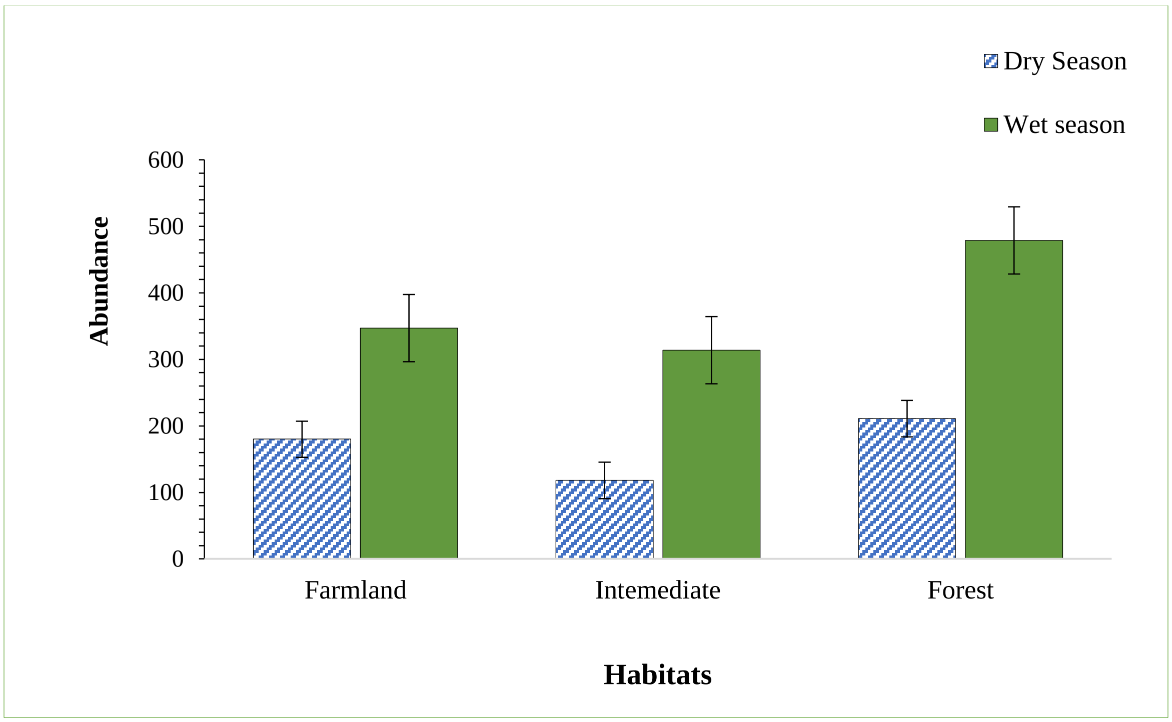

Figure 6: Seasonal variation of anuran species abundance between the habitat types in Kingwal Swamp and North Nandi Forest Reserve.

The most abundant species from the study and ranked first was *Ptychadena nilotica*, with 246 individuals (21.6% relative abundance) during the wet season and 167 individuals (32.8% relative abundance) in dry season across all the three habitats. The least abundant species across all habitats was *Amnirana albolaris* and ranked 17 in wet season with only

10 individuals (0.88% relative abundance) which was only being recorded in the forest habitat, while in the dry season there were a couple of species with no individuals observed (*Ptychadena oxyrhynhus, Ptychadena taenioscelis, Ptychadena mahnert, Ptychadena mascareniensis, Xenopus borealis, Phrynobatrachus scheffleri, Phrynobatrachus keniensis, Hyperolius cinnamomeoventris, Hoplobatrachus occipitalis, Leptopelis mackayi, and Amnirana albolabris*), but nonetheless, *Sclerophrys gutturalis* had the least abundance (6 individuals (1.18% relative frequency)) in dry season, occurring in all the habitats (Table 5).

Table 5: Abundance (Relative) of anuran species recorded in three habitat types of Kingwal Swamp (Farmland and Intermediate land) and North Nandi Forest Reserve (Forest) per season

Family	Species	Habitats						Total		Relative Abundance% (Rank)	
		FL		IL		FT					
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bufobidae	*Sclerophrys kisoloensis*	4	7	5	9	0	7	9	23	1.77(8)	2.02(9)
	Sclerophrys gutturalis	4	4	2	5	0	5	6	14	1.18(10)	1.23(13)
Ptychadenidae	*Ptychadena porossisma*	48	87	39	56	58	97	145	240	28.5(2)	21.1(2)
	Ptychadena nilotica	77	92	34	64	56	90	167	246	32.8(1)	21.6(1)
	Ptychadena oxyrhynchus	0	16	0	15	0	26	0	57	0	5(6)
	Ptychadena anchieta	9	13	4	17	22	20	35	50	6.88(4)	4.39(7)
	Ptychadena taenioscelis	0	20	0	31	0	15	0	66	0	5.79(5)
	Ptychadena mahnert	0	26	0	39	0	16	0	81	0	7.11(4)
	Ptychadena mascareniensis	0	0	0	0	0	16	0	16	0	1.4(11)
Pipidae	*Xenopus borealis*	0	8	0	3	0	0	0	11	0	0.96(16)
	Xenopus victorianus	4	6	3	6	0	9	7	21	1.38(9)	1.84(10)
Phrynobatrachidae	*Phrynobatrachus graueri*	13	26	9	17	12	14	34	57	6.68(5)	5(6)
	Phrynobatrachus natalensis	0	0	0	0	14	16	14	16	2.75(6)	1.4(11)
	Phrynobatrachus scheffleri	0	0	0	0	0	12	0	12	0	1.05(15)
	Phrynobatrachus keniensis	0	0	0	0	0	12	0	12	0	1.05(15)
Hyperoliidae	*Hyperolius viridiflavus*	0	7	0	6	12	25	12	38	2.36(7)	3.33(8)
	Hyperolius Cinnamomeoventris	0	0	0	5	0	8	0	13	0	1.14(14)
Dicroglossidae	*Hoplobatrachus occipitalis*	0	4	0	4	0	7	0	15	0	1.32(12)
Arthroleptidae	*Leptopelis mackayi*	0	0	0	0	0	11	0	11	0	0.96(16)
Pyxicephalidae	*Amietia nutti*	21	31	22	37	37	63	80	131	15.7(3)	11.5(3)
Ranidae	*Amnirana albolabris*	0	0	0	0	0	10	0	10	0	0.88(17)
Total Number of Individuals		**180**	**347**	**118**	**314**	**211**	**479**	**509**	**1140**	100.00	100.00
Total Number of Species		**8**	**14**	**8**	**15**	**7**	**20**	**10**	**21**		

Note that: FL= Farmland habitat; IL= Intermediate habitat; and FT= Forest habitat

In terms of habitats, *Ptychadena nilotica* had high individuals in the farmland both dry (42.8%) and wet season (26.5%), the least abundant species were *Xenopus victorianus*, *Sclerophrys gutturalis, and Sclerophrys kisoloensis* (2.22% each) in dry season with *Hoplobatrachus occipitalis* and *Sclerophrys gutturalis* (1.15% each) being least in wet season. As for intermediate land, *Ptychadena porossisma* (33.1%) led in dry season and *Ptychadena nilotica* (20.4%) in wet season, on the other hand, *Xenopus victorianus* (2.54%) was least in dry season and *Xenopus borealis* (0.96%) in wet season. Similarly, *Ptychadena porossisma* led in the forest but not only in dry season but also in wet season, on the other hand, *Hyperolius viridiflavus* and *Phrynobatrachus grauerie* (5.69%) had the least number of individuals in dry season while *Hoplobatrachus occipitalis* and *Sclerophrys kisoloensis* (1.46%) were least in the wet season (Appendix II).

Ptychadenidae was the most abundant family (1103 individuals from seven species in both dry and wet season across all habitats), followed by the Phrynobatrachidae (148 individuals from 4 species in both dry and wet season) and Ranidae was least (ten individuals from single species) (Table 5).

After testing the normality of the data and homogeneity of variance through Q-Q plots and explore via descriptive statistics, data was transformed through log10 to meet the assumptions of normality. Therefore, the one way analysis of variance (ANOVA) indicated that during the dry season, there was a highly significant difference in species abundance between habitats ($F= 89.457$, $df = 2$, $p = 0.001$). In addition, there was a significant difference in farmland (2.071 ± 0.161) and intermediate (1.321 ± 0.116) habitat means ($p = 0.025$), and a highly significant difference between the farmland and/ the intermediate habitat versus the forest (12.867 ± 1.264) habitat ($p = 0.001$). Thus, the means were not equal for all the habitats based on Tukey comparison test in ANOVA (Table 6; Figure 7).

Table 6: Tukey's means for groups in homogeneous subsets between habitats during dry season

Habitats	N	Subset for alpha = 0.05	
		1	2
Intermediate Habitat	84	1.3214	
Farmland Habitat	84	2.0714	
Forest Habitat	15		12.8667
Sig.		.225	1.000
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 33.158.			
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.			

The analysis still indicated that the forest habitat had a large (high abundance) array of data set compared to other habitats, followed by the farmland, while the intermediate had the least, displayed in Figure 7 based on the distance between the error bars during the dry season.

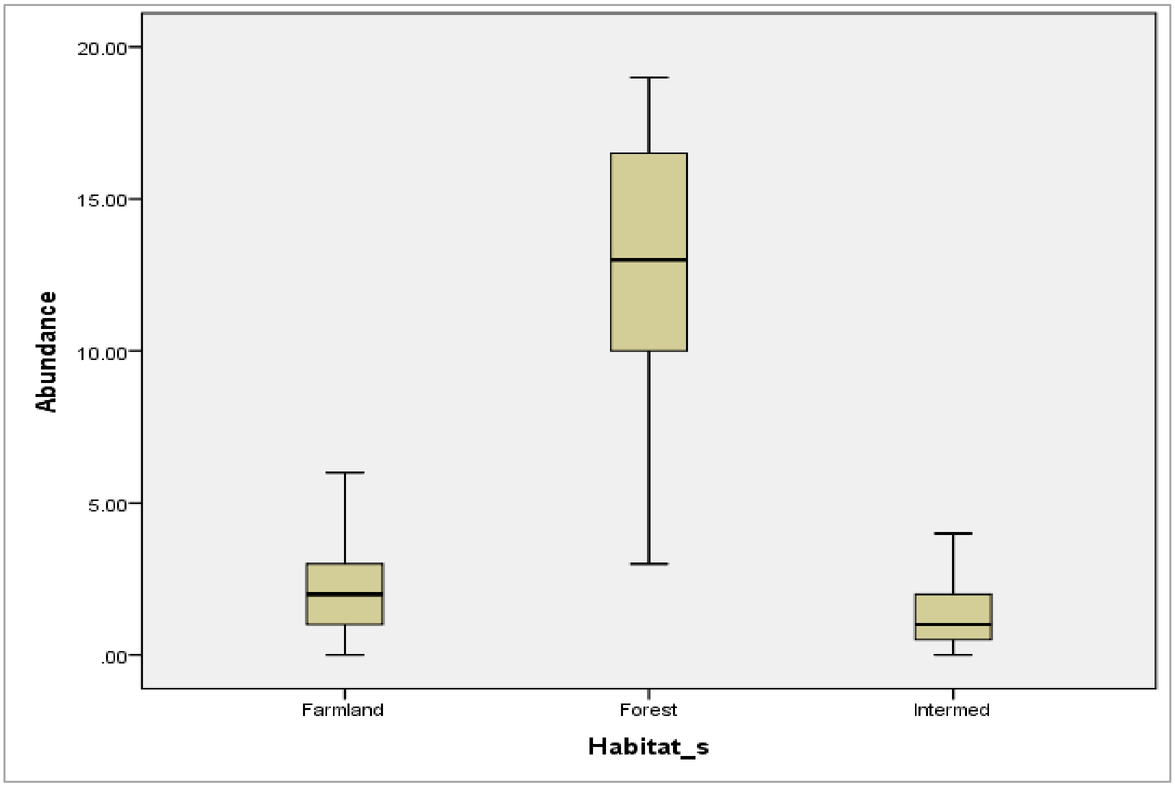

Figure 7: Variations in species abundance (mean) between habitats during the dry season.

In contrast, during the wet season, again after testing the normality of the data and homogeneity of variable through Q-Q plots and explore via descriptive statistics, data was transformed through log10 to meet the assumptions of normality. Therefore, the one way analysis of variance (ANOVA) indicated that during the wet season, there was no significant difference in species abundance between habitats (F= 2.433, df = 2, p = 0.091).

Table 7: Tukey's means for groups in homogeneous subsets between habitats during wet season.

Habitats	N (Samples)	Subset for alpha = 0.05	
		1	2
Intermediate Habitat	60	5.2333	
Farmland Habitat	60	5.7833	5.7833
Forest Habitat	60		7.9833
Sig.		.826	.051

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 60.000.
b. b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

There was no significant difference in farmland (5.783±0.452) and intermediate (5.233±0.439) habitat means (p = 0.826), and between farmland and forest (7.983±0.955) habitat (p = 0.051), while there was a significant difference between intermediate vs forest habitat means (p = 0.010). Thus, the means for farmland and intermediate habitats were equal, as well as farmland and forest habitat means, while for intermediate habitats were not equal with that of the forest habitat based on Tukey comparison test in ANOVA (Table 7; Figure 8).

Similarly with dry season, the forest habitat had a large (high abundance) array of data set compared to other habitats, displayed in Figure 8 based on the distance between the error bars.

