

Evaluation of species diversity and ecological functions of the anuran species in Kingwal swamp, a highland wetland of Kenya

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Abstract

Class amphibian comprises of bi-phasic life mode organisms sensitive to environmental changes. Anurans being among the class, are considered good indicators of functioning and non-functioning ecosystems (habitat quality). Globally, there has been a decline in anuran populations due to anthropogenic and abiotic factors, which include agricultural activities, wetland degradation, habitat loss, pollution, and climate change. Wetlands are considered the most preferable microhabitats as breeding sites for anurans, therefore surveys in tropical wetlands to understand anuran diversity and distribution patterns are desirable and justified for implementation of effective conservation actions. The aim of the study was to evaluate the biodiversity and functional concordance of anuran species in Kingwal Swamp, one of Kenya's least studied swamps. Through the use of visual encounters and pitfall traps with an x-drift fence, data was gathered in the wet season, morning and evening sampling between April and June 2023 from six sites along the swamp. A total of 664 individuals were recorded, from 15 different anurans belonging to seven different genera and seven families. Ptychadena was the most abundant family, while Hoplobatrachus was the least. The swamp is diverse ($H' = 2.271$, $D = 0.8626$) in anuran species with low dominance (0.1374), but evenly distributed ($E = 0.6457$). Most species encountered preferred insects and frogs in their diet, terrestrial and aquatic microhabitats, specifically stagnant water, and were predominately ground/wet terrestrial dwellers breeding during wet season, and of least concern. The structural complexity of microhabitats along the swamp provided diverse niches and varieties of ways to explore environmental resources, thus species biodiversity is a function of habitat quality and diversity. However, due to increased disturbances, the study recommends nature-based non-governmental organizations and conservationists to engage local people in wetland protection to curb threats for the survival of anurans in Kenya.

Keywords: Concordance; Conservation; Anuran species; Heterogeneity; Wetland

Introduction

Amphibians are considered bio-indicators of functioning and nonfunctioning ecosystems (Valencia-Aguilar *et al.*, 2013), and as it stands, the earth is experiencing an accelerated and unprecedented loss of biodiversity resulting in changed interactions among species and a decline in ecosystem functioning. Worldwide, these declines and loss of biodiversity are caused by human activities (Wake & Vredenburg, 2008; Thompson & Donnelly, 2018), specifically induced conversion of natural macro and microhabitats into agricultural fields. In the tropics, natural habitats suitable and preferred by wild animals have been fragmented anthropogenically from wetland degradation, rapid expansion in agricultural encroachment, timber harvesting, pollution, overexploitation, and climate change (abiotic) (Runting *et al.*, 2017; Hirschfeld *et al.*, 2016; Cheng *et al.*, 2011; Ficetola *et al.*, 2014; Hof *et al.*, 2011). Significantly, these threats have increased not only in Africa but worldwide with an impact on the biodiversity activity patterns including anuran that inhabit both wetland and terrestrial habitats (Asefa *et al.*, 2020; Estrada *et al.*, 2020; Archer *et al.*, 2018).

Wetlands being considered major habitat for anurans; it is important to understand how they operate for the survival of these organisms. Knowing biodiversity status in wetlands is one of the major goals of conservation ecology. In Kenya, past studies focused mainly on amphibians but mainly in key biodiversity areas, such as Taita Hills (Malonza *et al.*, 2010), Tana River forests, Cherangani Hills, Kakamega Forest (Lötters *et al.*, 2007), Arabuko-Sokoke Forest, Shimba Hills, and Mt. Kenya forest (Malonza *et al.* 2010; Bwong *et al.*, 2009; Bwong *et al.*, 2017; Ng'endo *et al.*, 2011; Malonza *et al.*, 2011; Malonza & Veith, 2012; Malonza *et al.*, 2018). So far, the recorded number of amphibian species in Kenya is about 100 (Malonza & Bwong, 2023), but there are still significant gaps in our knowledge regarding the anuran species of Kingwal Swamp. Not only do human activities influence anuran biodiversity patterns, but also habitat variations (heterogeneity) and productivity.

Suitable conservation enactments in wetland ecosystems rely heavily on the awareness and sympathetic of the biodiversity configurations of organisms (including anurans) dwelling in such environments (Nneji *et al.*, 2021; Rahman *et al.*, 2020). Kingwal Swamp has a significant and increased trend of habitat loss and destruction due to lack of conservation measure implementation (non-protected area), and this threatens anuran biodiversity, thus survey efforts on frogs and toads are desirable and justified.

To date, there is inadequate information on the diversity and distribution patterns of anuran species in the swamp (Kabanze *et al.*, 2023). Documented in this juncture are results providing vital baseline data for Kingwal Swamp, aimed at authenticating anuran species biodiversity and concordance in order to initiate long-lasting effective conservation guidelines or action plans to curb threats towards frogs and toads.

