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RESEARCH ARTICLE

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Anthropogenic effects of habitat modification on anuran species diversity in a swamp forest area, Kenya

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Abstract

Anuran species are some of the good environmental indicators of habitat quality and condition in ecosystems. This is due to their amphibious life modes and sensitivity to environmental change caused by rapid expansion of agricultural activities, advancement of forest destruction, climate change and emerging infectious diseases. Understanding their diversity and distribution patterns is crucial for the development and implementation of effective species and habitat conservation strategies. The study aimed at assessing and comparing anuran biodiversity and distribution patterns between a protected (North Nandi Forest Reserve) and a non-protected area (Kingwal swamp) to provide additional baseline information, both being among the underexplored areas in Kenya. Data were gathered in both dry and wet seasons, between October 2022 and June 2023 by employing standard sampling techniques for anurans(Visual encounter and pitfall traps with a drift fence) to maximise detection. Three habitat types- farmland, intermediate land and forest were exploited. A total of 1649 individuals from 21 different species, belonging to nine different genera and nine different families were recorded. Ptychadenidae was the most abundant family from the recorded anurans, while Dicroglossidae, Arthroleptidae, Pyxicephalidae and Ranidae were the least. High biodiversity was observed 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. There was a significant difference ($p < 0.05$) in diversity between the habitats in wet season, but no significance difference during dry season ($p > 0.05$) except for forest and farmland ($p < 0.05$). There was a significant difference in species abundance between seasons ($p < 0.05$), and between habitats ($p < 0.05$) in all seasons except for farmland and intermediate ($p > 0.05$), as well as farmland and forest ($p > 0.05$) during the wet season. Habitat type and season had no influence ($p > 0.05$) on species richness. Anuran biodiversity is a function of habitat diversity and season, with the associated differences in microhabitat structure providing diverse niches and ways of exploring resources. The modest sampling indicates that Kingwal Swamp and North Nandi Forest Reserve are rich and support anuran species, and the differences in anuran biodiversity between the 3 habitats demonstrates that conservation efforts continue to be a priority.

KEYWORDS
anurans, conservation, diversity, farmlands, frog, protected area

Résumé

Les espèces d'anoures font partie des bons indicateurs environnementaux de la qualité et de l'état de l'habitat dans les écosystèmes. Cela est dû à leur mode de vie amphibie et à leur sensibilité aux changements environnementaux causés par l'expansion rapide des activités agricoles, la progression de la destruction des forêts, le changement climatique et les maladies infectieuses émergentes. Il est essentiel de comprendre leur diversité et leurs schémas de répartition pour élaborer et mettre en œuvre des stratégies efficaces de conservation des espèces et des habitats. L'étude visait à évaluer et à comparer la biodiversité des anoures et leurs schémas de distribution entre une zone protégée (la réserve forestière de North Nandi) et une zone non protégée (le marais de Kingwal) afin de fournir des informations de base supplémentaires, ces deux zones faisant partie des zones sous-explorées du Kenya. Les données ont été recueillies pendant les saisons sèches et humides, entre octobre 2022 et juin 2023, en utilisant des techniques d'échantillonnage standard pour les anoures (rencontre visuelle et pièges à fosse avec une barrière de dérive) afin de maximiser la détection. Trois types d'habitats - terres agricoles, terres intermédiaires et forêts - ont été exploités. Au total, 1649 individus de 21 espèces différentes, appartenant à neuf genres différents et à neuf familles différentes, ont été enregistrés. Ptychadenidae était la famille la plus abondante parmi les anoures recensés, tandis que Dicroglossidae, Arthroleptidae, Pyxicephalidae et Ranidae étaient les moins nombreux. Une grande biodiversité a été observée dans l'habitat forestier (protégé) et une moindre dans les terres agricoles (non protégées). L'abondance, la diversité et la richesse des espèces étaient plus élevées pendant la saison humide que pendant la saison sèche. Il y avait une différence considérable (*p* 0.05) sauf pour la forêt et les terres agricoles (*p* 0.05), ainsi que pour les terres agricoles et la forêt ($p > 0.05$) pendant la saison des pluies. Le type d'habitat et la saison n'ont pas eu d'influence ($p > 0.05$) sur la richesse des espèces. La biodiversité des anoures est fonction de la diversité des habitats et de la saison, les différences associées dans la structure des microhabitats offrant diverses niches et manières d'explorer les ressources. Le modeste échantillonnage indique que le marais de Kingwal et la réserve forestière de North Nandi sont riches et abritent des espèces d'anoures, et les différences dans la biodiversité des anoures entre les 3 habitats démontrent que les efforts de conservation restent une priorité.

1 | INTRODUCTION

Globally, the rapid biological resources decline has reached a status within environmental communities, driving attention to the urgent need for understanding their status and distribution as a major goal in implementing appropriate species conservation actions. Primarily, an associated requirement is assessing the efficiency of current protected and non-protected areas in ensuring long-term preservation and conservation of anuran species. Over 8524 amphibian species have been documented, occupying virtually different types of macro and micro habitats worldwide except the driest and coldest regions, and remote oceanic islands (AmphibiaWeb, 2023; Ceríaco et al., 2014). Anurans are good environmental indicators of habitat quality and condition in ecosystems (Valencia-Aguilar et al., 2013) due to their amphibious life modes and sensitivity to environmental change (Hocking & Babbitt, 2014; Jongsma et al., 2014), their global population decline is attributed to the rapid expansion of agricultural activities, advancement of forest fragmentation and destruction (Thompson & Donnelly, 2018; Wake & Vredenburg, 2008), climate change (Dukes & Mooney, 2004; Runting et al., 2017), invasive species, pollution and emerging fungal infectious diseases (Cheng et al., 2011; Ficetola et al., 2014; Hirschfeld et al., 2016; Hof et al., 2011; Stuart et al., 2004; Zimkus et al., 2018).

These threats have significantly increased in Sub-Saharan Africa, certainly impacting the diversity and distribution patterns of associated flora and fauna (including anurans) that live in both wetland and terrestrial habitats (Archer et al., 2018; Asefa et al., 2020; Estrada et al., 2020).

The patterns of anuran diversity and distributions are determined by their interactions with biotic and abiotic factors (Eterovick & Sazima, 2000; Oda et al., 2016; Wells, 2007), as well as their evolutionary and historical processes (Piha et al., 2007). Coexistence and segregation of anuran species within the same habitat is influenced by microhabitat availability (Foerster & Conte, 2018), on the other hand, it allows anuran species differentiation among habitats (da-Silva et al., 2011; da-Silva & Rossa-Feres, 2011; Vasconcelos et al., 2009), and therefore, habitat variations (heterogeneity) and productivity are considered important factors for anuran species assemblage structure.

Kenya is considered one of the top countries rich in biodiversity, having two of the 35 global biodiversity hotspots (Sloan et al., 2014), the Eastern Afromontane (Afrotemperate) and the Coastal Forests of Eastern Africa hotspots. The former comprises the Taita Hills plus mountain and highland areas in western (Nandi Forests, Cherangani Hills, Kakamega Forest and Mau Hills) and central (Aberdare Range, Mt. Kenya, and Nyambene Hills) Kenya, and the latter comprises the coastal forests of Kenya (Arabuko-Sokoke Forest and Shimba Hills) (Malonza et al., 2018). There are about 100 species of amphibians in Kenya (Malonza & Bwong, 2023), Nandi Forests being one of the components, support high species endemism and richness, at the same time face considerable threats relative to the remaining area (Mittermeier et al., 2005; Myers, 2003; Myers et al., 2000).