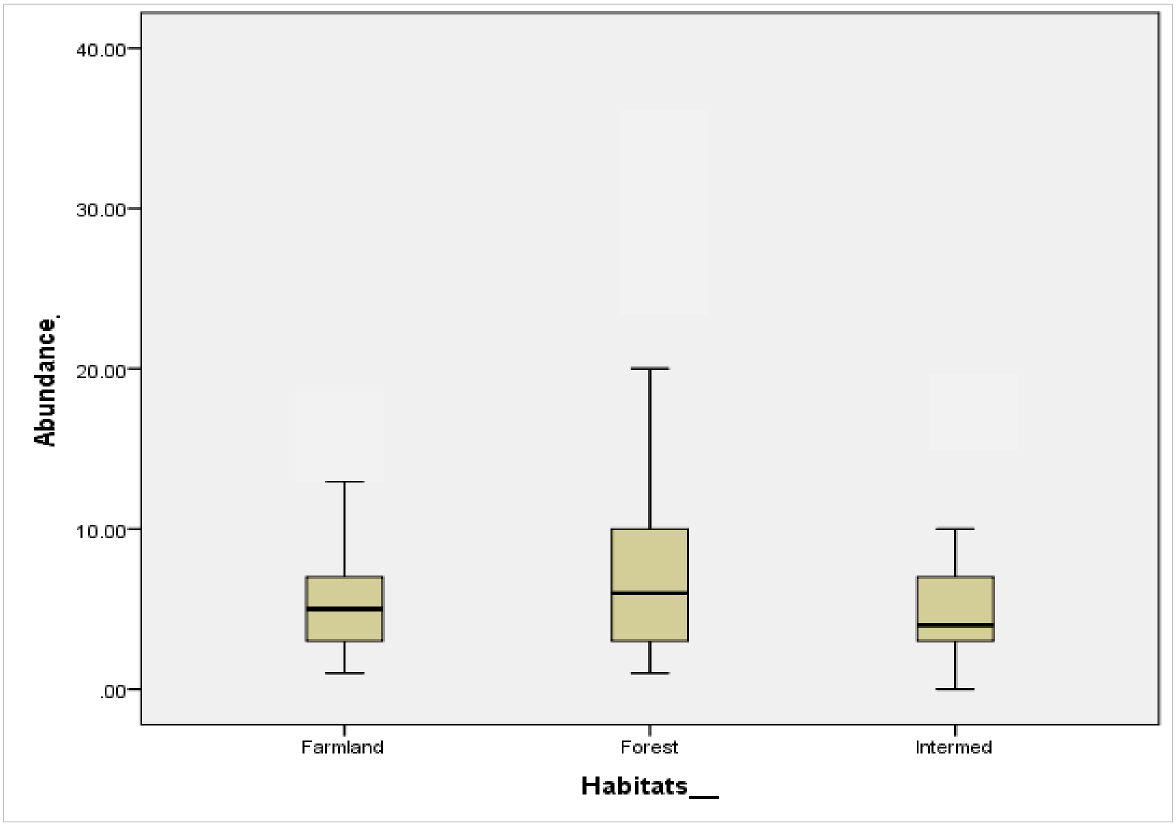

Figure 8: Variations in species abundance (mean) between habitats during the wet season.

In terms of differences in species abundance between dry season (2.612±0.266) and wet season (6.333±0.390), the independence t-test analysis showed that overall there was a highly significant difference (t = -10.289, df = 328, p = 0.0001). Similarly, there was a significant difference in species abundance in the farmland (t = -7.782, df = 131, p < 0.0001), Intermediate (t = -9.892, df = 120, p <0.0001), and the forest (t = 3.526, df = 73, p =0.001) habitat between dry and wet season. Therefore, their dry and wet seasons means were not equal i.e. farmland (2.143±0.179 and 5.783±0.452) (Figure 9), intermediate (1.405±0.152 and 5.233±0.439) (Figure 10), and forest habitat (14.067±1.822 and 7.983±0.955) (Figure 11).

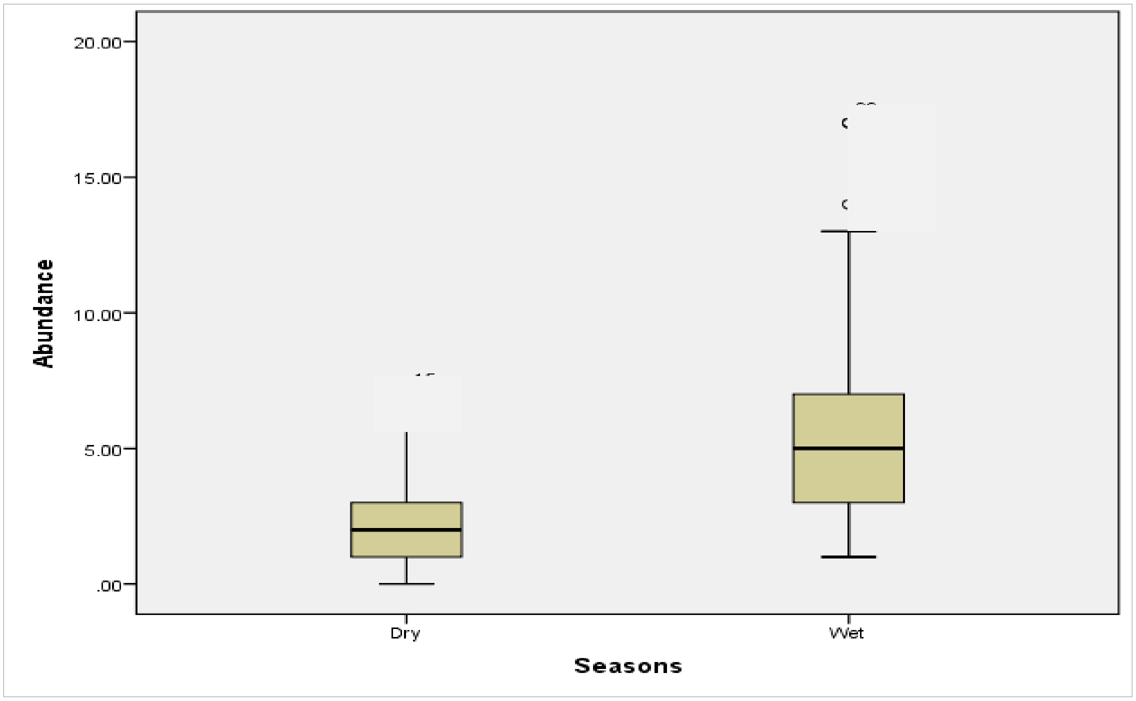

Figure 9: Variations in species abundance (mean) between seasons in the farmland habitat.

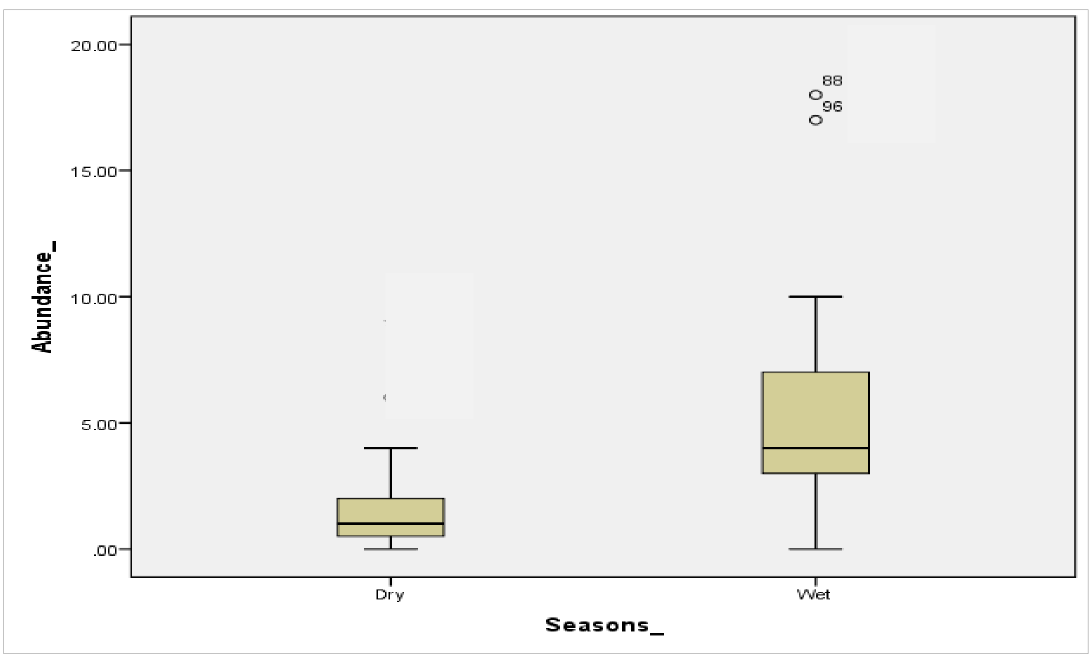

Figure 10: Variations in species abundance (mean) between seasons in the intermediate habitat.

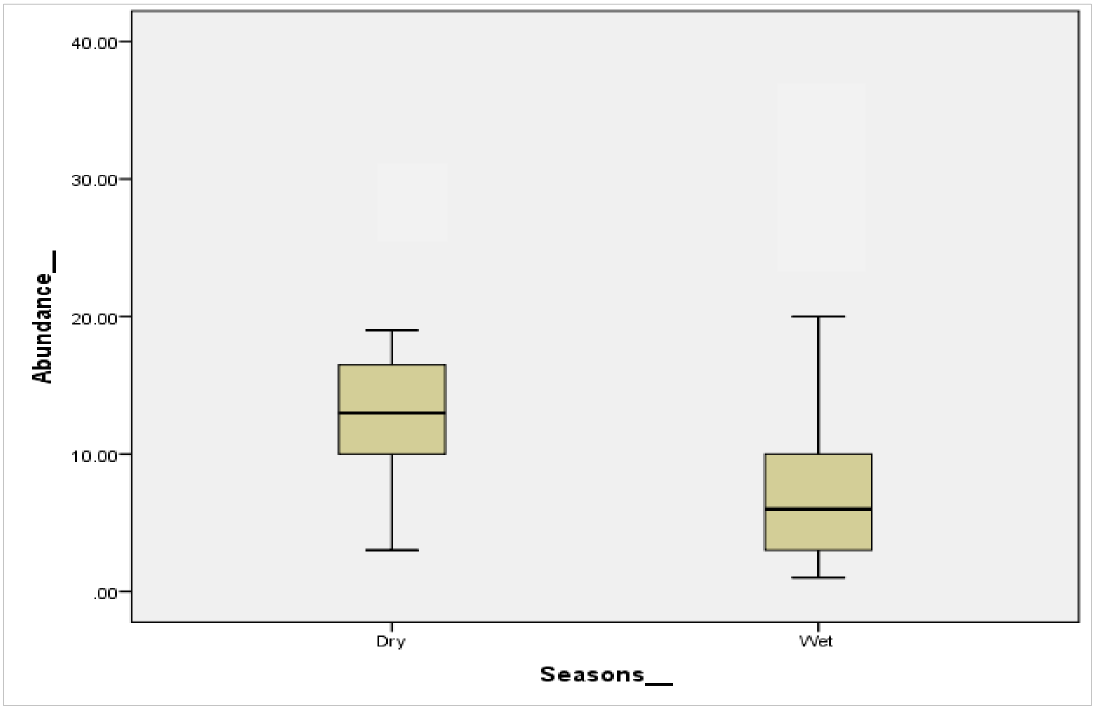

Figure 11: Variations in species abundance (mean) between seasons in the forest habitat.

4.4. Species accumulation curve and richness estimation per season and per habitat

In order to justify that sampling effort and sample size was adequate, species accumulation curves were prepared for all the seasons and per habitat (number of samples plotted against species richness). On the other hand, species rarefaction curves were designed to show differences in species diversity and richness per habitat and per season in the study area.

During the dry season sampling, all study habitats achieved asymptote (stabilized) but at a low rate of species richness except for the forest habitat (species increasing exponentially), meaning more sampling effort is still required in the forest habitat. Farmland reached asymptote on sampling day 5 in 15 samples, with 41 individuals from

8 species (Figure 12 a), Intermediate habitat on sampling day 5 in 15 samples as well, but with 32 individuals from 8 species (Figure 12 b), while the forest habitat species richness is increasing on a slow rate after reaching 12 samples on sampling day 4 with 64 individuals from 7 species (Figure 12 c).

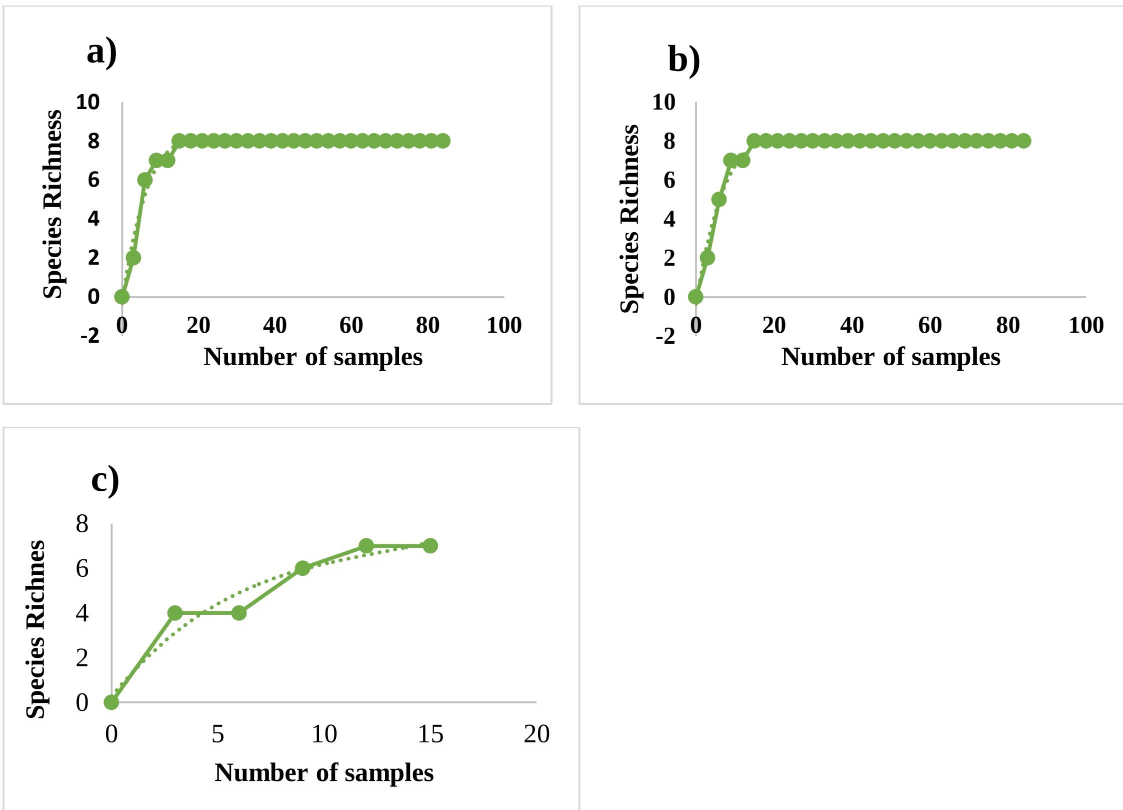

Figure 12: Species accumulation curves of anurans during dry season among habitats, a) Farmland, b) Intermediate habitat, and c) Forest habitat as plotted against survey effort (number of samples).