Materials and Methods

Study Area

Kingwal Swamp in Nandi County, western Kenya is an expansive swamp located within 0° to 0° 34" N and 34° 44" to 35° 25" E, deriving its main catchment from Uasin Gishu count near Kesses (Figure 1). Designed as a non-protected wetland, it is home to *Tragelaphus spekei*, encompassing the Kesses River, streams, springs, and interconnected swamps stretching from Lolminingai to Kombe locations (World Bank, 2014). It receives water from the above-mentioned water bodies flowing from the east and drains into the Kimondi (Kingwal) River while flowing to the west of the wetland. Positioned approximately 25 km from Eldoret town towards Kapsabet town, the vast swamp covers an area of 2.73 km² with varying rainfall patterns i.e. the northern parts receive an average annual ranging from 1200 to 1600 mm, while the southern part ranges from 1200 to 2000 mm which is attributed to the Lake basin atmospheric conditions. Regardless of higher rainfall patterns, the swamp experiences dry spells typically from the end of December to mid-March but with ample opportunities for diverse crop production (horticultural crops, pyrethrum, cereals, and fruit tree plantations) withstanding seasonal temperature variations ranging from 15°C to 20°C during wet seasons and peaks up to 24°C during dry seasons. Biodiversity-wise, various vegetation types thrive within the wetland i.e. forests, grasslands, reeds, papyrus, water lilies, and scrubland. *Andropogon gayanus*, *Heteropogon contortus*, *Panicum maximum*, and *Sporobolus pyramidalis* are some of the dominant grass species. However, 40% of the wetland has been converted into *Eucalyptus*, *Azadirachta indica*, and tea plantations (Sitieni *et al.*, 2012). Not only does it support the Sitatunga antelope, but is a habitat for different species of mammals, birds, fish, and herpetofauna. Human activities primarily consist of extensive crop farming of maize, horticulture, tea plantation, livestock keeping, agro-forest (*Eucalyptus* cultivation), and brick-making, leading to environmental issues i.e. wetland degradation and climate change, posing significant challenges to the wetland's biodiversity (Achieng *et al.*, 2014).

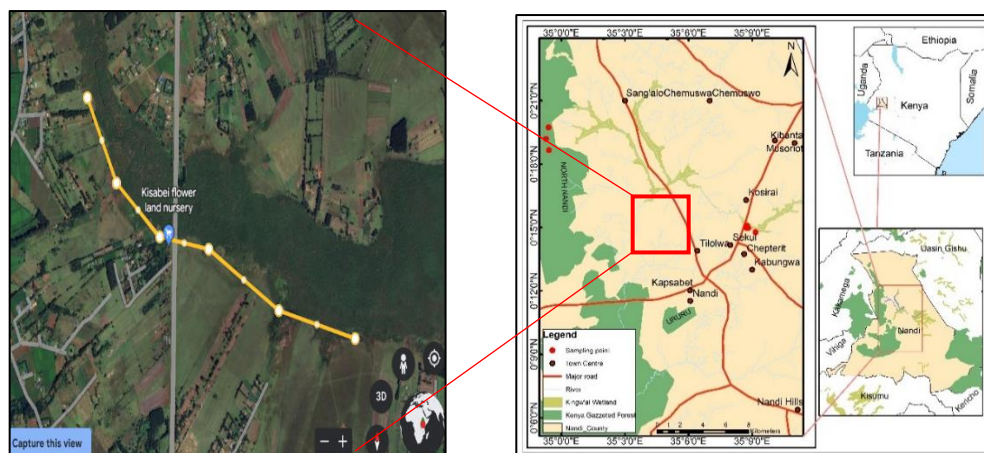


Figure 1: Map of the study area (Six yellow dotted sampling points along Kingwal Swamp) (Kabanze *et al.*, 2023)

Sampling Design

The frog surveys were carried out during the wet season from 11th April to 24th April 2023 and from 01st June to 10th June 2023, this was due to the assumption that anurans associate greatly with precipitation. The study area was stratified into six random sampling points. In each sampling point, a line transect (200 m by 10 m) was built starting at any random point (Rödel & Ernst, 2004), totaling to nine transects in the study area.