In some Kenyan localities, other taxonomic groups have attracted attention, for example invertebrates (Clausnitzer, 2003; Lehmann & Kioko, 2005), mammals (McDonald & Hamilton, 2010) and plants (Achieng et al., 2014; Luke, 2005) but other groups have been underexplored, for example, herpetofauna (Malonza & Bwong, 2023). Although, there has been past studies aimed at understanding the diversity, richness and distribution of amphibians in Key Biodiversity areas (KBA), and particularly diverse in forest areas of Kenya (Bwong et al., 2009, 2017; Lötters et al., 2007; Malonza et al., 2010, 2018; Malonza & Veith, 2012; Ng'endo et al., 2011; Wagner et al., 2008) but there is still a significant gap in our knowledge regarding some parts of western Kenya's anuran biodiversity patterns, that includes largely underexplored North Nandi Forest Reserve (Malonza, 2011) and Kingwal Swamp.

Appropriate anuran species conservation and management measures in protected and non-protected areas rely on the knowledge of their biodiversity and habitat preferences (Boyd et al., 2008; Nneji et al., 2021; Rahman et al., 2020), therefore, understanding the consequences of habitat change for biodiversity is critical. Currently, protected area network is insufficient to safeguard the majority of species in the World (Stuart et al., 2004), and their persistence depends upon the effectiveness of conservation action plans (Daily, 2001; Onga'oa et al., 2013; Vandermeer & Perfecto, 2007). To date, there is a little information on the diversity and distribution patterns comparison of anuran species in some protected and non-protected areas of Kenya. Presented here are results providing additional essential baseline data for North Nandi Forest Reserve and Kingwal Swamp, aimed at documenting anuran species diversity, abundance, richness and distribution to see if indeed they are a function of habitat quality and season, in order to initiate long-lasting conservation and management action plans.

2 | MATERIALS AND METHODS

2.1 | Study area

Anuran surveys were carried out in different habitats located in Western Kenya's protected (North Nandi Forest Reserve) and non-protected areas (Kingwal Swamp), both in Nandi County, inhabited by Nandi (sub-tribe of the large Kalenjin tribe).

North Nandi Forest Reserve (between 00°12.38′ to 00°25.10′ N and 4°57.58′ to 35°01.05′ E) is a component of western Kenya's biodiversity hotspot. This strip of the high-canopy forest comprises different habitat types, including forests and wetlands managed by the Kenya Wildlife Service (KWS) in collaboration with the Kenya Forest Service (KFS). It lies on the edge of the Nandi escarpment and above east of Kakamega Forest, covering a gazetted forest area of 10,500 ha, predominantly occupied by indigenous closed canopy forest, with scrubs, grasslands, cultivations and plantations zones in some remaining potions. This transitional forest between the montane forests of the central Kenya highlands and the West and Central Africa drains water mainly eastwards into Kingwal River systems, flowing southward and westward into Lake Victoria and Yala River. Has higher altitudes compared to Kakamega, but floristically less diverse. This moist forest with infrequent dry seasons receive 1600–2000 mm annual rainfall with peaks in April and September (Agwanda et al., 2009; Melly et al., 2020; Web & Glenday, 2009), and an annual mean temperature ranging between 17°C and 20°C. It is rich in biodiversity with over 628 plant species, mostly herbs, and shrubs accounting for nearly 10% of Kenya's total plant species, and it is home to a variety of birds (600 species), amphibians and primates among others (KEFRI, 2015). Cultivation and livestock farming are some of the anthropogenic activities surrounding the forest, with encroachment being the challenge due to population pressure leading to unsustainable removal of forest products (firewood, illegal timber extraction). However, a conversion of the forest to plantations has not taken place due to the implementation of conservation interventions aimed at protecting biodiversity and curbing the challenges (KEFRI, 2015).

Kingwal Swamp (between 0° to 0°34″ N and 34°44″ to 35°25″ E), is a non-protected wetland home to *Tragelaphus spekei*, encompassing the Kesses River, streams, and interconnected swamps flowing from the east and drains into the Kimondi river while flowing to the west of the wetland. Covers an area of 2.73 km^2 with varying rainfall patterns (1200–2000 mm annually) influenced by Lake Basin atmospheric conditions, and experiences

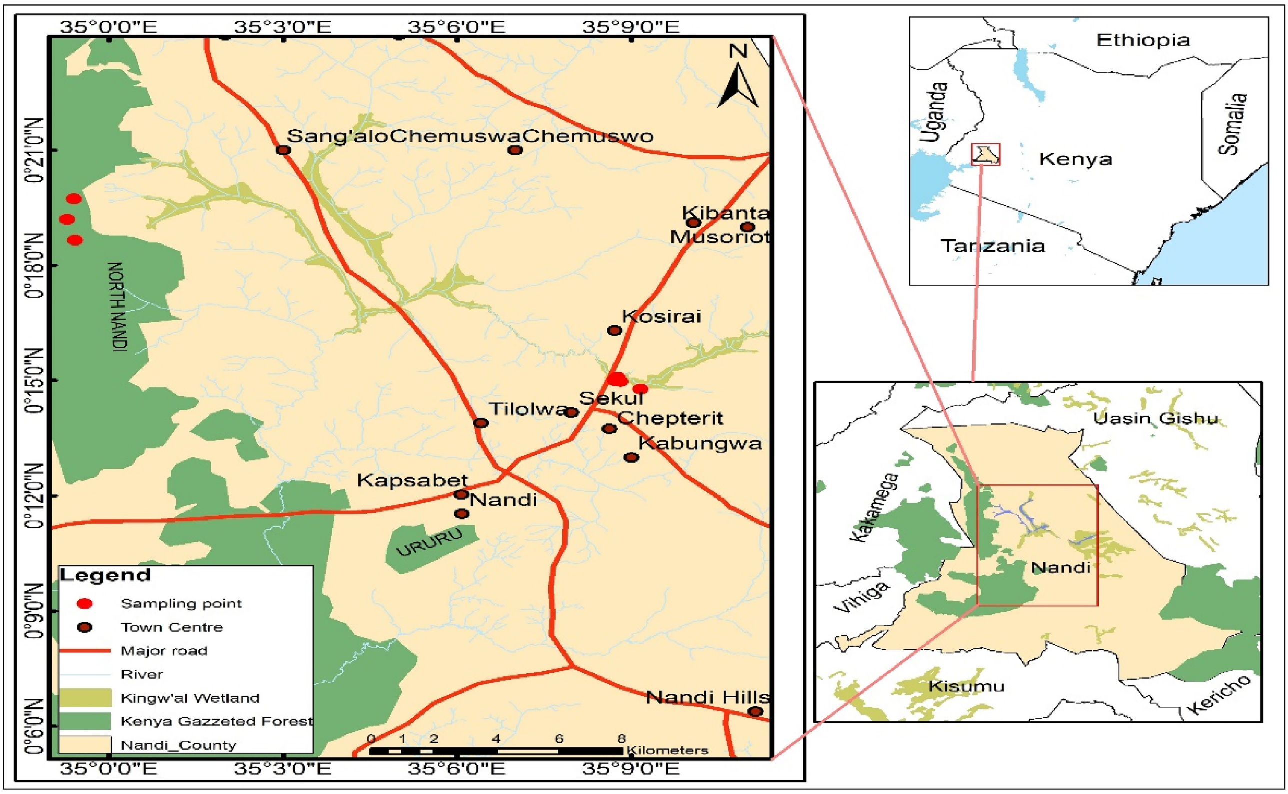

FIGURE 1 Map of the study area showing sampling points in Kingwal Swamp and North Nandi Forest Reserve.

a dry spell from the end of December to mid-March (World Bank, 2014). Temperature varies in terms of seasons, experiencing 15°C–20°C during wet seasons and peaks up to 24°C during dry seasons. Comprises of various vegetation types such as forests, grasslands, shrubs, reeds, papyrus, water lilies and scrublands, with 40% of the wetland converted into *Eucalyptus* species, *Azadirachta indica* and tea plantations (Sitienei et al., 2012). It also inhabits mongoose and foxes, birds, reptiles, amphibians and fish. Human activities in the wetland primarily consist of extensive crop farming of maize, horticulture, tea plantation, livestock keeping, agro-forest and brick-making among others, leading to environmental issues, that is, wetland degradation posing significant challenges to the wetland's sustainability. The swamp was stratified into Farmland and Intermediate habitats.