In contrast, the sampling effort was adequate during wet season in all the habitats. The farmland habitat achieved asymptote or was stabilized on sampling day 12 in 36 samples, with 249 individuals from 14 species (Figure 13 a), Intermediate habitat on sampling day 13 in 39 samples, with 236 individuals from 15 species (Figure 13 b), and forest at on sampling day 5 in 15 samples, with 256 individuals from 20 species (Figure 13 c).

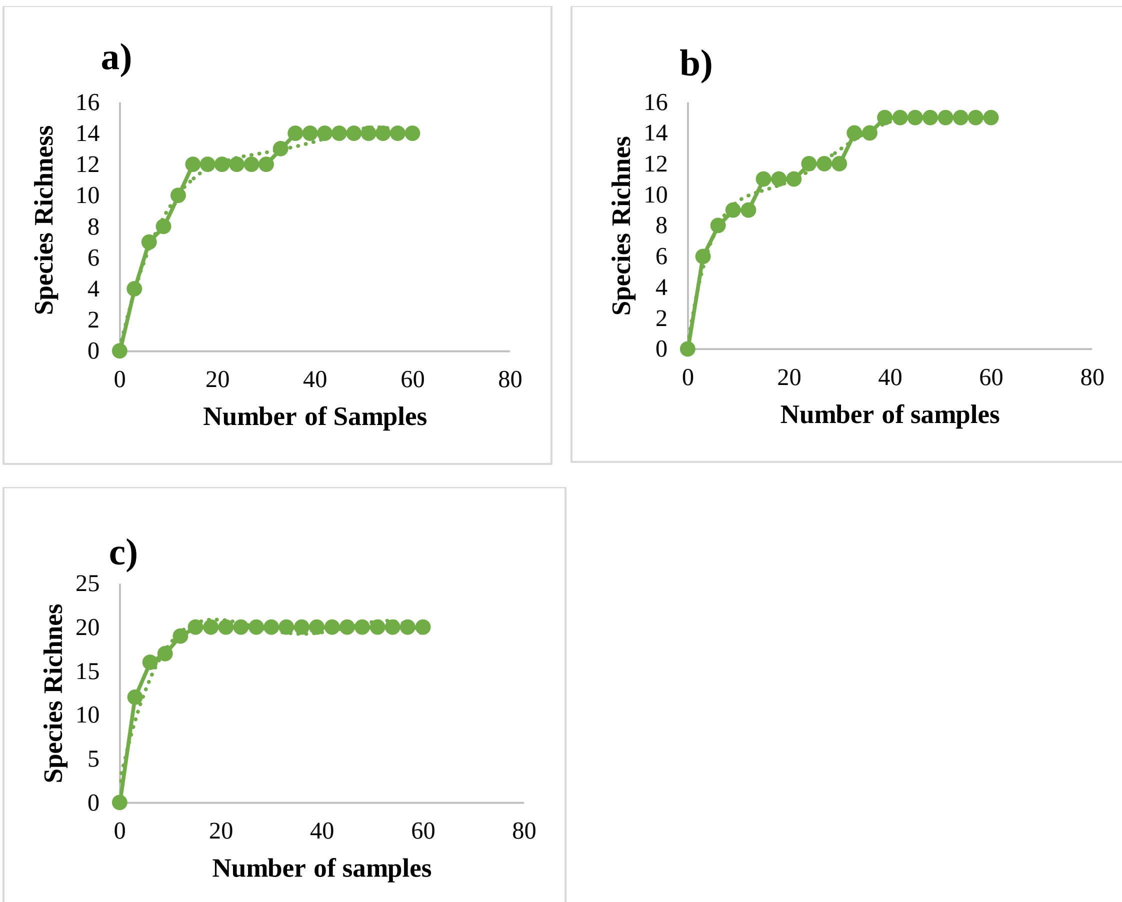

Figure 13: Species accumulation curves of anurans during wet season among habitats, a) Farmland, b) Intermediate habitat, and c) Forest habitat as plotted against survey effort (number of samples).

Overall, Figure 14 shows that all the habitats in the study area were stabilized regardless of sampling season. However, there are still chances of more new species to be discovered in the study area if sampling continues, albeit at a slower rate. At this sampling effort, the cumulative number of species based on number of samples and sampling days resulted in 14 species for farmland, 15 species for intermediate habitat, and 20 species for forest habitat.

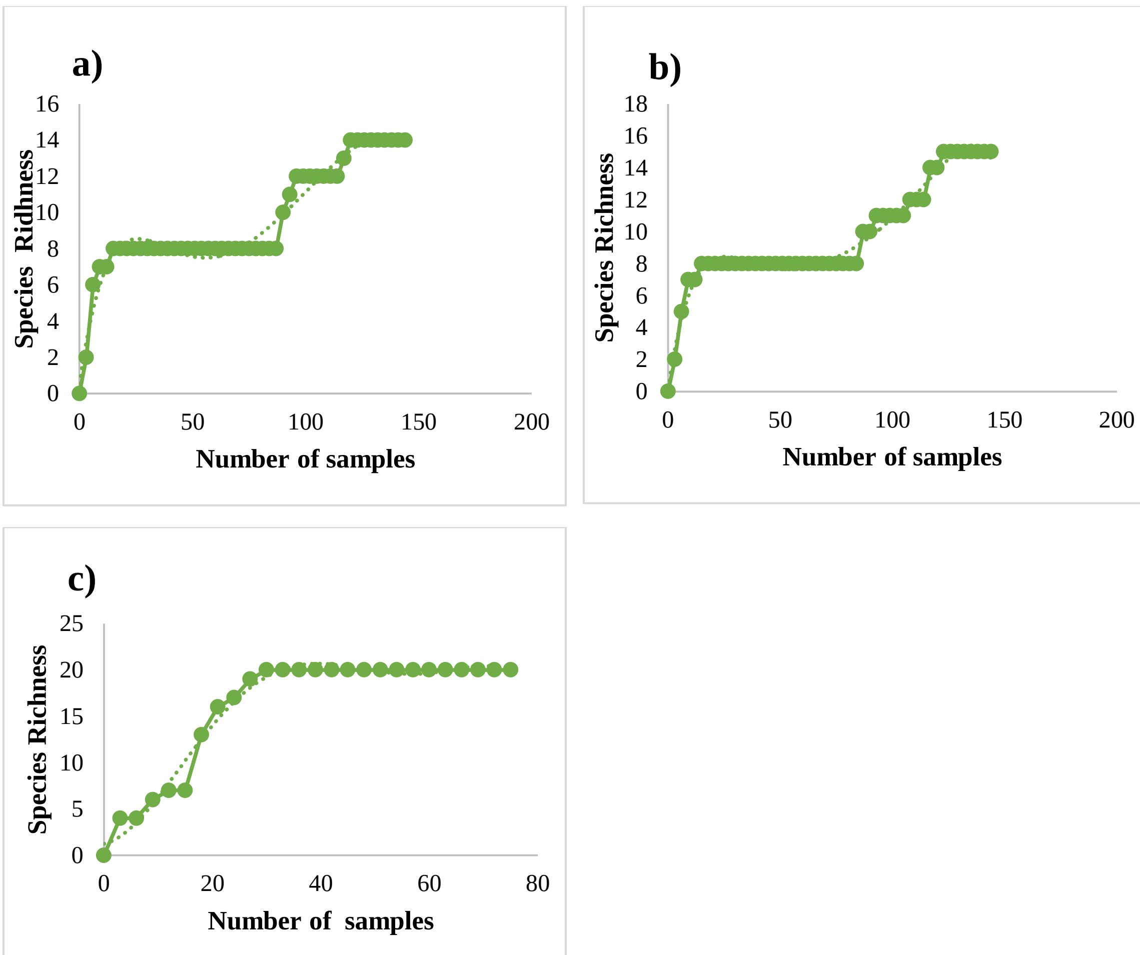

Figure 14: Overall species accumulation curves of anurans a) Farmland, b) Intermediate habitat, and c) Forest habitat plotted against survey effort (Number of samples).

As stated earlier that anuran species richness between the habitats in the study area was compared using rarefaction curves, the Chao1 index in iNEXT calculated the estimated differences in contrast to the species richness and individuals of each species per habitat type. Interpolation (rarefaction) and extrapolation curves showed that species richness ranged from 7 to 8 among habitats during the dry season (Figure 15(q=0)). Measures of diversity indicated that farmland (Chao1 = 8 ± 1.25, H'= 4.92 ± 0.80) and intermediate (Chao1 = 8 ± 1.75, H'= 5.20 ± 0.62) habitats had the highest (same number) species richness but differed in species diversity where intermediate habitat had high diversity than farmland. Although forest had the lowest species richness due to few sampling days in the dry season, it had the highest species diversity (Chao1 = 7 ± 0.00, H'= 5.89 ± 0.40) compared to other habitats during dry season (Figure 15).

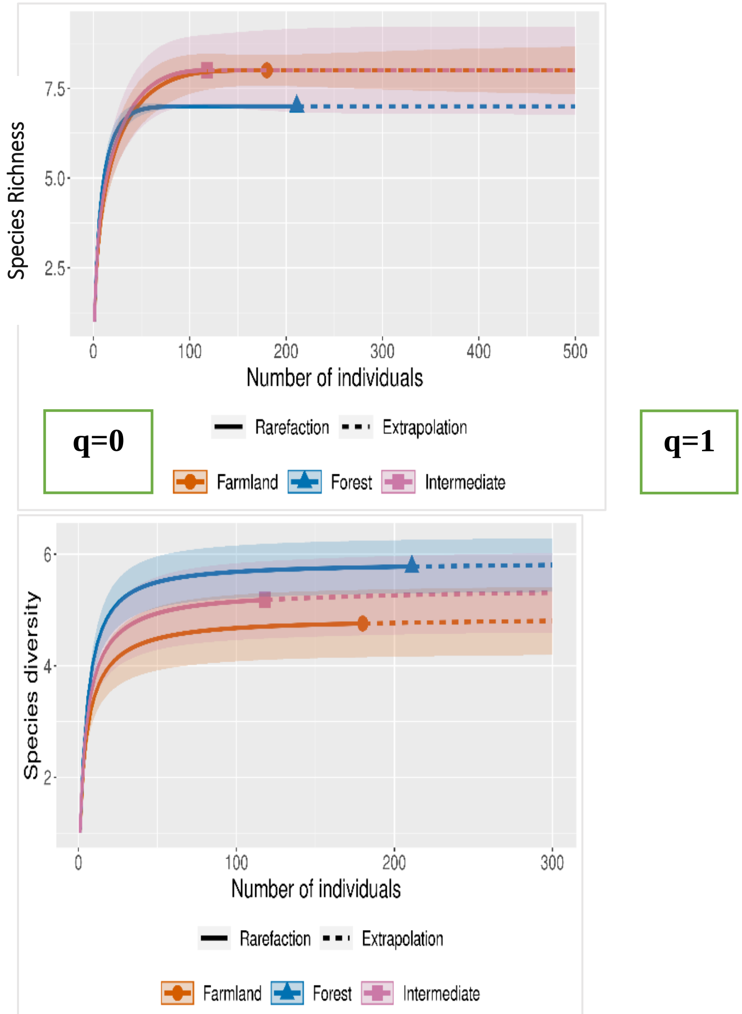

Figure 15: Comparison of the diversity of anuran species in three habitat types in Kingwal Swamp and North Nandi Forest Reserve through rarefaction (solid lines) and extrapolation (dotted lines). Species diversity was estimated using Hill numbers: q = 0 (anuran species) and q = 1 (exponential of Shannon index) in dry season.

On the other hand, during the wet season, interpolation (rarefaction) and extrapolation curves showed that species richness ranged from 14 to 20 among habitats (Figure 16(q=0)). Measures of diversity indicated that forest habitat had the highest diversity

(Chao1 = 20 ± 0.00, H'= 13.01 ± 1.55) and species richness, followed Intermediate habitat (Chao1 = 15 ± 0.85, H'= 10.08 ± 1.44), and the farmland habitat (Chao1 = 14 ± 0.20, H'= 8.02 ± 1.50) (Figure 16).