Data Collection

Data was gathered using the standard methods for sampling anuran species i.e. Visual encounter and pitfall traps with X-drift fence methods. Visual observations were conducted twice a day for 2 to 4 hours, 6 days per week, with two people walking along the transect at a constant speed from 06:00 am to 08:00 am (diurnal) and from 5:00 pm to 7:00 pm (nocturnal) to maximize species numbers and abundance (Heyer *et al.*, 1994). At each transect, pitfall traps with an X-drift fence were set to capture or detect some species that may not be easily found physically and visually i.e. they are small, primarily nocturnal, or crawling frogs. Similarly, they were also checked twice a day, early in the morning and late in the afternoons (Malonza *et al.*, 2018). Active random searches were employed in locations a few meters away from transects by carefully turning over logs, rocks, leaves or leaf litter, and other potential hiding places. Ecological and functional species attributes related to the utility of the taxa (frogs and toads) such as feeding guild, ecological guild, breeding guild, microhabitats, and conservation status, were noted using the existing literature review and online references. All species detected were identified using Field guide books (Channing & Howell, 2006).

Data Analyses

Collected data was arranged, organized, and entered into MS Excel 2013. Paleontological Statistics Software (PAST) version 4.12 was used to determine Alpha diversity (Hammer *et al.*, 2001), quantified as species richness, abundance, evenness, and dominance of anurans in the study area (Delatore & Nuneza, 2021).

The Shannon-Weaver index (H') was computed to analyze anuran species diversity as follows:

$$(H') = -\sum(Pi \ln Pi)$$

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

The Simpson diversity index was computed to determine the dominance of anurans or rather reflect how many types of species are in a community and how evenly distributed the population is, given as;

$$\text{Simpson diversity index} = (1/D)$$

Where $D = \frac{\sum ni(ni-1)}{N(N-1)}$, ni is the number of individuals in the i -th species, and N is the total number of individuals in the community (Singh et al., 2023).

To measure evenness, Shannon's evenness index (E) was employed, which is the ratio of observed diversity to maximum diversity and abundance, given as; $E = H' / \ln(s)$,

Where E is the Shannon evenness index; H' = the Shannon-Wiener diversity index; \ln = the natural logarithm of species richness, and s = the number of anuran species recorded in one community.

The evenness index has a range of values from 0 to 1; when values are close to 1, the species are evenly distributed and when close to 0, they are not evenly distributed (Shannon & Weiner, 1949).

Sampling effort and success were assessed using species accumulation curves generated from MS Excel 2013. Concordance (functional and ecological attributes) was analyzed through Ecological Guild Analysis, and guild classification was used to gain a greater understanding of spatial patterns of species richness as well as assemblage structure (Williams, 1997). Therefore anurans were classified into guilds on the basis of possible variables describing their functional ecology from order to species level.

Results

Species Diversity, Richness, and Abundance

The analysis indicated that Kingwal Swamp is diverse in anuran species, with a mean Shannon diversity index and Simpson diversity index of 2.271 and 0.8626 respectively. Apart from being diverse, habitats within the study area were evenly distributed with an evenness index value of 0.6457, hence increased diversity and evenness means low species dominance (0.1374) in the community (Table 1).

Table 1: Anuran biodiversity indices of anurans in Kingwal Swamp.

Diversity	Biodiversity Index Values
Taxa_S	15
Individuals	664
Dominance	0.1374
Shannon_H'	2.271
Evenness_e^H/S	0.6457
Simpson_1-D	0.8626

A total number of 15 species from seven different families and six different genera were recorded in Kingwal Swamp. Family Ptychadenidae had the highest dominant species richness (7 species), followed by families Hyperoliidae and Pipidae with 2 species each, and the least families were

Dicroglossidae and Pyxicephalidae with only a single species each. Genera *Ptychadena* had the highest number of species (n=6), followed by genera *Sclerophrys*, *Xenopus*, and *Hyperolius* (n = 2 species each), while genera *Phrynobatrachus*, *Hoplobatrachus*, and *Amietia* were the least with a single species each (Table 2).

In the evaluation of the species abundance described as the total number of individuals of all the species in the study area, a total of 664 individuals were recorded in the study area. The *Ptychadena nilotica* was the most abundant species with 158 individuals (23.8 %), followed by *Ptychadena porossisma* with 143 individuals (21.54 %), while *Hoplobatrachus occipitalis* was the least abundant species with only 7 individuals (1.05 %). Ptychadenidae was the most abundant family (n = 477 individuals), followed by Pyxicephalidae (n = 66 individuals), while the family Dicroglossidae was the least abundant (11 individuals). The most abundant genera was *Ptychadena* (individuals), while *Xenopus* and *Hyperolius* were the least (n = 23 individuals each) (Table 2).