2.2 | Sampling design and layout

Field surveys were carried out both during the dry and wet season from October 2022 to June 2023. The study area was stratified into three habitats: I. Farmland/agricultural habitat, II. Intermediate habitat, and III. Forest habitat. Habitat I and II were from Kingwal Swamp while Habitat III was from North Nandi Forest Reserve (Figure 1). The three habitats were later stratified into nine sampling points, three randomly selected sampling points per habitat. In each sampling point, a 200 m by 10 m line transect ($n=9$) was designed (Rödel & Ernst, 2004).

2.3 | 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 (Malonza et al., 2011; Rödel & Ernst, 2004; Veith et al., 2004). Regarding the visual encounter method, each transect was searched for 4–6 h/day, and 6 days/week. Two people walked along each transect 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 maximise detection (Heyer et al., 1994). Pitfall traps with X-drift fence were set along each transect to capture or detect species which may not be easily found physically and visually, that is, small, primarily nocturnal or crawling herpetofauna, and these were checked twice a day, early in the morning and late afternoons before sunset (Malonza et al., 2018). Employed active random searches in locations a few metres away from transects, which included logs, leaf litter, tree holes, rocks and potential hiding places. All observed and detected species were identified using Field guidebooks (Spawls et al., 2019), and unidentified species were later identified by supervisors through photographs (iPhone S8 Plus), and Geographic coordinates of the sites were taken using GPS devices.

2.4 | Data analyses

Collected data were curated into MS Excel version 2013. 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, abundance, evenness and dominance along different habitats per season (Delatore & Nuneza, 2021).

Shannon-Weaver index (H') was computed across each habitat per season to analyse frog species diversity as follows:

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

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

The Simpson diversity index was computed to measure the probability that any two individuals drawn at random from an infinitely large community belong to different species, 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:

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

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. Therefore, the inverse was calculated as Simpson's reciprocal index$=(1/D)$ (Singh et al., 2023).

To measure evenness in this study, Shannon's evenness index (E) was employed, which is the ratio of observed diversity to maximum diversity and abundance, using the formula:

$$E = H' / \ln(s),$$

where H' is the Shannon–Wiener diversity index, ln is the natural logarithm of species richness, and s is 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 vice versa (Shannon & Weiner, 1949).

Beta diversity, described as the measure of the degree of variation and similarities in species diversity or absence and presence of species from two habitats was analysed using similarity indices, that is, Bray–Curtis, Sorenson and Jacquard's Coefficient Similarity Index, given as:

$$B_c = b + c / 2a + b + c, \ \text{SCSI} = 2a / (2a + b + c), \text{and JCSI} = a / (a + b + c)$$

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; Jaccard, 1912; Sørensen, 1948).

Sampling effort was assessed using species accumulation curves generated from MS Excel 2013, and rarefaction curves with the default bootstraps to estimate 95% confidence limits (Chao et al., 2014; Hsieh et al., 2016) to test and estimate species richness and diversity was generated from iNEXT online using Hill numbers where we considered $q=0$ (frog species richness) and $q=1$(exponential of Shannon's entropy index), q representing the effective number of species from PAST version 4.12 (Hsieh et al., 2016). All statistical tests on richness, diversity and abundance between habitats and seasons were tested using PAST version 4.12 and IBM SPSS Statistics 20.

3 | RESULTS

3.1 | Species diversity per habitat and per season

Overall, the results demonstrate that the forest habitat had the highest species diversity ($H'=2.432$), followed by the Intermediate habitat ($H'=2.244$), and least 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). All the habitats were evenly and uniformly distributed (farmland, $E=0.547$; intermediate, $E=0.629$; forest, $E=0.569$). However, anuran species were more uniformly dispersed in the farmland and intermediate habitats compared to the forest habitat in all seasons (Figure 2b).

All the habitats had high diversities in the wet season compared to the dry season. However, the forest had the highest species diversity in all the seasons (dry season; $H=1.768$, $D=0.805$ and wet

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

Habitat and 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

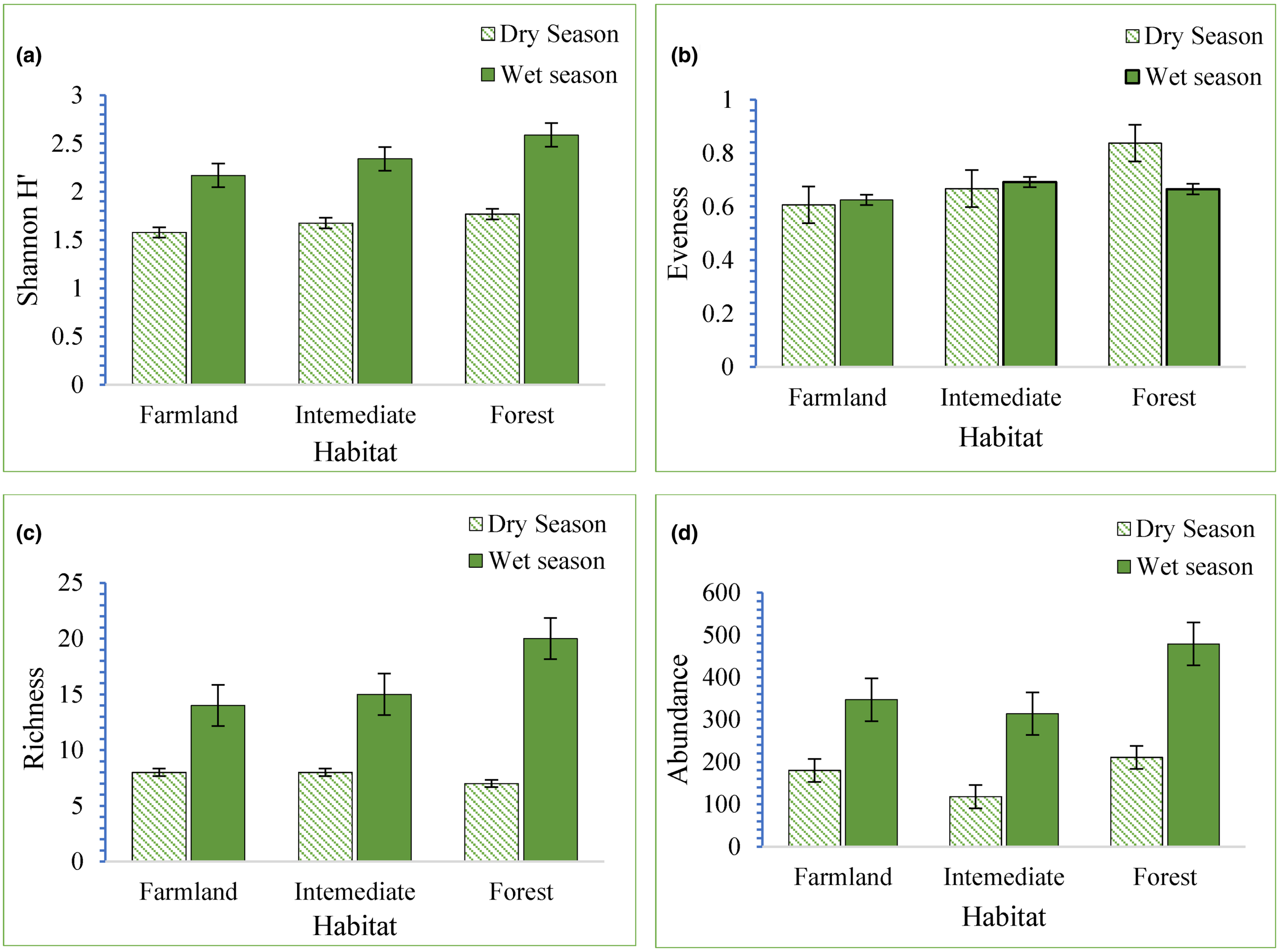

FIGURE 2 Seasonal variation of anuran species (a) diversity, (b) evenness and dispersal, (c) richness and (d) abundance between the habitat types in Kingwal Swamp and North Nandi Forest.