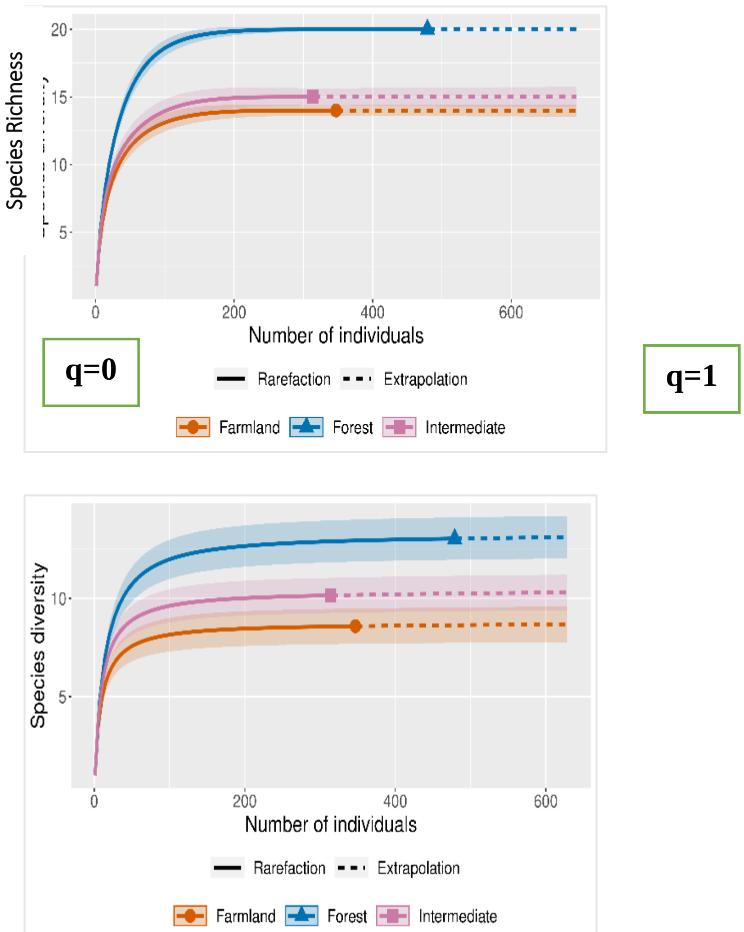

Figure 16: Comparison of the diversity of anuran species in three habitat types in Kingwal Swamp and North Nandi Forest Reserve through rarefaction (solid lines) and extrapolation (dotted lines) based on the number of individuals of the anuran species in wet season.

4.5. Beta diversity based on similarity indices of frog species between habitats per season

Species similarity analyses between paired farmland and intermediate land habitats, farmland and forest habitat, as well as intermediate land and forest habitat showed SCSI, JCSI, and BCSI values greater than 0.50 both in dry and wet season representing 100%, 67%, and 67% of species similarity by SCSI, 100%, 50%, and 50% of species similarity by JCSI, 78%, 75%, and 66% of species similarity by BCSI during dry season respectively (Table 8). During wet season, 97%, 76%, 80% species similarity were from SCSI, 93%, 62%, and 67% were from JCSI, while 82%, 75%, and 67% were obtained from BCSI. Therefore, the results indicated that all the habitats in both during dry and wet season, completely shared identical species (Table 8).

Table 8: Sorensen's Coefficient Similarity Index (SCSI), Jaccard's Coefficient Similarity Index (JCSI) and Bray-Curtis Similarity Index (BCSI) of anuran species among the three habitat types.

Paired Habitat	Number of Habitats								Similarity Indices					
	Unique to FL		Unique to IL		Unique to FT		Shared		SCSI		JCSI		BCSI	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
FL vs IL	0	0	0	1	-	-	8	14	1	0.97	1	0.93	0.78	0.82
FL vs FT	3	0	-	-	2	7	5	13	0.67	0.76	0.5	0.62	0.75	0.75
IL vs FT	-	-	3	0	2	6	5	14	0.67	0.8	0.5	0.67	0.66	0.67

Note: FL = Farmland, IL= Intermediate, FT= Forest,

Species dissimilarity analyses between paired farmland and intermediate land habitats, farmland and forest habitat, as well as intermediate land and forest habitat showed SCSI and BCSI values less than 0.50 both in dry and wet season representing 0%, 33%, and

33% of species dissimilarity by SCSI, 22%, 25%, and 34% of species dissimilarity by BCSI during dry season respectively. During wet season, 3%, 24%, and 20% were calculated from SCSI, while 18%, 25%, and 33% of species dissimilarity were obtained from BCSI. Therefore, the results indicated that all the habitats both in dry and wet season have exactly the same species composition or completely shared identical species (Table 9).

Table 9: Sorensen's Dissimilarity Index and Bray-Curtis dissimilarity Index as Beta indices of frog species among the three habitat types

Paired Habitat ⬇	Similarity Indices values				Dissimilarity(Beta) Indices			
	SCSI		BCSI		Sorensen's Dissimilarity Index		Bray-Curtis dissimilarity Index	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
FL vs IL	1	0.97	0.78	0.82	1-1= **0**	1-0.97=**0.03**	1-0.78=**0.22**	1-0.82=**0.18**
FL vs FT	0.67	0.76	0.75	0.75	1-0.67= **0.33**	1-0.76=**0.24**	1-0.75=**0.25**	1-0.75=**0.25**
IL vs FT	0.67	0.8	0.66	0.67	1-0.67=**033**	1-0.8=**0.2**	0-0.66=**0.34**	1-0.67=**0.33**

4.6. Species distribution based on percentage of detection per habitat and per season

With regards to the rate of total detection of anuran species, the analysis indicated that of the 21 species observed in the study area, 13 species were detected and observed in all the 3-different habitats i.e. they were distributed in all the habitats (both protected and non-protected ecosystems) (Figure 17). However, *Phrynobatrachus natalensis*, *Leptopelis mackayi*, *Ptychadena mascariensis*, *Phrynobatrachus scheffleri*, *Amnirana albolabris*, and *Phrynobatrachus keniensis* were only distributed in the forest habitat, this implies that they were forest habitat specialists i.e. species only adapted to forest microhabitats with no or little disturbances (Figure 17).

Although that was the case, *Hyperolius cinnamomeventris* occupied only both the forest and the intermediate habitats (forest associated species), while *Xenopus borealis* occupied only both the farmland and intermediate habitats (agricultural field associated species). Overall, most species regarded as generalists (utilizing both disturbed or modified habitats and un-disturbed habitats) were evenly (Table 1) distributed in the farmland, intermediate, and forest habitat but with high percentage of detection mostly in the protected reserve, in other words, the forest habitat had high species distribution compared to other habitats (Figure 17).

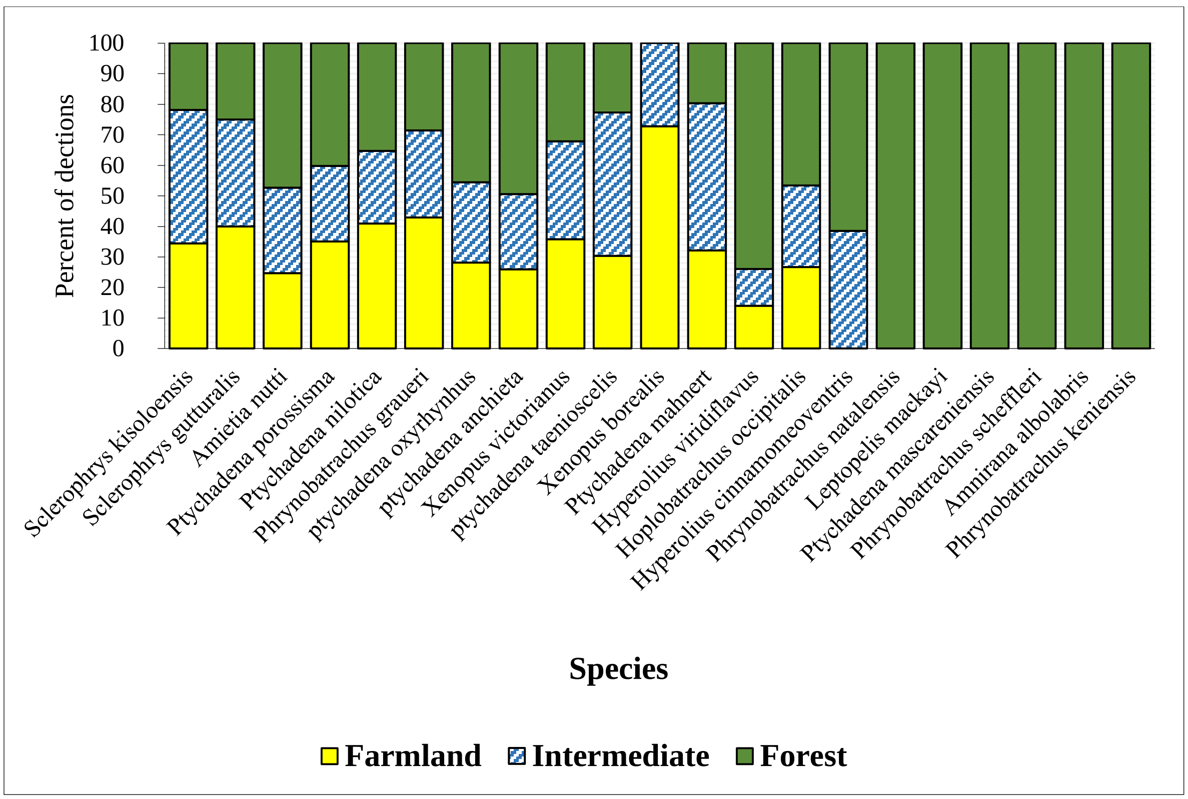

Figure 17: The percentage of total detections of the 21 anuran species located in Farmland, Intermediate, and Forest habitats in the study area.

Analysis displayed on Figure 18 indicate that most of the anuran species were distributed highly across all the habitats during the wet season. However, 11 species were distributed, observed, and detected only during the wet season, while 10 species were detected withstanding in both the dry and wet season, although only a few had almost equal rates of detection (*Ptychadena anchieta*, *Ptychadena nilotica*, and *Phrynobatrachus natalensis*) in both the seasons (Figure 18).

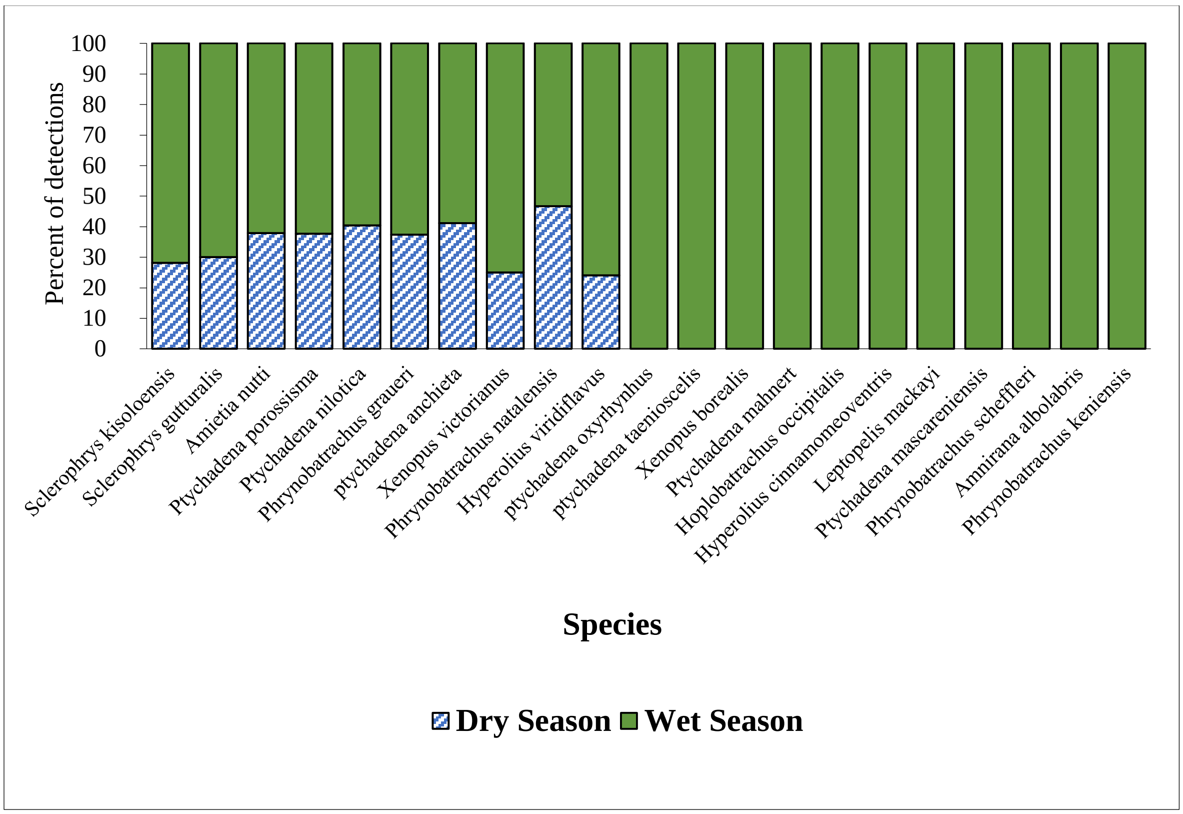

Figure 18: The percentage of total detections of the 21 anuran species located in Farmland, Intermediate, and Forest habitats in the study area between the dry and the wet season.

4.7. Species concordance of anurans in Kingwal Swamp and North Nandi Forest Reserve.

The analysis indicate that all the species observed in the study area were carnivorous (85.71 %; n= 15 species in the non-protected area, and n=17 species in the protected area), whereas *Leptopelis mackayi*, *Phrynobatrachus scheffleri* and *Amnirana albolabris* feeding items are unknown (14.29 %) and were all observed only in the forest habitats (Appendix III). Of the carnivorous species identified, along Kingwal Swamp (n= 15 species) most species fed predominantly on both insects and frogs (40%; 6 species) or on insects only (40%; 6 species), while 13.33 % (n= 2 species) fed on both insects, frogs, and fish, and only a single specie (6.67%) fed on insects, frogs, and reptiles. On the other hand, in North Nandi Forest Reserve (n= 17 species), most species (47.06%; 8 species) fed predominantly on insects and frogs, followed by insects only (41.18%; 7 species), while the least fed on insects, frogs, and fish (5.88%; 1 specie), or insects, frogs, and reptiles (5.88%; 1 specie) (Figure 19; Appendix III).