Table 2: Species composition, relative frequency (%), distribution, and conservation status of anurans in Kingwal Swamp

Family	Scientific name	Number of individuals	Distribution in Africa	IUCN Red list	Collection method
Bufonidae	<i>Sclerophrys kisoensis</i>	16 (2.41%)	East, and Southern	LC	VE
	<i>Sclerophrys pusilla</i>	9 (1.36%)	East, and Southern	LC	VE
Dicroglossidae	<i>Hoplobatrachus occipitalis</i>	7 (1.05%)	Sub-Saharan	LC	VE
Hyperoliidae	<i>Hyperolius viridiflavus</i>	13 (1.96%)	East	LC	VE
	<i>Hyperolius cinnamomeoventris</i>	10 (1.51%)	East, West, and Southern	LC	VE
Pipidae	<i>Xenopus borealis</i>	11 (1.66%)	Eastern	LC	PT
	<i>Xenopus victorianus</i>	12 (1.81%)	Eastern	LC	PT
Phrynobatrachidae	<i>Phrynobatrachus graueri</i>	43 (6.48%)	East, and Central	LC	VE
Ptychadenidae	<i>Ptychadena porossisma</i>	143 (21.54%)	East, and Southern	LC	VE
	<i>Ptychadena nilotica</i>	158 (23.8%)	East, and Northern	LC	VE
	<i>Ptychadena oxyrhynchus</i>	31 (4.67%)	East, Central, and Southern	LC	VE

	Ptychadena anchieta	29 (4.37%)	Eastern	LC	VE
	Ptychadena taenioscelis	51 (7.68%)	East, and Southern	LC	VE
	Ptychadena mahnert	65 (9.79%)	Eastern	LC	VE
Pyxicephalidae	Amietia nutti	66 (9.94%)	East, and Southern	LC	VE
Total number of individuals		664			
Total number of species		15			

Note: IUCN red list; LC = Least Concern; Methods used; VE= Visual encounters, PT= Pitfall traps with X-drift fence

Species Accumulation Curve and Richness Estimation

Species accumulation (sample-based) curves were generated to justify whether sampling effort and sample size were adequate in the study area.

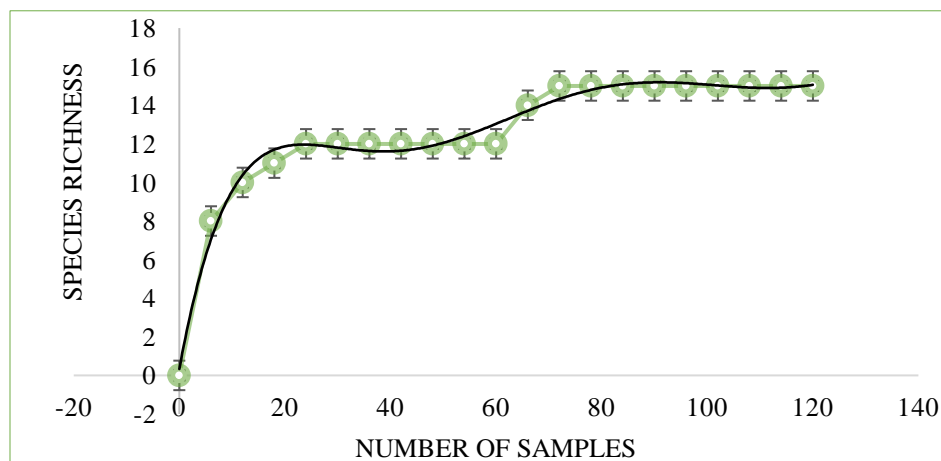


Figure 2: Species accumulation curves of anuran species along Kingwal Swamp

The species accumulation curve achieved an asymptote point (stabilized) at 469 individuals from 15 species on day 12 in 72 samples, hence the sampling effort and sample size were adequate but at a low rate of species richness. However, there are still chances that newer species could be discovered in the study area with additional sampling, albeit at a slower rate. During this sampling effort, the cumulative number of species based on the number of samples and sampling days resulted in 15 species in Kingwal Swamp (Figure 2).

Species Concordance

Used five functional attributes considered important for assessing the effects and response of anuran species to habitat variations due to anthropogenic activities; 1) Feeding guild (dietary) and major food item; 2) Ecological guild (they arboreal, leaf litter, aquatic, or terrestrial dwellers); 3)

Major habitats preference (terrestrial habitats, aquatic habitats, or both); 4) Micro-habitats preference (availability of stagnant water, flowing water, or both influencing their reproductive cycle); 5) Breeding behavior (location and seasonality of breeding). Species functional attributes were obtained from the African Amphibian scratchpad.