TABLE 2 Diversity *t*-test variation of anuran species between habitats during dry season.

Index	Habitats		Diversity *t*-tests		
(a)	Farmland	Intermediate	*t*	df	*p*(same)
Simpson_1–*D*	0.277	0.236	1.3316	295.99	0.184
Shannon_*H′*	1.56	1.645	−0.8546	272.22	0.393
(b)	Farmland	Forest	–	–	–
Simpson_1–*D*	0.277	0.198	3.0579	276.52	**0.002***
Shannon_*H′*	1.56	1.754	−2.4737	301.83	**0.014***
(c)	Intermediate	Forest	–	–	–
Simpson_1–*D*	0.236	0.198	1.6424	203.98	0.102
Shannon_*H′*	1.645	1.754	−1.2948	191.01	0.197

Note: The significance values are in bold.

season; $H=2.588$, $D=0.892$) compared to other habitats (Table 1; Figure 2), thus, increased evenness and diversity means low dominance in all the habitats (Table 1).

The diversity *t*-test indicated no significant difference between farmland and intermediate habitat ($t=-0.8546$, df = 272.22, $p>0.05$ for H'; $t=1.3316$, df = 295.99, $p>0.05$ for D), intermediate and forest ($t=-1.2948$, df = 191.01, $p>0.05$ for H'; $t=1.6424$, df = 203.98, $p>0.05$ for D) but there was a significant difference between farmland and forest habitats ($t=-2.4737$, df = 301.83, $p<0.05$ for H'; $t=3.0579$, df = 276.52, $p<0.05$ for D) during dry season (Table 2).

In contrast, during the wet season, there was a highly significant difference in H' between farmland and intermediate habitat ($t=-2.4998$, df = 658.29, $p<0.01$), farmland and forest habitat ($t=-6.5109$, df = 748.06, $p<0.01$), and intermediate versus forest

TABLE 3 Diversity *t*-test variation of anuran species between habitats during the wet season.

Index	Habitats		Diversity *t*-tests		
(a)	Farmland	Intermediate	*t*	df	*p*(same)
Simpson_1–*D*	0.161	0.123	2.8935	592.67	**0.004***
Shannon_*H′*	2.15	2.317	−2.4998	658.29	**0.013***
(b)	Farmland	Forest	–	–	–
Simpson_1–*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_1–*D*	0.123	0.108	1.4287	743.17	0.154
Shannon_*H′*	2.317	2.577	−4.2168	743.54	**0.0001***

Note: The significance values are in bold.

TABLE 4 Diversity *t*-test variation of anuran species between dry and wet season.

			Diversity *t*-test		
Index	Dry season	Wet season	*t*	df	*p*(same)
Simpson_1–*D*	0.225	0.123	9.1775	764.95	**0.0004***
Shannon_*H'*	1.749	2.472	−14.66	1098.4	**0.0001***

Note: The significance values are in bold.

TABLE 5 Tukey's means for groups in homogeneous subsets between habitats during (a) dry season, and (b) wet season.

		Subset for alpha = 0.05				Subset for alpha = 0.05	
(a) Habitats	*N* (samples)	1	2	(b) Habitats	*N* (samples)	1	2
Intermediate Habitat	84	1.3214		Intermediate Habitat	60	5.2333	
Farmland Habitat	84	2.0714		Farmland Habitat	60	5.7833	5.7833
Forest Habitat	15		12.8667	Forest Habitat	60		7.9833
Sig.		0.225	1.000	Sig.		0.826	0.051

Note: Means for groups in homogeneous subsets are displayed. Uses Harmonic Mean Sample Size = 33.158 for (a) and Mean Sample Size = 60.000 for (b). The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed in both (a) and (b).

habitat (t = −4.2168, df = 743.54, $p < 0.01$). However, as for *D*, there was a highly significant difference between farmland and intermediate habitat (t = 2.8935, df = 592.67, $p < 0.01$), and farmland versus forest habitat (t = 4.0422, df = 608.92, $p < 0.01$) only, while between intermediate and forest habitat (t = 1.4287, df = 743.17, $p > 0.05$) there was no significant difference (Table 3).

There was a highly significant difference between seasons both in Shannon diversity index (t = −14.66, df = 1098.4, $p < 0.01$) and Simpson diversity index (t = 9.1775, df = 764.95, $p < 0.01$) of frog species in the study habitats (Table 4).

3.2 | Species richness per habitat and per season

A total of 21 anuran species, from nine families were recorded in the study area within the three habitats. Family Ptychadenidae had the highest dominant species richness (seven species), while families Dicroglossidae, Arthroleptidae, Pyxicephalidae and Ranidae had the least (one species each). Of the 21 species, regardless of seasons, the forest had the highest number of species (20 species) while the farmland had the least (14 species), whereas intermediate had 15 species (Appendix 1).

During the dry season, the farmland and intermediate habitats (eight species) had the highest species richness, while the forest habitat had the least (seven species), on the other hand, the forest had the highest species richness (20 species) during wet season compared to intermediate (15 species) and farmland (14 species) habitats (Figure 2c; Appendix 1). All habitats had high species richness during the wet season (21 species) compared to the dry season (nine species) (Figure 2c).

Statistically, Chi-squared tests indicated that there was no significant association between species richness and seasons ($X^2([1], N = [2]) = [2.00], p = 0.157$), meaning the 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.