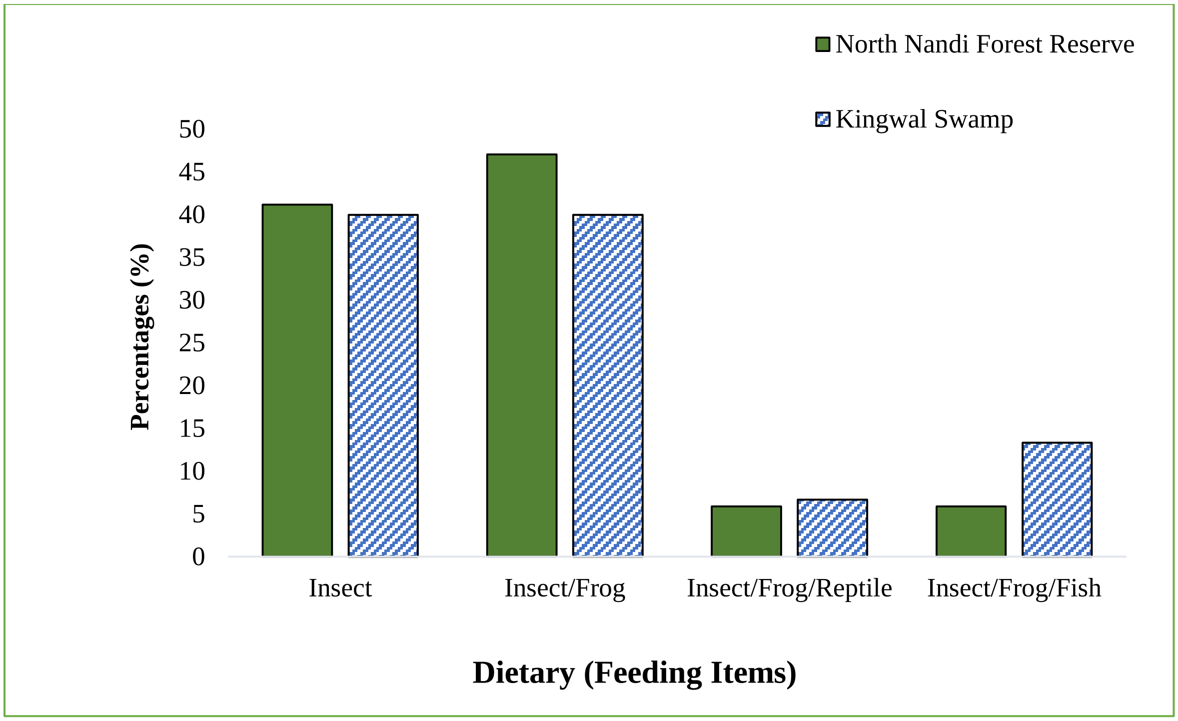

Figure 19: Dietary (food item) of anuran species in Kingwal swamp and North Nandi Forest Reserve.

In terms of ecological guild of anuran species observed, along the non-protected swamp, analysis show that the most dominant species were ground/terrestrial dwelling (53.33%), followed by aquatic/ stream dwelling (26.67%), then arboreal dwelling (13.33%), while puddle frogs found in leaf litters we (6.67%). In contrast, the most dominant species in the protected forest were also ground/terrestrial dwelling (45%), followed by arboreal dwelling and leaf litter frogs each with 4 species (20% each), while aquatic/stream dwelling were the least (15%) (Figure 20; Appendix III).

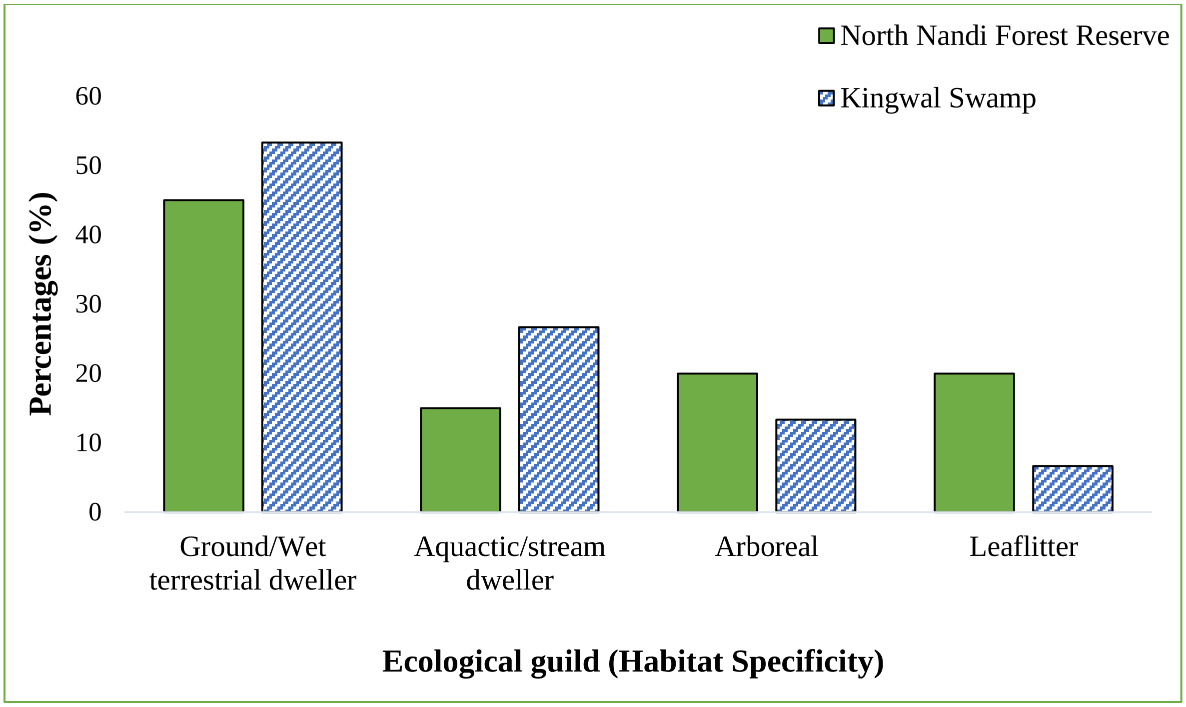

Figure 20: Ecological guild of anuran species in Kingwal swamp and North Nandi Forest Reserve.

Analysis on major habitats occupied by anuran species in the current study indicated that most species both along Kingwal Swamp (86.67%) and North Nandi Forest Reserve (95%) inhabit both terrestrial and aquatic habitats (biome), and only few occupies aquatic environments only (13.33% along the swamp, and 5% in the forest) (Figure 21, a); Appendix III). Similarly with major habitats, most species observed both in the non-protected area (86.67%) and the protected area (90%) breed during wet season, and only a few vary in breeding seasons (13.33 % along the swamp, and 10% in the reserve) (Figure 21, b); Appendix III).

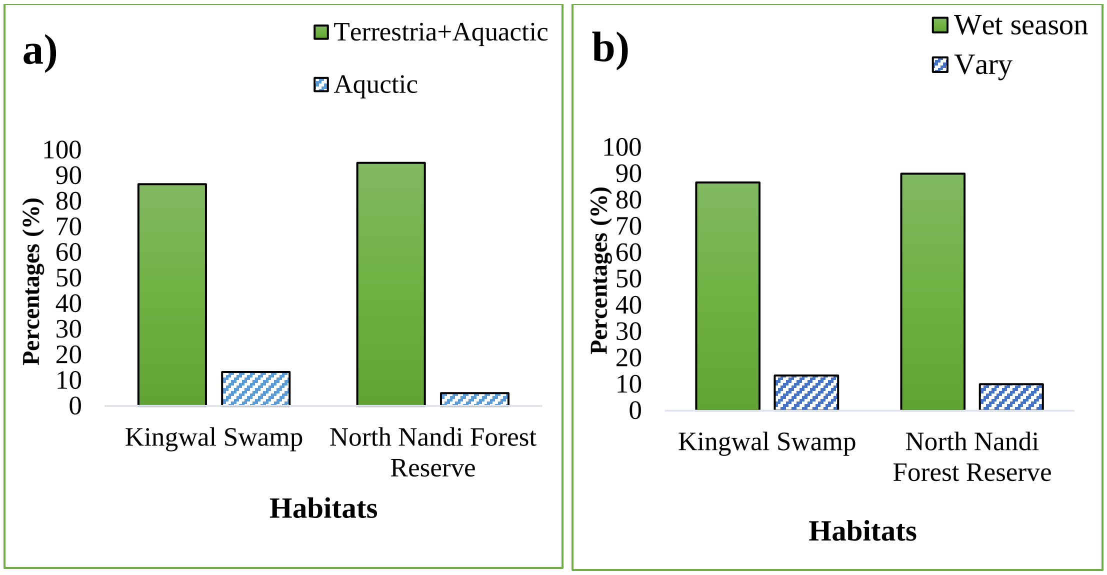

Figure 21: a) Major habitats/biome, and b) breeding season of anuran species in Kingwal Swamp and North Nandi Forest Reserve.

In terms of micro-habitats where breeding occurs based on the availability of stagnant water, flowing water, or both in influencing their reproductive cycle, the analysis show that most species requires stagnant water (Lotic) only for breeding purpose both along the swamp (66.67%) and in the forest (60%) habitats, while the least species in both the habitats (6.67% in Kingwal Swamp, and 10% in North Nandi Forest Reserve) require flowing water (Lentic) only for completion of their reproductive cycle (Figure 22; Appendix III).

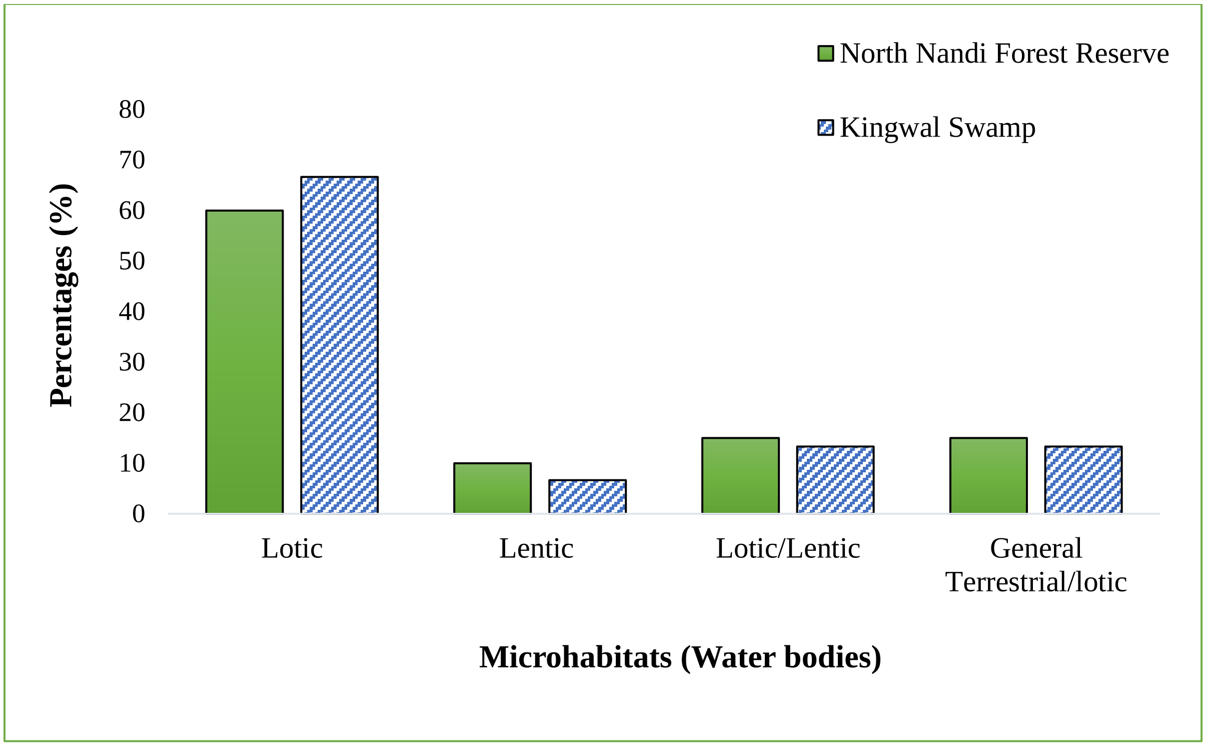

Figure 22: Microhabitats for breeding based on the availability of water influencing reproductive cycle of anuran species in the study area.

In terms of micro habitat type and breeding location, the results indicated that both along the swamp and in the forest reserve, almost half of anuran species observed use water bodies as their breeding sites (both eggs and the larvae in water) with 46.67% along Kingwal Swamp and 55% in the forest reserve, followed (26.67% in the swamp, and 25% in the forest) by those that use both vegetation near water bodies and water bodies (eggs laid on the vegetation and sometimes fall into water bodies), and similarly between the habitats, the least species prefer or use vegetation near water bodies only i.e. marshes or herbaceous plants at edges of water bodies (13.33 % along Kingwal Swamp, and 10% in North Nandi Forest Reserve) or lay eggs in trees/arboreal habitats but larvae develops in water bodies such as puddles (13.33 % along the non-protected area, and 10% in the protected area) (Figure 23; Appendix III).

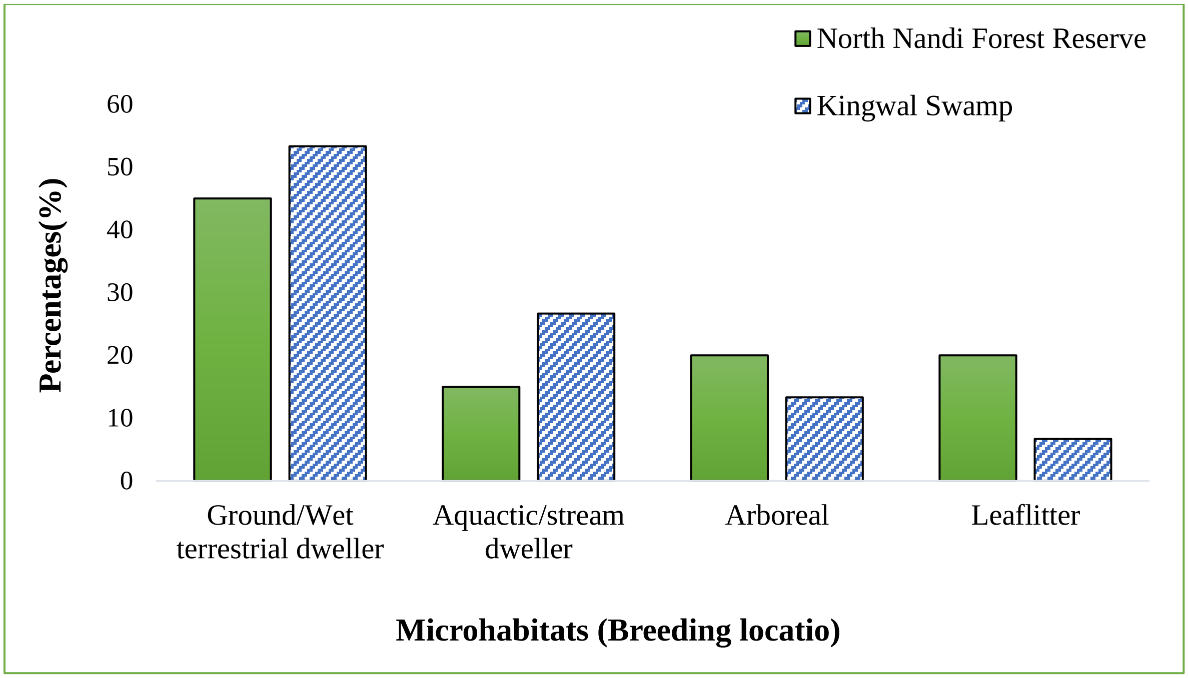

Figure 23: Microhabitat type and breeding location of anuran species in Kingwal Swamp and North Nandi Forest Reserve.