All the observed anuran individuals were carnivorous species (Appendix 1). Of the carnivorous species identified, most (40% per guild) feed either predominantly on insects and frogs only ($n = 6$ species), or on insects only ($n = 6$ species), while 13.33 % ($n = 2$ species) feed on insects, frogs, and fish, and only a single species feed on insects, frogs, and reptiles (6.67 %) (Figure 3, a); Appendix 1). In terms of ecological guilds, most anuran species (53.33 %) were ground/wet terrestrial dwellers, while 26.67 % were Aquatic/stream dwellers, 13.33 % were arboreal ($n = 2$ species), and only a single puddle frog on leaf-litters was observed (6.67 %) (Figure 3, b); Appendix 1).

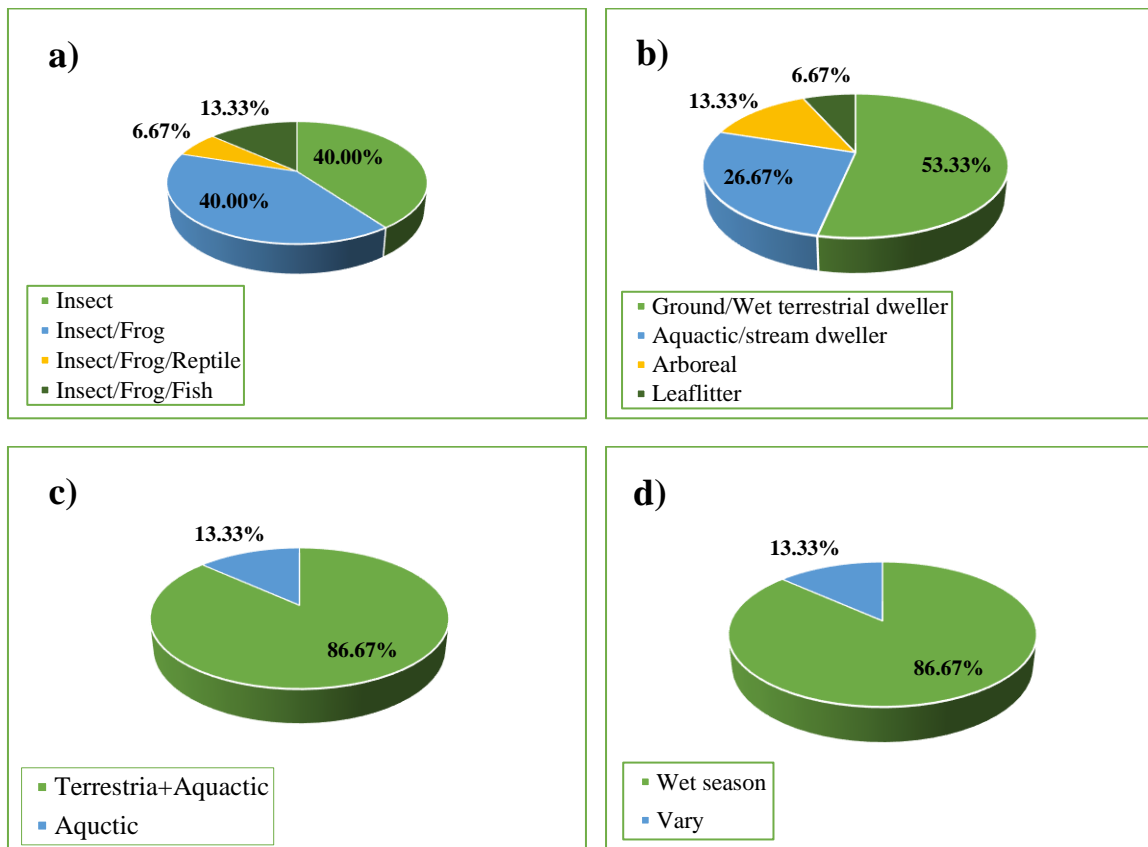


Figure 3: a) Dietary (food item), b) ecological guild, c) major habitats/biome, and d) breeding season of anuran species in Kingwal swamp

Regarding major habitats, the majority (86.67 %) of anuran species observed inhabit both terrestrial and aquatic habitats (biome), while 13.33 % ($n = 2$ species) occupy aquatic habitats only (Figure 3, c); Appendix 1). Similarly, 86.67 % ($n = 13$ species) of the species breed during the wet season, and only 13.33 % were found to vary in breeding seasons (Figure 3, d); Appendix 1).

In terms of micro-habitats where breeding occurs based on the availability of stagnant water, flowing water, or both influencing their reproductive cycle, the analysis shows that most anuran species (66.67 %) observed in Kingwal Swamp specifically require stagnant water for breeding purposes, whereas 13.33 % (n = 2 species) requires both flowing and stagnant water, similarly, 13.33 % of the anurans use both general terrestrial and stagnant water, and only a single species (6.67 %) requires specifically flowing water for its reproductive cycle (Figure 4, a); Appendix 1).