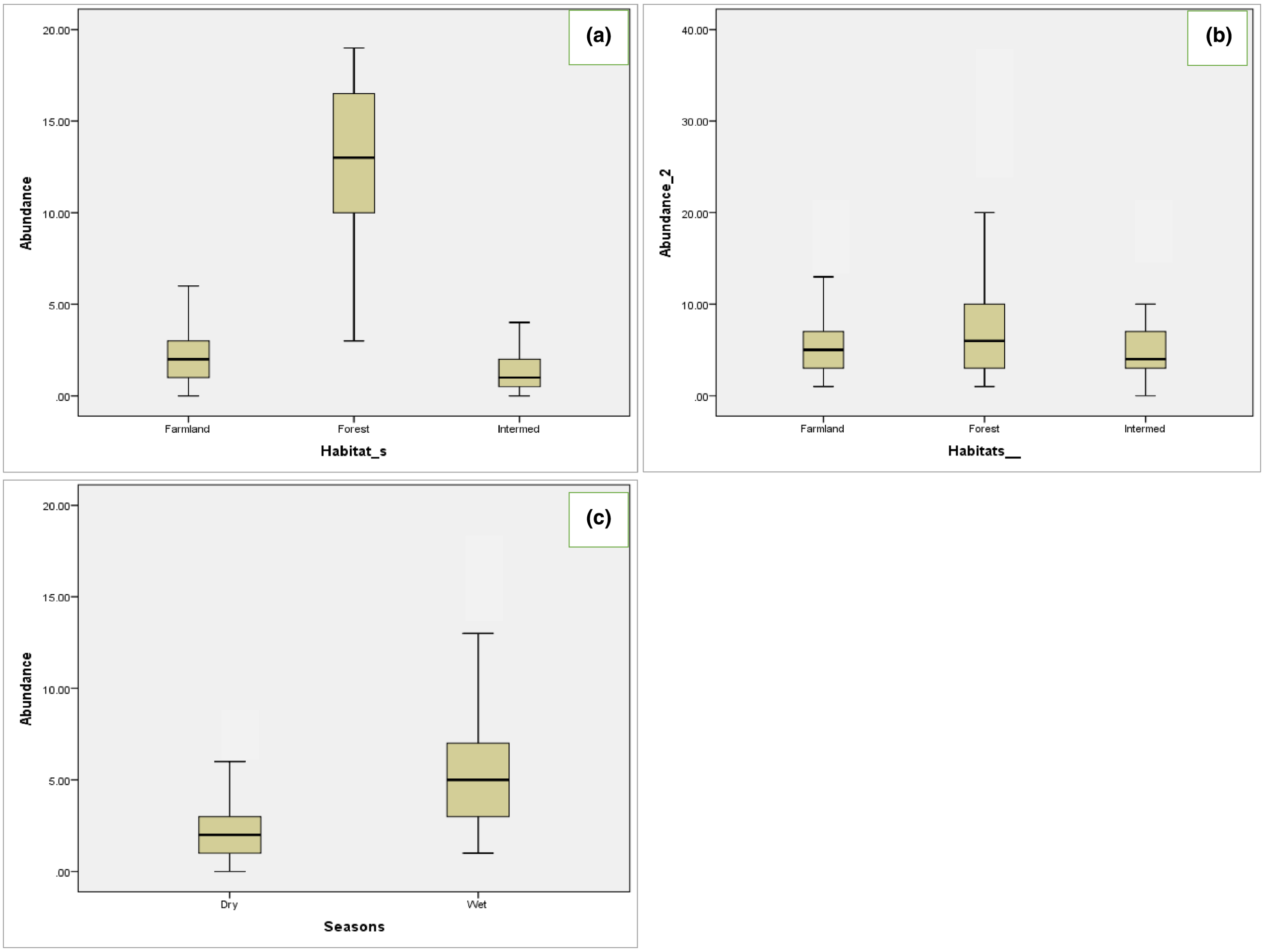

FIGURE 3 Variations in species abundance (mean) between habitats during (a) the dry season, (b) the wet season and (c) between dry and wet season.

3.3 | Species abundance and composition per habitat and per season

A total of 1649 individuals were recorded and identified (Appendix 1). Of the individuals recorded, the forest habitat had the highest species abundance (690 individuals; 211 individuals during the dry season, 479 individuals during the wet season), while the intermediate habitat had the least (432 individuals; 118 during the dry season and 314 during the wet season), and the farmland consisted of 527 individuals (180 during the dry season and 347 during the wet season) (Figure 2d). All the habitats were highly abundant during the wet season (1140 individuals) compared to the dry season (509 individuals) (Appendix 1).

The most abundant species from the study and ranked first was *Ptychadena nilotica*, with 240 individuals (21.6% relative abundance) in wet season and 167 individuals (32.8% relative abundance) in dry season across all the habitats, and the least was *Amnirana albolabris* ranked 17th with only 10 individuals (0.88% relative abundance) in wet season (only recorded in the forest habitat), while *Sclerophrys gutturalis* had the least abundance ranked 10th with only six individuals (1.18% relative frequency) in dry season, occurring in all the habitats. Ptychadenidae was the most abundant family (1103 individuals) in all the seasons across all habitats, while Ranidae was the least (10 individuals) (Appendix 1).

Statistically, 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 between 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 ($p=0.001$). The means were not equal for all the habitats based on Tukey comparison test (Table 5a; Figure 3a).

In contrast, during the wet season, there was no significant difference in species abundance between habitats ($F=2.433$, df $=2$, $p=0.091$). That is, there was no significant difference between 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 versus forest habitat means ($p=0.010$). The means for farmland and intermediate habitats were equal, as well as farmland and forest habitat means, while for intermediate and forest habitat means were not equal (Table 5b; Figure 3b).

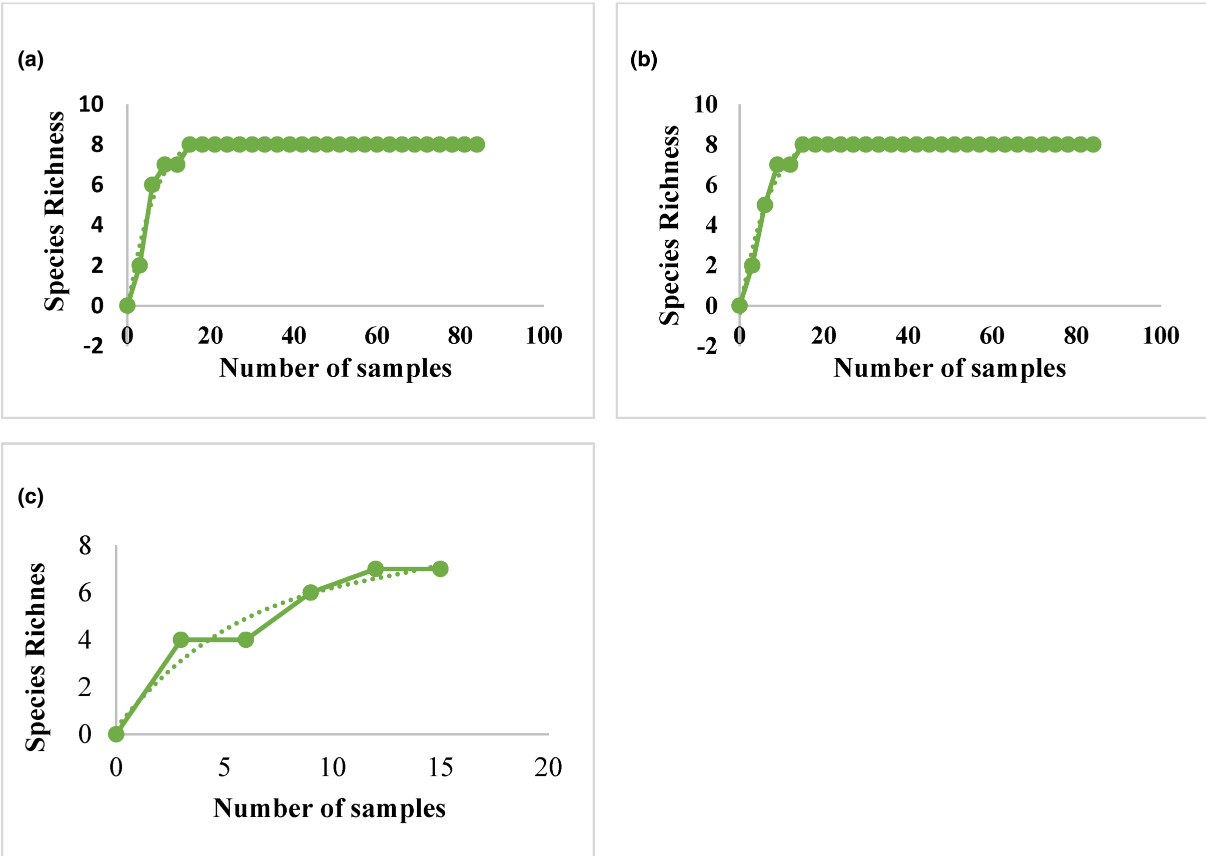

FIGURE 4 Species accumulation curves of anurans during dry season among habitats, (a) Farmland, (b) Intermediate habitat and (c) Forest habitat plotted against survey effort (number of samples).

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 indicated that overall there was a highly significant difference ($t = -10.289$, df = 328, $p < 0.0001$) (Figure 3c). 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 season means were not equal, that is, farmland (2.143 ± 0.179 and 5.783 ± 0.452), intermediate (1.405 ± 0.152 and 5.233 ± 0.439) and forest habitat (14.067 ± 1.822 and 7.983 ± 0.955).

3.4 | Species accumulation curve and richness estimation per season per habitat

During dry season sampling, all study habitats achieved asymptote (stabilised) but at a low rate of species richness except for the forest habitat (species increasing exponentially, meaning more sampling effort is still required). Farmland reached asymptote on sampling day 5 in 15 samples, with 41 individuals from 8 species, intermediate habitat on sampling day 5 in 15 samples as well, but with 32 individuals from eight species, while the forest habitat species richness is increasing on a slow rate after reaching 12 samples on sampling day 4 with 64 individuals from seven species (Figure 4). In contrast, the sampling effort was adequate during the wet season in all the habitats. The farmland habitat achieved asymptote on sampling day 12 in 36 samples, with 249 individuals from 14 species, Intermediate habitat on sampling day 13 in 39 samples, with 236 individuals from 15 species, and forest at on sampling day 5 in 15 samples, with 256 individuals from 20 species (Figure 5).

Overall, sampling effort in all the habitats in the study area was adequate regardless of sampling season. However, there are still chances of more new species to be discovered 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, and 20 species for forest habitat.