4.8. Anuran species Checklist of Kingwal Swamp and North Nandi Forest Reserve

One of the key objectives of this study was to compile an anuran species checklist for Kingwal Swamp and North Nandi Forest since none has been compiled before. Based on the survey, this present study compiled a total of twenty one (15 species in Kingwal Swamp and 20 species in North Nandi Forest Reserve) anuran species belonging to nine families (7 families in Kingwal Swamp and 9 families in North Nandi Forest), and nine genera (Table 10). Among the nine families, Ptychadenidae had the highest number of species (n = 7 species; only 6 species in the swamp and all 7 species in the forest), followed by family Phrynobatrachida (n = 4 species; only 1 species in the swamp and all 4 species in the forest), Bufonidae (n = 2 species; all occured in both), Pipidae (n = 2 species; 2 species in the swamp and only 1 species in the forest), and Hyperoliidae (n = 2 species; all occured in both). Family Dicroglossidae (n = 1 species; occurred in both), Arthroleptidae (n = 1 species; only in the forest), Pyxicephalidae (n = 1 species; occurred in both), and Ranidae (n = 1 species; only in the forest) represented the least number of species (Table 10).

In terms of genera, *Ptychadena* (n = 7 species) and *Phrynobatrachus* (n = 4 species) had the highest number of species representative. Two species were reported for genera *Sclerophrys*, *Pipidae*, and *Hyperolius*, while the rest of the genera (*Hoplobatrachus*, *Leptopelis*, *Amietia*, and *Amniran*) were represented by only a single species (Table 10).

An evaluation of the IUCN Red list conservation status of the anuran species showed that all the species except *Leptopelis mackayi* (Vulnerable; n = 1 species (4.76 %) observed only in North Nandi Forest Reserve) were categorized as least concern (95.24%) (LC; n = 15 species along Kingwal Swamp, n = 19 species in North Nandi Forest Reserve) (Table 10). In terms of distribution across Africa, 33.33% (n = 7 species) of the species are distributed in East Africa only, 28.57% (n = 6 species) in East and West Africa only, 9.52% (n =2 species) in East, West, and South of Africa only, similarly to Sub-Saharan Africa (n = 2 species).The rest of the remaining species are found in East and Central Africa; East, Central, and South of Africa; East, West, and Central Africa; East, West, Central, and South of Africa; and lastly in East and North Africa, each with one species (4.76%) (Table 10).

Table 10: Checklist of anuran species in Kingwal Swamp and North Nandi Forest Reserve

Family	Scientific Name	KS	NNFR	IUCN Red list status	Distribution (ASA, 2022; Amphibiaweb, 2023)
Bufonidae **(2)**	*Sclerophrys kisoloensis*	X	X	LC	East, South Africa
	Sclerophrys gutturalis	X	X	LC	East, South Africa
Ptychadenidae **(7)**	*Ptychadena porossisma*	X	X	LC	East, South Africa
	Ptychadena nilotica	X	X	LC	East, North Africa
	Ptychadena oxyrhynchus	X	X	LC	East,Central,South Africa
	Ptychadena anchieta	X	X	LC	East, South Africa
	Ptychadena taenioscelis	X	X	LC	East, South Africa
	Ptychadena mahnert	X	X	LC	East Africa
	Ptychadena mascareniensis	-	X	LC	Sub-Saharan Africa
Pipidae **(2)**	*Xenopus borealis*	X	-	LC	East Africa
	Xenopus victorianus	X	X	LC	East Africa
Phrynobatrachidae **(4)**	*Phrynobatrachus graueri*	X	X	LC	East, Central Africa
	Phrynobatrachus natalensis	-	X	LC	East, West, South Africa
	Phrynobatrachus scheffleri	-	X	LC	East Africa
	Phrynobatrachus keniensis	-	X	LC	East Africa
Hyperoliidae **(2)**	*Hyperolius viridiflavus*	X	X	LC	East Africa
	Hyperolius cinnamomeoventris	X	X	LC	East, West, South Africa
Dicroglossidae **(1)**	*Hoplobatrachus occipitalis*	X	X	LC	Sub-Saharan Africa
Arthroleptidae **(1)**	*Leptopelis mackayi*	-	X	VU	East Africa
Pyxicephalidae**(1)**	*Amietia nutti*	X	X	LC	East, South Africa
Ranidae **(1)**	*Amnirana albolabris*	-	X	LC	East,West,Central,South Africa

Note that: Numbers in the parentheses indicate the total number of species.

For study area, KS= Kingwal Swamp (Non-protected); NNFR= North Nandi Forest Reserve (Protected area).

For IUCN present status, E= Endangered; LC=Least Concern; VU=Vulnerable; DD= Data Deficiency;

CHAPTER FIVE

DISCUSSIONS

5.1. Diversity of anuran species

A high species diversity in the forest habitat compared to the intermediate and farmland habitat is attributed to the more diverse microhabitats in North Nandi Forest Reserve spatially. The intermediate habitat and farmland had wetland and agricultural dominated microhabitats while the forest habitat had in addition to forest; swamps and other wetland microhabitats. This concurs with past studies that have shown that diversity and distribution of anuran species is highly influenced by habitat preferences (Jongsma et al., 2014; Onadeko, 2016; da Silva & Rossa-Feres, 2011), environmental factors associated with their habitat structure (Pearman, 1997), and habitat productivity which is a function of rainfall.

This in deed is proofed that anuran species diversity is a function of habitat diversity. The significance difference in species diversity between the protected forest habitat and habitats in Kingwal swamp was due to habitat variability (heterogeneity) which is associated with the structural complex microhabitats providing diverse ways of exploring resources (invertebrates as food, and predation cover) and niches, hence increasing anuran species diversity (Malonza, 2011; Malonza and Bwong, 2023). In support, Neckel-Oliveira et al. (2001) on Brazil's Amazonian savannas and surroundings forests also detected high diversities in the forest compared to the surrounding habitats. Additionally, Auguste & Hailey (2018) noted that wetlands in Trinidad's Aripo Savannas Scientific Reserve were more diverse compared to those in agricultural fields. In line with this study, this is due to high intensity of anthropogenic disturbances such as overgrazing, expansion in agricultural activities, water drainage for nursery irrigation, use of agrochemicals (Oda, et al. 2016), eucalyptus agroforest, and encroachment ruining the preferred microhabitats for breeding purposes of anuran species in farmland and intermediate habitats. For example, use of pesticides pollutes water bodies impacting not only on aquatic species (*Xenopus* species), but also those species (*Ptychadena* species) that use them as breeding sites. Due to the high taxonomic turnover in anuran species, wetland microhabitat protection and conservation is critical in both protected and non-protected areas.

However, Rahman et al., (2022), and Kassie et al., (2023) on frog diversity and distribution in regions of Bangladesh and Keffa, contradicts this current study by noting that agricultural fields were more diverse than the forest habitat, this may be due to the fact that in the forest there may be frog specialists and in the farms generalist species that make use of the modified habits or habitat patchiness, leading to forests having few species but of conservation concern e.g. endemics (Kassi et al., 2023; Malonza and Bwong, 2023). This results from the fact that the forest patches was not in an area designed for conservation, and the area is enormously interfered with by humans, and for the agricultural field, most of the water bodies were highly vegetated creating room for anuran breeding.

Although some studies (Ndriantsoa et al., 2017) have indicated that agricultural land harbors a lot of frog species due to the availability of different microhabitats for breeding purposes such as plantations that are a significant component of amphibian diversity, in this current study that was not the case. The aquatic habitats within the farmland were modified into unsuitable habitats for breeding, not suitable as sites for predation cover, and of course less variability in resources for foraging (Dodd, 2010). The lower diversities in farmland and intermediate habitat may also be consequences of pollution generated from the agricultural fields (nursery and gardens) (Oda, et al., 2016). For example use of pesticides that pollutes water bodies for not only aquatic anuran species (*Xenopus* species), but as well those species (*Ptychadena* species) that use them as breeding sites.

But all in one, as suggested by Le Cœur et al.,(2002) that natural and semi-natural remnant areas serve as important refuges for wild animal diversity, the analysis of this study is indeed proof that natural (forest habitat), and semi-natural regions (intermediate habitat) are more diverse than habitats with high agricultural activities (farmland).

According to Akoto et al., (2015), when the similarity indices values are greater than 0.5, then the paired habitats share the same species, but if the index values are less than 0.5 then the paired habitats share different species. Therefore, the results of the current study revealed that the habitats within the study area shared similar species (composition). These findings are supported by several studies based on either species diversity in protected areas (Vonesh, 2001) and agricultural fields (Tumushimire et al., 2020) where some species were observed in both protected areas and agricultural fields. Nneji et al. (2019), stated that forest habitats and agricultural fields had the highest similarity in species composition. In line with this current study, the result showed that the forest, intermediate, and farmland habitat had high BCSI, SCSI, and JCSI.

Mostly this can be associated with ecological and feeding guilds that is using the same niche i.e. breeding sites which are found in both protected forests, riverine intermediate habitats, as well as in agricultural fields, these can either be microhabitat preferences as breeding sites (highly vegetated water bodies, availability of same prey species (invertebrates) both in forests and farmlands, or even shelter protecting them against predation (Oda et al, 2016). These species in simpler terms utilize both forest patches and farmland field as habitats (generalists) (da Silva & Rossa-Feres, 2007). Additionally, this can be associated with sampling methods being successful and used to sample anuran species in other studies, with the inclusion of areas that were natural remnants of native vegetation and areas used for agricultural purposes (Santos et al. 2009).

However, some unique species were not shared between the habitats, for example, this current study identified some arboreal frog (*Leptopelis mackayi*) species and puddle frogs found on the forest litter (*Phrynobatrachus natalensis, Phrynobatrachus scheffleri*, and *Phrynobatrachus keniensis*) only observed in the forest habitats. The dissimilarities in unique species can probably be associated with the variability in ecological settings of the habitats under study such as the intensities of disturbance from anthropogenic and environmental factors (seasonal variations) (Hammond & Pokornỳ, 2020).

5.2. Abundance and richness of anuran species

The analysis of species richness and abundance within habitats in protected areas harbor higher anuran species than any other locality. Similarly to diversity, the higher species richness and abundance in the forest habitat is associated with more diverse micro habitats (heterogeneity such as highly vegetated water bodies i.e. lotic, for example ponds, puddles; and lentic, for example slow flowing shallow streams) which are suitable as breeding sites for anuran species, others include variability in resources for foraging, and predator cover, therefore all influences frog habitat selection or dependability, hence increasing species richness and abundance.

The protect forest habitat in this current had a high species richness and abundance compared to the non-protected habitats (farmland and intermediate), proving that conservation efforts play a critical role in anuran species biodiversity, similarly to some studies on anurans conducted in locations such the eastern arc mountains and coastal forests in eastern Africa, Shimba Hills National Reserve (Nyamache et al. 2017; Malonza et al. 2018), Kitobo Forest of Kenya (Malonza et al, 2011), Taita Hills (Malonza et al, 2010).

The higher species richness figures stated in the above studies (localities) may be related to differences in sampling efforts and sampling methods (visual encounter search and use of drift fences and pitfall traps) of which is proof that North Nandi forest habitat as a protected area had more species richness and abundance compared to Kingwal swamp's habitats. This is all because the sampling method used in this current study was successful to sample anuran species just like in other studies, specifically areas with native vegetation and agricultural areas (Oda, et al., 2016). Therefore, increased sampling methods increases detection, hence increases species richness and abundance.

In support, Nneji et al., (2021), Rahman et al., (2020) and Drayer & Richter (2016), and Muro-Torres et al, (2020) also found that wetlands in protected reserves inhabits different anuran species. Their argument is based on the availability of healthy productive aquatic microhabitats providing diverse variabilities of food sources. A higher species richness and abundance in the forest habitat was influenced by the vegetation structure of the environment, this can be attributed or confirmed by similar results from a study by da

Silva & Rossa-Feres, (2011), who found that vegetation structure is associated with providing vocalization sites during the breeding season for anuran e.g. *Hylidae* and *Ptychadena* species.

Mathwin *et al*., (2021) also concurs with this study by suggesting that maintaining water sources has an impact on the anuran community, hence increases species richness and assists in their conservation. This is the case because most water bodies with vegetation at the edges in the protected forest (current study) were undisturbed and less exposed to agrochemicals (which changes the variables of water i.e. PH, conductivity, dissolved oxygen, as well as temperature), thus there was no havoc towards anuran populations. However, Oda et al., (2016) found that anuran species prefer water bodies in agricultural landscapes as their breeding habitats. In line with this current study, the findings denotes species abundance varying according to the three habitats which were under study with a few common anuran species coexisting with a large number of rare anuran species.