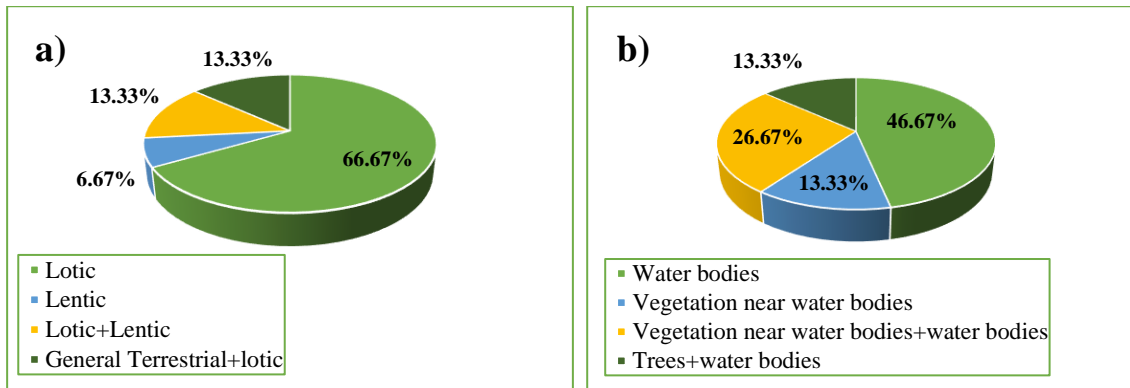


Figure 4: a) Microhabitats for breeding based on the availability of water influencing the reproductive cycle, and b) microhabitat type and breeding location of anuran species in Kingwal Swamp

In terms of microhabitat type in relation to breeding location, 46.67 % (n = 7 species) of the observed anurans use water bodies as breeding sites (both eggs and the larvae in water), 26.67 % (n = 4 species) use both vegetation near water bodies and water bodies (eggs laid on the vegetation and sometimes fall into water bodies). The remaining species, 9.52 % (n = 2 species) use vegetation near water bodies only (marshes or herbaceous plants at edges of water bodies) while the other 9.52 % of species lay eggs in trees/arboreal habitats but larvae develop in water bodies (Figure 4, b); Appendix 1). Regarding the conservation status, all the species observed were categorized under least concern (LC) (Table 2). In terms of distribution across Africa, most (33.33 % per locality) of the species are distributed in either Eastern Africa (n = 5 species) only or in Eastern and Southern Africa (n = 5 species) only. The rest of the remaining species are found in Sub-Saharan Africa; Eastern and Central Africa; Eastern, Central, and Southern Africa; Eastern, Western, and Southern Africa; and lastly in Eastern and Northern Africa, each with a single species (6.67 % per locality) (Table 2).



Figure 5: Some of the frog pictures recorded from Kingwal Swamp. A) *Amietia nutti*; B) *Sclerophrys kisoensis*; C) *Ptychadena nilotica*; D) *Hyperolis viridiflavus*; E) *Phrynobatrachus graueri*; F) *Xenopus victorianus*; G) *Ptychadena porossisma*; H) *Sclerophrys pusilla*; I) *Hyperolius cinnamomeoventris*.

Discussions

Diversity, Richness, and Abundance

A relatively high species diversity, abundance, and average richness in Kingwal swamp is attributed to habitat heterogeneity spatially. This concurs with past studies that have shown that herpetofauna biodiversity is highly influenced by habitat productivity which is a function of rainfall, and environmental factors associated with their habitat structure (Pearman, 1997; Jongma et al., 2014; Onadeko, 2016; da-Silva & Rossa-Feres, 2011; Kassie et al., 2023). In line with the analysis, species biodiversity i.e. diversity, richness, composition, and abundance is a function of habitat diversity and season in such a way that the structural complexity of the former provides diverse niches (breeding sites, for example highly vegetated healthy lotic and lentic water bodies i.e. puddles, ponds and slow flowing streams within agricultural fields and other microhabitats along the swamp) and varieties of ways in terms of exploring environmental resources (invertebrates as food, and predation cover) (Tews et al., 2004; Malonza, 2011; Auguste & Hailey 2018; Rahman et al., 2022; Ndriantsoa et al., 2017).