During the dry season, interpolation (rarefaction) and extrapolation curves showed that species richness ranged from 7 to 8 among habitats during dry season (Figure 6 ($q = 0$)). 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 species richness but differed in species diversity where intermediate habitat had high diversity than farmland. Although forest habitat had the lowest species richness, it had the highest species diversity (Chao1 = 7 ± 0.00, H' = 5.89 ± 0.40) compared to other habitats (Figure 6).

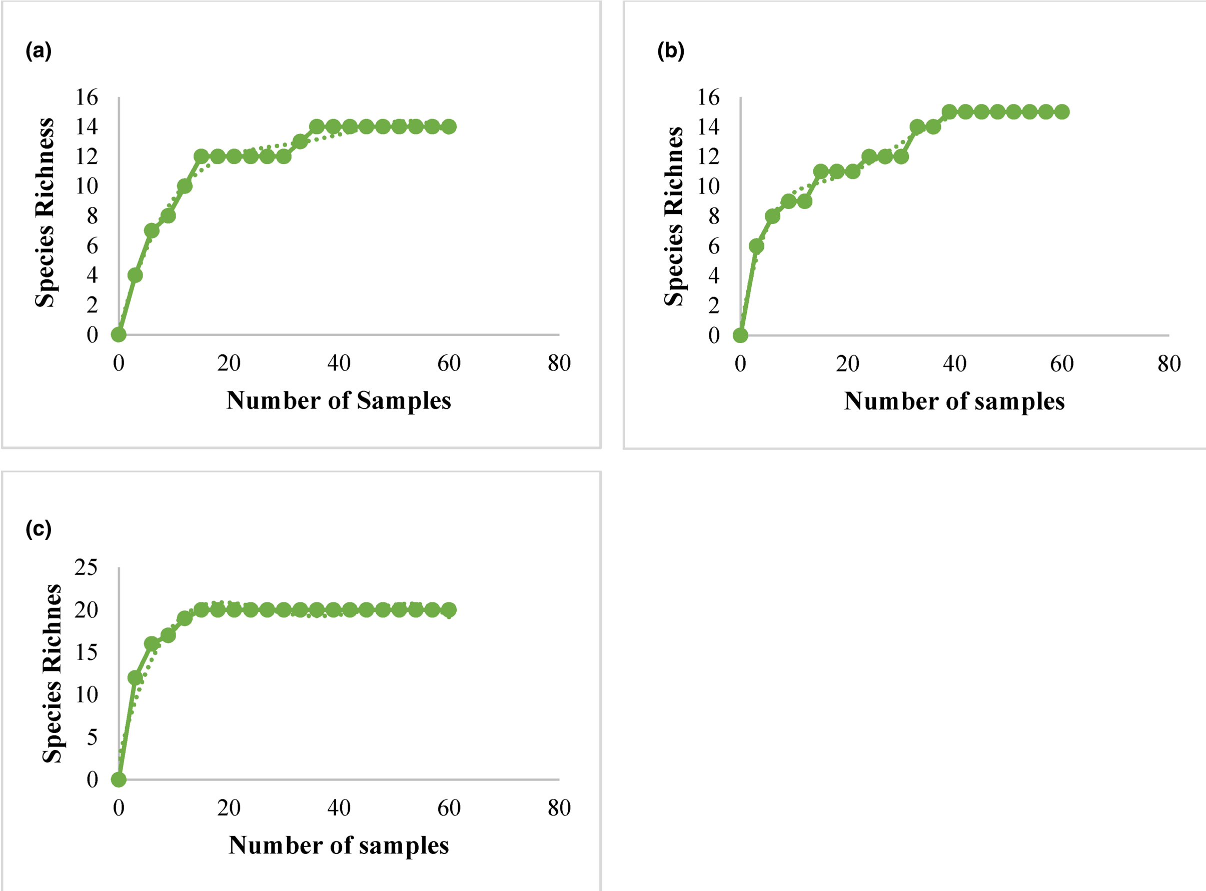

FIGURE 5 Species accumulation curves of anurans during the wet season among habitats, (a) Farmland, (b) Intermediate habitat and (c) Forest habitat plotted against survey effort (number of samples).

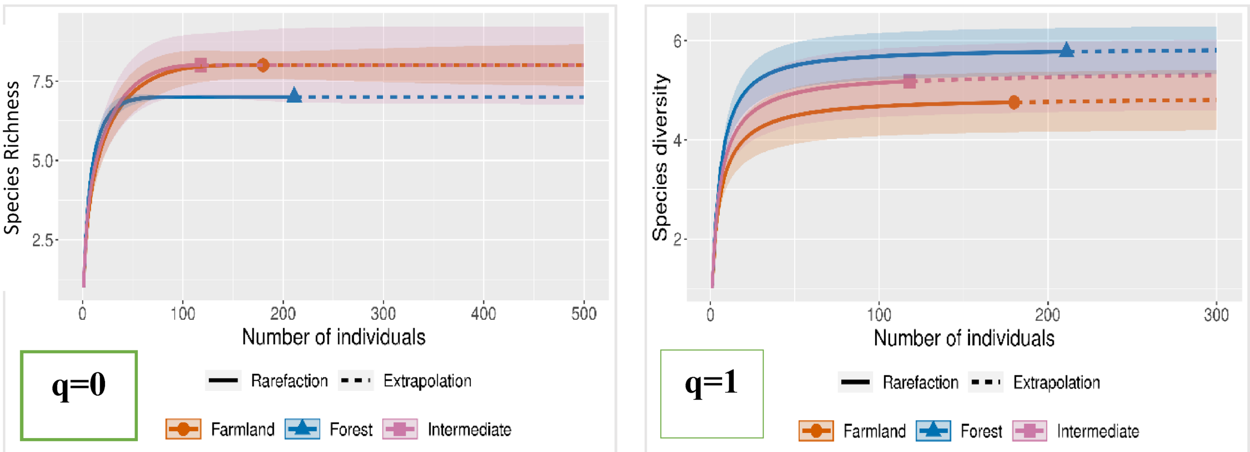

FIGURE 6 Comparison of the diversity and richness of anuran species in three habitat types in Kingwal Swamp and North Nandi Forest Reserve through rarefaction solid lines and extrapolation dotted lines during dry season.

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 7 ($q=0$)). Measures of diversity indicated that forest habitat had the highest species richness and diversity (Chao1 = 20 ± 0.00, $H'=13.01\pm1.55$), followed by the intermediate habitat (Chao1 = 15 ± 0.85, $H'=10.08\pm1.44$), and the farmland habitat (Chao1 = 14 ± 0.20, $H'=8.02\pm1.50$) (Figure 7).

3.5 | Beta diversity based on similarity indices of frog species between habitats per season

Species similarity analyses between paired farmland and intermediate habitats, farmland and forest habitat, as well as intermediate and forest habitat showed SCSI, JCSI and BCSI values greater than 0.50 in all the seasons representing 100%, 67% and 67% of

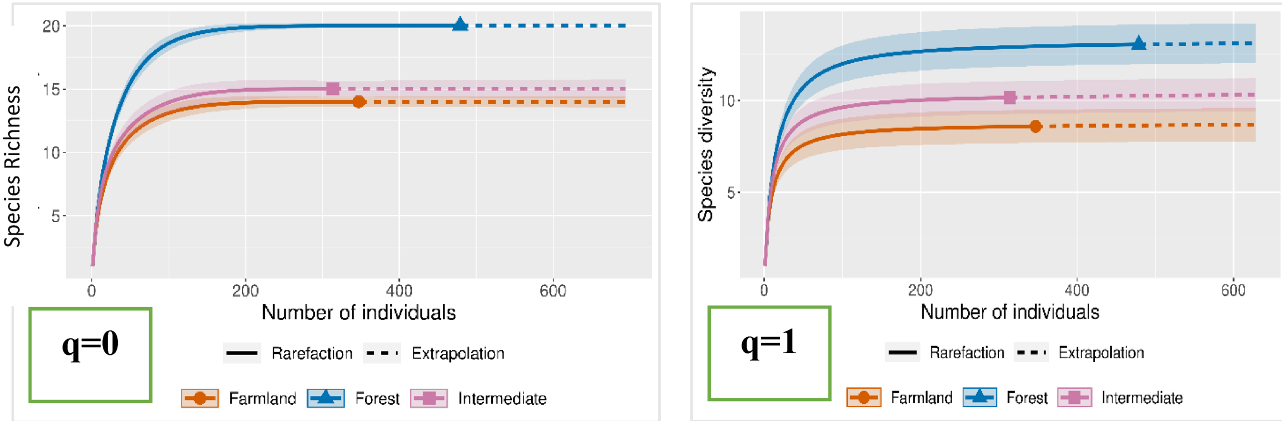

FIGURE 7 Comparison of the diversity and richness of anuran species in three habitat types in Kingwal Swamp and North Nandi Forest Reserve through rarefaction solid lines and extrapolation dotted lines during wet season.