Wetlands with greater forest cover have been associated with a higher population of anurans compared to those with limited coverage i.e. Valleys and depressions are characterized by low anuran populations compared to relatively flat topography or mid-slope habitats, where canopy covers in forests located within wetlands have been linked to support mechanisms for enhanced breeding and survival of anurans (Browne *et al.*, 2009; Wallace & Tronstad, 2019). Similarly with the current results, wetlands or water bodies inside the forest had a high species richness and abundance compared to those in the farmland and the intermediate habitats, this can be attributed to features such as high canopy cover or variability in vegetation structure in the forest that are not only used as breeding but as well as proving varieties of foraging resources for anurans. In addition, the lower species richness and abundance in farmland and intermediate habitats of Kingwal swamp may also be a consequence of habitat fragmentation due to agricultural activities (clearing the land suitable habitats for frog species into orchards, fish ponds, and livestock grazing areas) (World Bank, 2014; Foerster and Conte, 2018)

On the other hand, the farmland habitat had a high abundance compared to intermediate habitat (both having low vegetation cover), this can be associated to the fact that anurans travel to agricultural land in search of food, or the availability of adequate water in the paddy fields (organic pool or pond) serving as breeding sites compared to intermediate habitat. In support by Karunakaran & Jeevanandham, (2017) and Attademo et al., (2019), availability of water bodies (both stagnant and man-made streams acting) as observed in the farmland habitat compared to the intermediate habitat play a critical role in species richness and abundance. However, the slight difference in the number of species between intermediate and farmland habitats, is associated with the utilization of both forest remnants and agricultural land as their habitat (generalist species) (da Silva & Rossa-Feres, 2007; Oda, et al., 2016).

Despite the fact that the species cumulative curve in all the habitats stabilized, that is reaching an asymptote in all the season except the forest in dry season, the possibility of local species richness expansion cannot be excluded. Therefore, increased effort would add new species in the forest habitat. Overall, increased effort in this current study would add to the species richness very slowly, as evidenced by richness estimators displayed on rarefaction curves. In line with this current study, a study in Ethiopia by Kassie (2023) displayed species accumulation curves with asymptotic points. Similarly, they also emphasized the significance of investigating and sampling anuran species using a variety of sampling methods (Malonza et al, 2010; Malonza et al, 2011; Rahman et al, 2022) in order to sample species that cannot be encountered and gain a more complete understanding of their ecology (Maritz et al, 2007; Ribeiro et al, 2008) since species diversity, abundance, and richness is closely related to the sampling effort invested by researchers (Costa-Campos & Freire, 2019). In line with this study again, sampling effort was boosted by collection of data in early morning (diurnal sampling) and in evenings (nocturnal sampling), the well-known time for anuran species to be active.

The species accumulation curves stabilized in relatively low species richness during dry season for all the habitats under study, while during wet season it was on an adequate number of species. Similarly, this was also displayed on the rarefaction curves, this simply indicated that additional sample effort was or is required not only for the forest habitat, but for all the habitat in dry season to improve on the relative low species richness observed, as there are chances of additional species.

5.3. Distribution of anuran species

The location and availability of a specific species depend on the ecosystem and habitat characteristics that are unique to that setting. As the analysis stated that anuran species were distributed differently within the habitats influencing rates of detection, this concurs with Souza & Avila (2015) who elaborated that those differences in distribution were influenced by diversity of prey species and variations in the type or quality of habitats. Anuran species are distributed or located in different microhabitats within major terrestrial and aquatic ecosystems, this again is associated with the availability of breeding sites in these favorable ecosystems (Oda *et al.,* 2016) as in the forest habitats in this current study.

For instance, in cases where most species were distributed and active enabling rates of detection in all the habitats, is attributed to the environmental structures that has been observed to be linked to the distribution patterns of anurans, not only in different but also in similar habitats (Menin *et al.,* 2005). Almo, (1991), Donelly, (1991), and Junca & Entrovic, (2007), observed that dietary (feeding items) in feeding ecology studies influences distribution patterns of coexisting anuran species, specifically in cases related to concordance where this study found that some puddle frogs feeding on the same invertebrates for example *Ptychadena* species were distributed in both the farmland and the forest reserve habitats. Additionally, variations on how species utilize microhabitats and the foraging strategies they impose are also associated with their distribution patterns (Franca *et al*., 2004).

As explained by Malonza & Veith (2012), Gould *et al*. (2012), Maurer *et al.* (2014), and Mi *et al*. (2022), distribution of anuran species is not only influenced by elevation, habitat type, adaptation and lifestyle, or climate change but also human disturbances (anthropogenic activities). Concurring with the current study, species were evenly distributed in all the habitats but highly in the forest reserve compared to other habitats which were exposed to high intensities of disturbances. For example, some anuran species having a direct developing mode of reproduction and/ habitat specialists decreased with an increasing habitat modification in Taita hills which corroborate with the current study. Therefore, generalists may be high in agricultural fields but lack forest specialists.

5.4. Seasonal variations in anuran species diversity, abundance, richness, and distribution between habitats

Considering the rapid advancement of habitat destruction and forest fragmentation due to anthropogenic activities, understanding anuran species diversity and distribution is crucial for the development of conservation strategies both in protected and non-protected areas.

Giaretta & Menin (2004) and Giaretta et al., (2008) noted that the duration (start and end) of anuran breeding season is influenced by climate conditions. In tropical regions with seasonal climates, the majority of these species breed during the wet (rainy) season (Nneji et al., 2019). In line with the current study, this explains the seasonal variations in species diversity, abundance, and richness within and between the three habitats. In support, Watanabe et al, (2005) and Giaretta et al, (1999) also found seasonal variations in anuran communities of Iriomote Island of the Ryukyu Archipelago and montane forest of Brazil. A study in the tropical forests of Uganda with defined dry and wet seasons by Vonesh (2001), noted a significant impact of precipitations on the diversity and abundance of anuran species.

This is true with the current study, anuran species diversity, abundance, distribution, and richness recorded in the study area were high during the wet (rainy) season compared to the dry season, and this was due to the availability of sufficient water bodies flowing, and highly vegetated, suitable as breeding sites for anuran species compared to dry season.

A highly significant difference between the seasons in terms of diversity indices and abundance was observed. Increased species abundance, distribution, richness, and diversity during the wet season can be attributed to higher rates of adult frogs moving around for suitable microhabitats used as breeding sites (vegetation at edges of water bodies, in some puddles, ponds, pools, and swampy areas in the forest leaf litter understory) (Giaretta & Menin, 2004).

During dry season, there was no significant difference in species diversity and abundance between habitats due to low movement of species in breeding sites, while in wet season there was a significant difference between the habitats, this can be associated with seasonal fluctuations resulting from abiotic factors that influence dispersion and recruitment in frogs, involving processes of hibernation and aestivation when there are no favorable conditions for breeding purposes. However, Causaren et al., (2016) differed from the current study, he found high anuran species abundance in riparian habitats (Intermediate habitats in the current study) during the dry season and in natural forests during the wet season. This could be associated with microclimatic conditions of riparian areas (Intermediate habitats) which did not suffer drastic variations during the dry season (De Souza & Eterovick, 2010; Dixo & Martins, 2008). Therefore, this clearly show that riparian areas should be protected and conserved because they are very crucial in maintaining microclimates and providing critical microhabitats for not only anuran species but other vertebrate and invertebrates taxa inclusively.

High rates of species detection during the wet season influencing variations in patterns of distribution is associated with breeding activities initiated by rainfall (Duellman & Treub, 1986) which results in more active individuals during the wet periods and warm seasons (Howell, 2004), going into hibernation i.e. in the temperate areas (corroborating with the current results), or aestivation (in the tropics) when unfavorable conditions are imposed on them. In line with the study, this occurred during the dry season mostly on forest associated frog specialists in the reserve.

High rainfall rates and the availability of a distinct seasons were observed in the study area. This fact might be partially explained by the existing significant seasonal variation in the anuran species richness, diversity, distribution, and abundance in Kingwal Swamp and North Nandi Forest Reserve.

5.5. Species concordance and checklist

Our knowledge of Kingwal Swamp and North Nandi Forest on anuran species still remains poor due to little information in the localities. These are some of the areas in Kenya that still needs more attention thorough herpetological surveys because they are underexplored. What this current study has provided is just an additional eye opener into what can be found through rapid and continuous assessments. The results show that long term systematic sampling will unquestionably lead to possible detection of additional new anuran species. The fact that this study could not detect many species may be attributable to the limited sampling effort, specifically the study period in terms of data collection. The location (being close to Kakamega Forest where plenty of anuran species have been observed in some studies) of the study area makes it an important biodiversity hotspot. A good number of anurans may occur in the sites that were not collected in the current study surveys.

All in one, functional attributes as concordance, this current study looked at feeding attributes based on dietary and type of feed item consumed by the anuran species, followed by the ecological guild based on the specific location in the ecosystem they occupy, then microhabitats where they normally engage into breeding like laying eggs and where the larvae is found, then the major habitats where they are distributed globally, concluding with their breeding seasons.

In addition, an evaluation of the IUCN conservation status of the anuran species showed that most species were categorized as of least concern (IUCN, 2023), meaning they are not on the merge of extinction, such observation can be attributed to the effectiveness of conservation efforts of forest and wetland habitats because once the water bodies are polluted and the vegetation is degraded, their survival within the microhabitats is compromised.

The broad taxonomy and distribution patterns noted in all the anuran species detected in this current study are supported and derived from the Amphibian Species of the World relating from versions 3.0 to 6.2 (an online Reference that is from 1998 to 2023), Amphibian Survival Alliance (ASA) manuals and guides (ASA, 2022), the IUCN Red List of Threatened Species (IUCN, 2023), the Amphibia Web Taxonomy (AmphibiaWeb, 2023), and an online Reference relating to the scientific nomenclature and discontents such as the structure of the taxonomic records from contributors and reviewers for Amphibian species of the world (Frost, 2023).

Vonesh (2001) on natural history and biogeography of amphibians and reptiles of Kibale National Park in Uganda found that all the anuran species identified in the study area were carnivorous species feeding predominantly on insects only in exception of *Xenopus victorianus* which included some fish in the stomach contents analyzed. In line with this current study, it is true because some of the species (*Phrynobatrachus graueri*, *Sclerophrys kisoloensis*) listed in his study were also detected with similar feeding items.

Not only did this study support the feeding ecology part, but also in terms of distribution of the observed anuran species in Africa by noting some of the species that are found in East African countries (Uganda, Rwanda, Tanzania, and Kenya) and West African countries like Cameroon. *Hyperolius cinnamomeoventris, Ptychadena mascarenensis, Amnirana albolabris, Xenopus victorianus,* and *Hyperolius viridiflavus* were some of the species observed in such distribution areas respectively (Schiotiz, 1999; Schiotiz, 1975; Malonza et al., 2018; Malonza et al., 2006; Measey et al., 2009 and Vlock et al., 2013).

This current study identifies some specie's micro habitats being stagnant water, flowing water, or vegetation on edges of water bodies. In support, a study in the Democratic Republic of Congo by Badjedjea et al., (2016) observed and detected *Hopbatrachus occipitalis* in ponds and puddles of within the forest, as well as in the Kponyo River. *Ptychadena mascareniensis* was also observed in the puddles filled with shallow rain water. In addition to that, *A. albolabris* was detected on leaves of some forest habitats while *Hyperolius* species were observed on the vegetation at edges of pools and slow flowing streams just like in the current study observations. This in deed is proof that water bodies are essential in the survival of anuran species (Vlok et al., 2013).

The analysis categorized the anuran species observed in Kingwal swamp and North Nandi Forest either as ground/wet terrestrial dwellers (*Sclerophrys* and *Ptychadena* species)some , aquatic/stream dwellers (*Xenopus* species), puddle frogs on the forest litters (*Phrynobatrachus* species), or arboreal (*Hyperolius* species). This is backed by Tumushimire (2020), Vonesh (2001), and Vlok et al., (2013) whose results showed that anuran species can either inhabit both aquatic and terrestrial or aquatic habitats only. This can be attributed to breeding life cycles, where by some species lay eggs on terrestrial floor and the larvae develops in aquatic environments. These two studies labelled *Hyperolius* species as arboreal species with the reproduction cycle of laying eggs on vegetation (trees) near water and larvae developing in aquatic environments, noted *Ptychadena mascareniensis* as a terrestrial dweller but laying eggs in water bodies. Similarly on *A.albolabris* (occupies swampy forest but laying eggs in water) and *P.grauei* (being leaf litters) was observed in both the current and the previous studies.

Breeding in wet season results from the availability of water bodies acting as breeding sites for anuran species, there is always abundant invertebrates to sustain the survival of frogs. In line with this study, Roelke & Smith (2010) observed a lot of different anuran species in Rwanda during wet season in different breeding sites, which are highly vegetated permanent and temporal pools, ponds, and puddles. In addition, some species of genus *Ametia* were detected along slow flowing streams both in agricultural fields and edges of forests in Mt. Sabinyo. Other species included *A. kisoloensis*, *Hyperolius viridiflavus*, and *P. grauei* were also observed during this season in breeding sites. For species with the varying breeding season, might be attributed to those that mostly inhabit swampy areas with plenty of water through the year such as man-made streams for irrigation, and permanent pools and ponds of water (Spawls et al., 2019; Channing & Howell, 2006; Kassie et al., 2023).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Based on the results , this study suggest a surprisingly high diversity, abundance, and richness of anuran species across habitats survive in Kingwal Swamp and North Nandi Forest Reserve regardless of the study being the second to provide and address herpetofauna related topic for the vast forest and swamp in western Kenya. However that was the case, habitats (Forest) within the protected area are highly diverse, abundant, and has high anuran species compared to habitats (Farmland and Intermediate land) within non protected area. Conserved areas (Forest habitat) inhabits high number of anuran species (mostly specialists) compared to agricultural practiced land farmland and intermediate habitats), although there are some species that occupy and utilize habitats within protected areas and agricultural fields (generalists).