The vast wetland is surrounded by agricultural fields (referred to as anthropogenic disturbances) but still, there are relatively high figures in diversity, abundance, and richness. This can be associated with the fact that species detected in these microhabitats are generalists who make use of modified habitats or habitat patchiness (Ndriantsoa et al., 2017; da-Silva & Rossa-Feres, 2007). Increased species richness and abundance can also be associated with the application of different modes of sampling methods and time of the day as suggested by other studies (Nyamache et al., 2017; Oda, et al., 2016). For the generalist species (utilizing both forest remnants and agricultural land as their habitat), the structure of the habitat could be associated with providing vocalization sites during breeding seasons. For example, *Hylidae* and *Ptychadena species* found on vegetation at edges of water bodies such as pools, ponds, and slow flowing streams. During the wet season, regarded as the breeding season (Kabanze et al., 2023; Nneji et al., 2019; Watanabe et al., 2005; Giaretta et al., 1999; Vonesh, 2001; Giaretta & Menin, 2004; Ribeiro et al., 2018) in relation to the current study, anurans travel to agricultural land (surrounding environments along Kingwal swamp) in search of food, or the availability of adequate water in the paddy fields (organic pool or pond) serving as breeding sites (Karunakaran & Jeevanandham, 2017; Attademo et al., 2019). Anuran activities tend to vary with the season due to their reliance on local environmental conditions i.e. moisture and temperature, the fact that the current study sampling was done during the wet season, the early months of the rains can be seen to be ideal for anurans appearing to be breeding and were active to allow for detection.

However, the fact that we only got no more than 15 species and 664 individuals maximum along the swamp is of special concern in conservation. The swamp experiences anthropogenic disturbances since it's a non-protected wetland, from wetland degradation to brick-making (World Bank, 2014). The vegetation structure of Kingwal swamp microhabitats is affected by the drainage

of water for irrigational purposes, harvesting of papyrus sedge for economic benefits, clearing of bast land with native biodiversity for crop production, eucalyptus plantation, tea plantation, and as pasture for livestock. All in one, they compromise species richness, abundance, and diversity of anurans depending on the swamp. This current study established that the wetland is experiencing high-intensity of anthropogenic disturbances i.e. overgrazing, expansion in agricultural activities, water drainage for nursery irrigation, use of agrochemicals, eucalyptus agroforest, and encroachment ruining the preferred microhabitats for breeding purposes in anuran species, hence results in havoc towards anuran populations (Oda, et al., 2016; Dodd, 2010). For example, the use of pesticides pollutes water bodies impacting not only 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. Mathwin et al., (2021) reported that maintaining water sources has an impact on the anuran community, hence increasing species richness and assisting in their conservation. Therefore, water bodies are ideal components to the survival of anuran species.

Species Accumulation Curve and Richness Estimation

Despite the fact that the species cumulative curve in the wetland stabilized, the possibility of local species richness expansion cannot be excluded, hence increased effort in this study would add to the species richness very slowly, as evidenced by richness estimators (standard errors) displayed by the curve. Kassie et al. (2023) reported that frogs along a wetland in Ethiopia displayed species accumulation curves with asymptotic points which conforms to the findings in this study. 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 visually or physically and also to gain a more complete understanding of their ecology (Maritz et al., 2007; Ribeiro et al., 2008) since species biodiversity i.e. diversity, abundance, and richness is associated with sampling effort invested by researchers (Costa-Campos & Freire, 2019). The stabilization of curves can be attributed to combined diurnal and nocturnal sampling, seasonality i.e. breeding season when anurans are in their active state (not hibernating).

Species Concordance

Our knowledge of Kingwal Swamp on anuran species still remains poor. Thus, the swamp is one of the areas in Kenya that still needs more thorough herpetological surveys. This study has provided an eye-opener into what can be found through rapid and continuous assessments. The results of the study show that long-term systematic sampling will unquestionably lead to possibly additional new anuran species. The fact that it could not detect many species may be attributable to limited sampling effort (period of data collection). A good number of anurans may occur in the sites that were not sampled in this study surveys. The broad taxonomy and distribution patterns noted in all the anuran species detected in this 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), 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), the Amphibian Survival Alliance (ASA, 2022), IUCN Red List of Threatened Species (IUCN, 2023), and the Amphibia Web Taxonomy (AmphibiaWeb, 2023).

Vonesh (2001) on amphibians of Kibale National Park in Uganda found that all the anuran species identified in the study area were carnivorous species, predominantly feeding on insects only. Similarly findings were reported in this current study as it is true because most species were found to be predominantly insect and frog eaters. Not only did it support feeding items but gave more emphasis on their distributions in Eastern and Western African ecosystems i.e. Uganda, Rwanda, Tanzania, Kenya, and Cameroon relating to observations by Kabanze et al. (2023), Schiotiz, (1999), Schiotiz, (1975), Malonza et al., (2018), Malonza et al., (2006), Measey et al., (2009), and Vlock et al., (2013) respectively. Most species in the current study, based on the availability of water influencing the reproductive cycle, preferred stagnant water. In support, a study by Badjedjea et al. (2016) in DRC also found that ponds and puddles filled with shallow rainwater were the main breeding sites of anuran species. However, it also emphasized that some species bred in the Kponyo River, while some on leaves of forest habitats (*A. albolabris*), egeation at edges (*Hyperolius* and *Ptychadena* species) of pools and slow-flowing streams. This indeed is proof that water bodies are essential for the survival of anuran species.