TABLE 6 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

Abbreviations: FL, Farmland; FT, Forest; IL, Intermediate.

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 5). 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 (Table 6).

3.6 | Anuran species checklist of Kingwal Swamp and North Nandi Forest Reserve

The present study compiled a total of 21 (15 species in Kingwal Swamp and 20 species in North Nandi Forest Reserve) anuran species belonging to nine families, and 9 genera (Table 7). All the species detected except *Leptopelis mackayi* (Vulnerable; $n=1$ species; 4.76%) were categorised under least concern (LC; $n=20$ species; 95.24%) (Table 7).

In relation to 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 East and North Africa, each with one species (4.76%) (Table 7).

4 | DISCUSSION

4.1 | Diversity and distribution

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 (da-Silva & Rossa-Feres, 2011; Jongsma et al., 2014; Onadeko, 2016), environmental factors associated with their habitat structure (da-Silva et al., 2012; Pearman, 1997), and habitat productivity which is a function of rainfall. This indeed is proof that anuran species diversity is a function of habitat diversity and quality. The significant 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 and niches, hence increasing anuran species diversity (Malonza, 2011). In support, Neckel-Oliveira et al. (2001) also detected high diversities in the forest compared to the surrounding habitats. Additionally, Auguste and Hailey (2018) noted that wetlands in Trinidad's Aripo Savannahs Scientific Reserve

TABLE 7 Checklist of anuran species in Kingwal Swamp and North Nandi Forest.

Family	Scientific name	Kingwal swamp	North Nandi Forest reserve	IUCN status	Distribution
Bufonidae (2)	*Sclerophrys kisoloensis*	X	X	LC	East, South Africa
	Sclerophrys gutturalis	X	X	LC	East, South Africa
Ptychadenidae (7)	*Ptychadena porosissima*	X	X	LC	East, South Africa
	Ptychadena nilotica	X	X	LC	East, North Africa
	Ptychadena oxyrhynchus	X	X	LC	East, Central, South Africa
	Ptychadena anchietae	X	X	LC	East, South Africa
	Ptychadena taenioscelis	X	X	LC	East, South Africa
	Ptychadena mahnerti	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

Note: Numbers in the parentheses indicate the total number of species. For IUCN present status, DD, Data Deficiency; EN, Endangered; LC, Least Concern; VU, Vulnerable.

were more diverse compared to those in agricultural fields. In line with this study, this is due to high intensity of anthropogenic disturbances, that is, 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 aquatic species (*Xenopus* species) but also those species (*Ptychadena* species) that use them as breeding sites.

However, Kassie et al. (2023), Ndriantsoa et al. (2017) and Rahman et al. (2022) argue by stating that agricultural fields are more diverse compared to the riverine forest (in this case the intermediate habitat) in regions of Keffa and Bangladesh. This can be attributed to the fact that in the forest there are frog specialists and in the farms generalists' species that make use of the modified habits or habitat patchiness. Thus, the forest habitat may have few species but of conservation concern, for example, endemics. This can also be associated with forest patches enormously interfered with by humans (encroachment and illegal harvesting of timber/charcoal burning). As suggested by Le Cœur et al. (2002) that natural and semi-natural remnant areas serve as important refuges for animal diversity, this study is proof that natural (forest habitat), semi-natural regions (intermediate habitat) are more diverse than habitats with high agricultural activities.

4.2 | Species richness and abundance

The analysis of this study on species richness and abundance differed by showing that the forest habitat (protected area) harbours higher anuran species compared to any other habitats (farmland and intermediate habitats). Similarly to diversity, this is associated to more diverse micro habitats (heterogeneity such as highly vegetated water bodies [lotic, e.g. ponds, puddles; and lentic, e.g. slow-flowing shallow streams]) suitable as breeding sites for anuran species, variability in resources for foraging and predator cover, which all influences frog habitat selection, hence increasing species richness and abundance. In support, Nneji et al. (2019) and Drayer and 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 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 (da-Silva et al., 2011; da-Silva & Rossa-Feres, 2011), associated with providing vocalisation sites during the breeding season 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, Appendix 2) were undisturbed and less exposed to agrochemicals leading to no havoc towards anuran populations. However, a few common anuran species coexisted with a large number of rare anuran species within the habitats. High records of anuran species and abundance in some past herpetological studies in localities such as Shimba Hills National Reserve (Bwong et al., 2017; Malonza et al., 2018), Kitobo Forest of Kenya (Malonza et al., 2011), and Taita Hills (Malonza et al., 2010) can be associated with differences in sampling efforts and sampling methods (visual encounter search and pitfall traps with drift fence) applied, increased sampling methods increases detection, hence increases species richness and abundance.

On the other hand, the farmland habitat had a high abundance compared to intermediate habitat, 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 (Attademo et al., 2019; Karunakaran & Jeevanandham, 2017). Indeed, in the current study such water bodies (both stagnant and man-made streams acting) were observed in the farmland habitat compared to the intermediate habitat. However, 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). There was a slight difference in the number of species between intermediate and farmland habitats, this was because the anurans species recorded in these habitats utilise both forest remnants and agricultural land as their habitat (generalists species) (da-Silva & Rossa-Feres, 2007; Oda et al., 2016).

4.3 | Species accumulation curves and richness estimation

Despite the fact that the species cumulative curve in all the habitats stabilised in all the seasons except the forest in the dry season, the possibility of local species richness expansion cannot be excluded. Therefore, the increased effort would add new species to the forest habitat. Overall, increased effort in this current study would add to the species richness very slowly, as evidenced by richness estimators displayed by rarefaction curves. In line with this current study, Kassie et al. (2023) displayed species accumulation curves with asymptotic points. Similarly, they also emphasised the significance of investigating and sampling anuran species using a variety of sampling methods (Malonza et al., 2010, 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 biodiversity is closely related to the sampling effort invested by researchers (Costa-Campos & Freire, 2019). In support of this study, the sampling effort was boosted by diurnal and nocturnal sampling. The species accumulation curves stabilised in relatively low species richness during the dry season for all the habitats under study, while during the wet season, it was on an adequate number of species. Similarly, this was also displayed on the rarefaction curves, this imply that additional sample effort is required not only for the forest habitat in the dry season but for all the habitats.

4.4 | Beta diversity of anuran species between the habitats in the study area

According to Akoto et al. (2015), this current study revealed that the habitats within the study area shared similar species (composition), this is because the similarity indices values were greater than 0.5. 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 this current study, the result showed that the forest, intermediate, and farmland habitat had high BCSI, SCSI, and JCSI. This could be associated with ecological and feeding guilds that are using the same niches (breeding sites and prey availability) which are found in both protected forests, riverine intermediate habitats, and agricultural fields, utilising both forest patches and farmland fields (generalist) (da-Silva & Rossa-Feres, 2007). However, some unique species were not shared between the habitats, for example, this current study identified some arboreal frog species and puddle frogs found on the forest litter only in the forest habitat. 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 & Pokorný, 2020).