This is attributed to similarities in breeding sites such as stagnant water bodies (pool, pond, and puddles), flowing water bodies (slow flowing stream), and swampy terrestrial vegetation in both protected and non-protected area even though in agricultural lands such microhabitats are affected by degradation, use of agro-chemicals, as well as habitat expansion for agricultural activities. On the other hand, such microhabitat (breeding sites) are less interfered with due to conservation efforts, thus they provide a healthy ecosystem with wide variety of resources (cover, invertebrates) necessary for the survival of anuran species.

This research clearly illustrates protected areas as evenly distributed areas with high species abundance and richness, but it also raises the question of why such results are vice versa during dry season specifically in terms of species richness.

Based on the analysis of this study, one can conclude that season has an influence on the diversity, abundance, richness, and distribution of anuran species between Kingwal Swamp and North Nandi Forest Reserve. High biodiversity is attributed to wet season (rainy) as it is the breeding season for most anuran species due to the availability of water which plays a critical role in their reproductive cycle, acting as home for the both eggs and larvae in some species and predominantly home for larvae in some species.

The results of this study also imply that habitats in protected and non-protected areas can be equally crucial in terms of maintaining anuran species populations and this suggests the considerations of all the habitats regardless of the conservation status (protected or not) when developing management zones.

All in one, anuran species diversity, abundance, distribution, and concordance is a function of habitat diversity or quality and season, with the associated differences in microhabitat structure that provide diverse ways of exploring resources. The modest sampling indicates that Kingwal Swamp and North Nandi Forest Reserve are rich and support anuran species.

However, given the scarcity of herpetofauna assessments and monitoring in some parts of western Kenya, the current study act as an essential contribution to the country‘s ecological research in the field of herpetology. The new compiled checklist of frogs and information on the distribution, feeding guild, ecological guild, as well as breeding behaviors presented in this study serve and act as a source of further or future research as well as aiding management and conservation authorities in setting subsequent and significant plans for monitoring anuran biodiversity.

Despite its limitations, the study certainly contributes to our understanding of the anuran biodiversity between habitats of a protected (North Nandi Forest Reserve) and a non-protected (Kingwal Swamp) areas and clearly elaborates that conservation efforts of micro habitats is essential for anuran biodiversity.

Due to the fact that observations of this current study showed anuran diversity and distribution in and around habitats in the study area, it have generated the base line data for the anurans biodiversity in Kingwal Swamp and North Nandi Forest Reserve, Nandi County.

6.2. Recommendations

Given the observed increasing number of human induced habitat modification and expansion to fulfil agricultural practices along the wetland and the forest , this study would recommend conservation interventions through continuous assessment, regular evaluation, and monitoring of anuran conservation status along the wetland and the forest by Kenya Wildlife Services, Kenya Forest Services, conservationists, researchers, scholars, and other nature-based organizations for the survival of anuran biodiversity in Kenya.

Based on the results, this research advices the strengthening of anuran species conservation and their habitats both along the swamp and the forest through creation and running of environmental awareness programs not only in schools but to the entire public (specifically along Kingwal Swamp) so as to involve and inform them about ecosystem services, habitat management, aiming at mitigating or changing their negative imprecisions and perceptions of human activity pressures towards herpetofauna populations.

The differences in anuran species diversity and abundance in the 3-habitats demonstrate that conservation efforts continue to be a priority. Therefore, the government should help the local members or rather turn or transform Kingwal Swamp into a protected area either owned by the locals or the government for as long as it will serve as a reserve for biodiversity and benefiting the people. In this case, the wetland will not be threatened, but rather act as a tourism attraction site.

There is a need to boost conservation interventions on habitats within non-protect areas such as wetlands, riverine forests, swampy forests, as well as horticultural and agro plantations that play critical roles both in providing suitable microhabitats for anuran species and ensuring the food security to the local communities.

With regards to fragmented land scape due to human activities, the study recommends preserving artificially constructed water bodies within agricultural fields and forest edges as they aid in maintaining anuran populations.

Below are some of the recommended future research to cover some of the aspects on anuran species;

i. All though this study has stated that the sampling effort was adequate both in dry and wet season, a varied range of habitats (apart from farmland, intermediate, and forest) both in protected and non-protected must be investigated to determine or maintain a high anuran species biodiversity and the extent of population distribution in the suitable habitat.

ii. Dietary assessment in different agricultural land use patterns, protected forests and wetlands is suggested to understand the feeding ecology of anuran species, as feeding ecology influences the diversity and abundance of anurans.

iii. Assessment on abundance, not only in numbers but as well as density for better clarifications in terms of populations and habitat preferences.

iv. Functional diversity and distribution of anuran species in Kingwal swamp and North Nandi Forest Reserve, as to see whether the functional attributes (breeding behaviors, feeding guild, ecological guild) influences diversity and abundance of these species.

v. Level of awareness and Perceptions of local community members on the values (ecosystem services) of anurans, as to assess the provisional, cultural, regulating, and supporting importance generated from anurans, this might aid in changing their perception and turn the wetland into a protected area.

vi. There is a need to carry out a study focusing on the influence of environmental variables that effects anuran species abundance and distribution in both the protected and non-protected area.

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APPENDICES

Appendix I: Some of the frog and toad species recorded in Kingwal Swamp and North Nandi Forest Reserve. (A) *Amietia nutti*; (B) *Sclerophyrs kisoloensis*; (C) *Ptychadena nilotica*; (D) *Hyperolis viridiflavus*; (E) *Xenopus victorianus*; (F) *Ptychadena porossisma*; (G) *Sclerophrys guturallis*; (H) *Phrynobatrachus scheffleri*; (I) *Hyperolius cinnamomeoventris*; (J) *Amnirana albolabris*; (K) *Phrynobatrachus keniensis*; (L) *Phrynobatrachus natalensis*; (M) & (N) *Phrynobatrachus graueri* (Author, 2023).


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Appendix II: Relative abundance of anuran species recorded in three habitat types of Kingwal Swamp and North Nandi Forest Reserve.

Family	Species	Habitats						Total		Relative Abundance (Rank)	
		Farmland		Intermediate		Forest					
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bufonidae	*Sclerophrys kisoloensis*	4(2.22%)	7(2.02%)	5(4.24%)	9(2.87%)	0(0%)	7(1.46%)	9	23	1.77(8)	2.02(9)
	Sclerophrys gutturalis	4(2.22%)	4(1.15%)	2(1.69%)	5(1.59%)	0(0%)	5(1.04%)	6	14	1.18(10)	1.23(13)
Ptychadenidae	*Ptychadena porossisma*	48 (26.7%)	87 (25.1%)	39(33.1%)	56(17.8%)	58 (27.5%)	97(20.3%)	145	240	28.5(2)	21.1(2)
	Ptychadena nilotica	77 (42.8%)	92 (26.5%)	34(28.8%)	64(20.4%)	56 (26.5%)	90(18.8%)	167	246	32.8(1)	21.6(1)
	Ptychadena oxyrhynchus	0(0%)	16 (4.61%)	0(0%)	15(4.78%)	0(0%)	26(5.43%)	0	57	0	5(6)
	Ptychadena anchieta	9(5%)	13 (3.75%)	4(3.39%)	17(5.41%)	22 (10.4%)	20(4.18%)	35	50	6.88(4)	4.39(7)
	Ptychadena taenioscelis	0(0%)	20 (5.76%)	0(0%)	31(9.87%)	0(0%)	15(3.13%)	0	66	0	5.79(5)
	Ptychadena mahnert	0(0%)	26 (7.49%)	0(0%)	39(12.4%)	0(0%)	16(3.34%)	0	81	0	7.11(4)
	Ptychadena mascareniensis	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	16(3.34%)	0	16	0	1.4 (11)
Pipidae	*Xenopus borealis*	0(0%)	8(2.31%)	0(0%)	3(0.96%)	0(0%)	0(0%)	0	11	0	0.96(16)
	Xenopus victorianus	4(2.22%)	6(1.73%)	3(2.54%)	6(1.91%)	0(0%)	9(1.88%)	7	21	1.38(9)	1.84(10)
Phrynobatrachidae	*Phrynobatrachus graueri*	13 (7.22%)	26 (7.49%)	9(7.63%)	17(5.41%)	12(5.69%)	14(2.92%)	34	57	6.68(5)	5(6)
	Phrynobatrachus natalensis	0(0%)	0(0%)	0(0%)	0(0%)	14(6.64%)	16(3.34%)	14	16	2.75(6)	1.4(11)
	Phrynobatrachus scheffleri	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	12(2.51%)	0	12	0	1.05(15)
	Phrynobatrachus keniensis	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	12(2.51%)	0	12	0	1.05(15)

Hyperoliidae	*Hyperolius viridiflavus*	0(0%)	7(2.02%)	0(0%)	6(1.91%)	12(5.69%)	25(5.22%)	12	38	2.36(7)	3.33(8)
	Hyperolius cinnamomeoventris	0(0%)	0(0%)	0(0%)	5(1.59%)	0(0%)	8(1.67%)	0	13	0	1.14(14)
Dicroglossidae	*Hoplobatrachus occipitalis*	0(0%)	4(1.15%)	0(0%)	4(1.27%)	0(0%)	7(1.46%)	0	15	0	1.32(12)
Arthroleptidae	*Leptopelis mackayi*	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	11(2.3%)	0	11	0	0.96(16)
Pyxicephalidae	*Amietia nutti*	21 (11.7%)	31 (8.93%)	22(18.6%)	37(11.8%)	37(17.5%)	63(13.2%)	80	131	15.7(3)	11.5(3)
Ranidae	*Amnirana albolabris*	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	10(2.09%)	0	10	0	0.88(17)
Total Number of Indviduals		180	347	118	314	211	479	509	1140	100	100
Total Number of Species		8	14	8	15	7	20	10	21		

Appendix III: Functional attributes for the carnivorous anuran species recorded in Kingwal Swamp and North Nandi Forest Reserve (AmphibiaWeb, 2023; ASA, 2022; Aurthor, 2023).

Scientific name	Common name	Food item	Ecological guild	Micro-habitats based on water availability	Breeding location	Microhabitat type in relation to Breeding location	Major habitat	Breeding season
Sclerophrys kisoloensis †	Kisolo Toad	Insects, Frogs	Ground Dwelling/Terrestrial	Lotic water	Slow stream, pool	Water bodies	Terrestrial, Aquatic	Wet
Sclerophrys gutturalis †	Guttural Toad	Insects, Frogs, Reptiles	Ground Dwelling/Terrestrial	Lotic water	Pond, pool	Water bodies	Terrestrial, Aquatic	Vary
Amietia nutti †	Nutt's River Frog	Insects, Frogs	Stream Dwelling	Lentic water	Shallow water	Water bodies	Terrestrial, Aquatic	Wet
Ptychadena porossisma †	Striped Rocket Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic water	shallow water, sedge	Vegetation near water	Terrestrial, Aquatic	Vary
Ptychadena nilotica †	Nile Rocket Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic water	Pool, marsh	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus graueri †	Grauer's Puddle Frog	Insects	Leaf Litter	General terrestrial/Lotic	Leaf litter, swampy forest edges, eggs deposited in water	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Ptychadena oxyrhynchus †	Sharp Nosed Rocket Frog	Insects	Wet terrestrial dwelling	Lotic water	Herbaceous vegetation on edge of shallow water bodies (puddles, ditches)	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Ptychadena anchieta †	Archita's	Insects	Ground	Lotic water	Vegetation	Vegetation near	Terrestrial,	Wet

	Ridged Frog		Dwelling/Terrestrial		near Shallow water/pond	water bodies	Aquatic	season
Xenopus victorianus †	Lake Victoria Clawed Frog	Insects, Frogs,	Aquatic dwelling	Lotic water	Pond, pool	water bodies	Aquatic	Wet
Ptychadena taenioscelis †	Small Rocket Frog	Insects	Wet terrestrial dwelling	Lotic water	Shallow water (flooded grassland, pools)	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Xenopus borealis §	Marsabit Clawed Frog	Insects, Frogs, Fish	Aquatic dwelling	Lotic/Lentic water	Fresh water pools/ponds, even steams	water bodies	Aquatic	Wet
Ptychadena mahnert †	Mahnert's Rocket Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic water	herbaceous marshes and permanent ponds	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Hyperolius viridiflavus †	Common Reed Frog	Insects	Arboreal	Lotic water	Eggs deposited into water bodies (aquatic habitats)	water bodies	Terrestrial, Aquatic	Wet
Hoplobatrachus occipitalis †	Eastern Groove-Crowned Bullfrog	Insects, Frogs, Fish	Aquatic dwelling	Lotic/Lentic water	Slow moving heavily vegetated streams	Vegetation near water bodies/Water bodies	Terrestrial, Aquatic	Wet
Hyperolius cinnamomeoventris †	Cinnamon-Bellied Reed Frog	Insects	Arboreal	General terrestrial/Lotic	Eggs arboreal, larvae aquatic)	On trees/vegetation near water bodies	Terrestrial, Aquatic	Wet
Leptopelis mackayi ‡	Mackay's forest tree frog	**?**	Arboreal	General terrestrial/Lotic	Eggs on forest floor, tadpoles in puddles	On tree/vegetation near water bodies	Terrestrial, Aquatic	Wet

Ptychadena mascareniensis‡	Mascarene Ridged Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic/Lentic water	Puddles, ditches and ruts	water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus scheffleri ‡	Scheffler's Puddle Frog	**?**	Leaf Litter	Lentic water	Lake edges, rivers, streams and pools	Water bodies	Terrestrial, Aquatic	Wet
Amnirana albolabris ‡	Forest White-lipped Frog	**?**	Arboreal	Lotic water	Shallow water, Swampy forest/valley bottom	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus natalensis‡	Natal Puddle Frog	Insects, Snails, Frogs	Leaf Litter	Lotic/Lentic water	Puddles, ditches, streams, ponds	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus keniensis ‡	Upland Puddle Frog	Insects	Leaf Litter	Lotic water	shallow standing waters	Water bodies	Terrestrial, Aquatic	Wet

Note: †= Observed in both Kingwal Swamp and North Nandi Forest Reserve; ‡ = North Nandi Forest Reserve only; § = Kingwal Swamp

Appendix IV: Similarity Report

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