The analysis categorized the anuran species observed in Kingwal swamp as either ground/wet terrestrial dwellers (*Sclerophrys* and *Ptychadena* species), aquatic/stream dwellers (*Xenopus* and *Amietia* species), leaf litters (Puddle frogs), or arboreal (*Hyperolius* species). In support, Tumushimire et al. (2020), Vonesh (2001), Vlok et al., (2013), and Kabanze et al. (2023) also showed similar anuran species inhabiting both aquatic and terrestrial macro habitats, or aquatic habitats only. This can be attributed to breeding life cycles, where some species lay eggs on the terrestrial floor and the larvae develop in aquatic environments. The above studies also categorized *Hyperolius* species as arboreal species with a reproduction cycle of laying eggs on vegetation (trees) near water and larvae developing in aquatic environments, noted *Ptychadena* species as a terrestrial dweller but laying eggs in water bodies, and *A.albolabris* occupying swampy forest but laying eggs in water. Breeding in the wet season results from the availability of water bodies acting as breeding sites for anuran species, as there are always abundant invertebrates to sustain the survival of frogs. In line with this study, some studies observed different anuran species in Uganda during the wet season in different breeding sites (highly vegetated permanent and temporal pools, ponds, and puddles). For example, species of genus *Ametia* were detected along slow-flowing streams both in agricultural fields and edges of forests in Mt. Species with the varying breeding season might be attributed to those that mostly inhabit swampy areas with plenty of water throughout the year (Spawls et al., 2019; Channing & Howell., 2006; Kassie et al., 2023).

Conclusions

Based on the analysis, the study suggests a surprisingly high diversity, abundance, and richness of anuran species across habitats surviving in Kingwal Swamp. The structural complexity of microhabitat structures in the swamp provided diverse niches and varieties of ways of exploring environmental resources, thus species biodiversity is a function of habitat quality and diversity, as well as season, hence increased habitat diversity increases anuran species diversity, richness, abundance, and composition in a community. Increase anthropogenic activities along the swamp i.e. wetland degradation, agricultural expansions, encroachment, and use of agrochemicals affect species biodiversity. The only way to curb such disturbances is by boosting wetland (habitats) conservation efforts and interventions that is KWS and KFS educating local communities on the ecosystem services generated from nature or designating such habitats as protected reserves for the benefit of anuran survival in Kenya, and Africa at large. This study recommends continuous assessment with increased sampling efforts including both the dry and the wet seasons, as well as sampling varieties of microhabitats to see variations between microhabitats and between seasons for better-improved conservation plans.

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Appendix 1: Functional attributes for the carnivorous anuran species recorded in Kingwal Swamp

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

<i>Xenopus victorianus</i>	Lake Victoria Clawed Frog	Insect, Frog	Aquatic dwelling	Lotic water	Pond, pool	water bodies	Aquatic	Wet
<i>Ptychadena taenioscelis</i>	Small Rocket Frog	Insect	Wet terrestrial dwelling	Lotic water	Shallow water (flooded grassland, pools)	Vegetation near water bodies	Terrestrial, Aquatic	Wet
<i>Xenopus boreali</i>	Marsabit Clawed Frog	Insect, Frog, Fish	Aquatic dwelling	Lotic/Lentic water	Fresh water pools/ponds, even steams	Water bodies	Aquatic	Wet
<i>Ptychadena mahnert</i>	Mahnert's Rocket Frog	Insect, Frog	Wet terrestrial dwelling	Lotic water	Herbaceous marshes and permanent ponds	Vegetation near water bodies	Terrestrial, Aquatic	Wet
<i>Hyperolius viridiflavus</i>	Common Reed Frog	Insect	Arboreal	Lotic water	Eggs deposited into water bodies (aquatic habitats)	Water bodies	Terrestrial, Aquatic	Wet
<i>Hoplobatrachus occipitali</i>	Eastern Groove-Crowned Bullfrog	Insect, Frog, Fish	Aquatic dwelling	Lotic/Lentic water	Slow moving heavily vegetated streams	Vegetation near water bodies/Water bodies	Terrestrial, Aquatic	Wet
<i>Hyperolius cinnamomeoventris</i>	Cinnamon-Bellied Reed Frog	Insect	Arboreal	General terrestrial/Lotic water	Eggs arboreal, larvae aquatic	On trees/vegetation near water bodies	Terrestrial, Aquatic	Wet

Source: Kabanze et al., (2023)