4.5 | Seasonal variations in anuran species diversity, abundance and richness between habitats

Giaretta and Menin (2004) noted that the duration (start and end) of the anuran breeding season is influenced by climate conditions (temperature and moisture). 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, supported by Watanabe et al. (2005) and Giaretta et al. (1999) who also found seasonal variations in anuran communities of Iriomote Island of the Ryukyu Archipelago and montane forest of Brazil. A study (Vonesh, 2001) in the tropical forests with defined seasons found a significant impact of precipitations on the diversity and abundance of anuran species. This is true, anuran species diversity, abundance and richness recorded in the study area were high during the wet season compared to the dry season. Similarly, all the water bodies were flowing and highly vegetated, suitable as breeding sites for anuran species (Ribeiro et al., 2018). A highly significant difference between the seasons in diversity indices and abundance can be associated with increased rates of adult frogs moving around suitable microhabitats used as breeding sites (Giaretta et al., 1999; Giaretta & Menin, 2004).

During the dry season, there was no significant difference in species diversity and abundance, while in the 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. In general most of the anurans were inactive in dry season making them occur in low densities. However, Causaren et al. (2016) differed from the current study by detecting 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 not suffering drastic variations during the dry season (De Souza & Eterovick, 2010; Dixo & Martins, 2008). Therefore, this clearly shows 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 also other vertebrate taxa inclusively. High rainfall rates and the absence of a distinct dry season were observed in the study area. This fact might be partially explained by the existing significant seasonal variation in the anuran species richness, diversity and abundance in Kingwal Swamp and North Nandi Forest Reserve.

4.6 | Species checklist

The results of the study give assumptions that long-term systematic sampling might unquestionably lead to possibly additional new anuran species. The fact that this study could not detect many species may be attributable to the limited sampling effort (study period in terms of data collection), since the location (being close to Kakamega Forest where plenty of anuran species have been observed) 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. The high number of species categorised under least concern indicates that they are not on the verge of extinction, and such observation is attributed to conservation efforts towards forest and wetland habitats being effective. The broad taxonomy and distribution patterns noted for all the anuran species detected are supported and derived from the Amphibian Species of the World versions 3.0 to 6.2 (an online Reference that is from 1998 to 2023), an online Reference relating to the scientific nomenclature and discontents (structure of the taxonomic records from contributors and reviewers for Amphibian species of the world) (Frost, 2023), Amphibian Survival Alliance (ASA, 2022), IUCN Red List of Threatened Species (IUCN, 2023) and Amphibia Web Taxonomy (AmphibiaWeb, 2023). Vonesh (2001) on amphibians of Kibale National Park identified anuran species as carnivorous species, predominantly feeding on insects only. Similarly with the current study, it is true because most species were found as predominantly insect and frog eaters. Not only did it support feeding items but also gave more emphasis on their distributions in Eastern and Western African ecosystems in relation to observations respectively by Schiøtz (1975, 1999), Malonza et al. (2006, 2018), Malonza and Bwong (2023), Measey et al. (2009) and Vlok et al. (2013).

5 | CONCLUSIONS

Due to the fact that observations of this current study showed anuran diversity and distribution in and around habitats in the study area, it may have generated and added to the baseline data for the anurans biodiversity in Kingwal Swamp and North Nandi Forest Reserve. Anuran biodiversity is a function of habitat diversity and season, with the associated differences in microhabitat structure that provide diverse niches and ways of exploring resources. The differences in anuran species diversity and abundance in the three habitats demonstrate that conservation efforts continue to be a priority. Thus, given the increasing number of human-induced habitat modifications and expansion to fulfil agricultural practices along swamps and forests in Kenya, the study would recommend conservation interventions through continuous assessment, regular evaluation and monitoring of anuran conservation status countrywide. Due to the high taxonomic turnover in anuran species, wetland microhabitats; riverine forests; swampy forests; horticultural and agro plantations preservation and conservation is critical in both protected and non-protected areas. However, we recommend non-governmental organisations and conservationists to engage local people in wetland and forest protection and conservation to curb encroachment for the benefit of the survival of anuran biodiversity.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available from the lead author on request.

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APPENDIX 1

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

		Habitats						Total		Relative abundance (rank)	
		Farmland		Intermediate		Forest					
Family	Species	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bufobidae	*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 porosissima*	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 anchietae	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 mahnerti	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 Individuals		180	347	118	314	211	479	509	1140	100	100
Total number of species		8	14	8	15	7	20	10	21		

APPENDIX 2

Functional attributes for the carnivorous anuran species recorded in Kingwal Swamp and North Nandi Forest Reserve.

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[a]	Kisolo Toad	Insects, Frogs	Ground Dwelling/ Terrestrial	Lotic water	Slow stream, pool	Water bodies	Terrestrial, Aquatic	Wet
Sclerophrys gutturalis[a]	Guttural Toad	Insects, Frogs, Reptiles	Ground Dwelling/ Terrestrial	Lotic water	Pond, pool	Water bodies	Terrestrial, Aquatic	Vary
Amietia nutti[a]	Nutt's River Frog	Insects, Frogs	Stream Dwelling	Lentic water	Shallow water	Water bodies	Terrestrial, Aquatic	Wet
Ptychadena porossisma[a]	Striped Rocket Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic water	Shallow water, sedge	Vegetation near water	Terrestrial, Aquatic	Vary
Ptychadena nilotica[a]	Nile Rocket Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic water	Pool, marsh	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus graueri[a]	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[a]	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[a]	Archita's Ridged Frog	Insects	Ground Dwelling/ Terrestrial	Lotic water	Vegetation near Shallow water/pond	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Xenopus victorianus[a]	Lake Victoria Clawed Frog	Insects, Frogs	Aquatic dwelling	Lotic water	Pond, pool	Water bodies	Aquatic	Wet
Ptychadena taenioscelis[a]	Small Rocket Frog	Insects	Wet terrestrial dwelling	Lotic water	Shallow water (flooded grassland, pools)	Vegetation near water bodies	Terrestrial, Aquatic	Wet
Xenopus borealis[c]	Marsabit Clawed Frog	Insects, Frogs, Fish	Aquatic dwelling	Lotic/Lentic water	Fresh water pools/ ponds, even steams	Water bodies	Aquatic	Wet
Ptychadena mahnerti[a]	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[a]	Common Reed Frog	Insects	Arboreal	Lotic water	Eggs deposited into water bodies (aquatic habitats)	Water bodies	Terrestrial, Aquatic	Wet

(Continues)

APPENDIX 2 (Continued)

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
Hoplobatrachus occipitalis[a]	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[a]	Cinnamon-Bellied Reed Frog	Insects	Arboreal	General terrestrial/Lotic	Eggs arboreal, larvae aquatic	On trees/vegetation near water bodies	Terrestrial, Aquatic	Wet
Leptopelis mackayi[b]	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[b]	Mascarene Ridged Frog	Insects, Frogs	Wet terrestrial dwelling	Lotic/Lentic water	Puddles, ditches and ruts	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus scheffleri[b]	Scheffler's Puddle Frog	?	Leaf Litter	Lentic water	Lake edges, rivers, streams and pools	Water bodies	Terrestrial, Aquatic	Wet
Amnirana albolabris[b]	Forest White-lipped Frog	?	Arboreal	Lotic water	Shallow water, Swampy forest/valley bottom	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus natalensis[b]	Natal Puddle Frog	Insects, Snails, Frogs	Leaf Litter	Lotic/Lentic water	Puddles, ditches, streams, ponds	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus natalensis[b]	Upland Puddle Frog	Insects	Leaf Litter	Lotic water	Shallow standing waters	Water bodies	Terrestrial, Aquatic	Wet
Phrynobatrachus keniensis[b]	Upland Puddle Frog	Insects	Leaf Litter	Lotic water	Shallow standing waters	Water bodies	Terrestrial, Aquatic	Wet

[a] Observed in both Kingwal Swamp and North Nandi Forest Reserve.

[b] North Nandi Forest Reserve only.

[c] Kingwal Swamp only.