NYIKA-VWAZA TRUST RESEARCH STUDY REPORT

Assessing the habitat value of bracken fern (*Pteridium aquilinum*) stands for avian and reptile communities in Nyika National Park

Lumbani Benedicto Banda

December 2024

Acknowledgements

I sincerely appreciate and thank the Nyika-Vwaza Trust for funding this study and the Department of National Parks and Wildlife (DNPW) for providing the research permit and granting access to Nyika National Park. I extend my gratitude to the staff and management of Nyika National Park for their support with logistical arrangements during data collection. Specifically, I thank Mr P. Chioko, the park manager; Mr J. Fote, the Chelinda station manager; and the following park rangers: Mr M. Foster, Mr L. Chitseko, Mr O. Chandiona, and Mr H. Shaibu, for their invaluable assistance during data collection. Lastly, I also thank Mr N. Gawani and Mr L. Kachedzula for their help with data collection.

Table of Contents

ABSTRACT

The invasive bracken fern (*Pteridium aquilinum*) poses a significant challenge in the Nyika National Park as it encroaches on grasslands that serve as critical feeding grounds for herbivores. Understanding its effects on various species is vital for monitoring its impacts. While recent studies have begun exploring the effects of bracken fern invasion, its impacts on bird and reptile populations remain poorly understood. This study investigated how bracken fern invasion affects bird and reptile species and their functional diversity.

Bird and reptile surveys were conducted in bracken-invaded and non-invaded habitats. Species diversity was compared using Hill's numbers, beta diversity measured species composition differences, and functional diversity assessed the impact on ecological roles.

The study recorded 59 bird species, with 27 in invaded habitats and 48 in non-invaded habitats. For reptiles, six species were recorded, two in invaded and four in non-invaded habitats. The results showed that bracken-invaded habitats had significantly lower numbers of bird species and lower functional diversity than non-invaded habitats. Bird species composition also differed, driven by species turnover rather than nestedness. Despite reduced diversity, invaded habitats were still utilized by some bird species, particularly mixed-feeding and ground-dwelling birds. For reptiles, the study could not isolate significant differences due to the low number of species recorded in both habitat types.

These findings suggest that invasion by bracken fern negatively impacts bird communities by altering species composition and reducing ecological roles and trait diversity. Conservation efforts should focus on controlling the spread of bracken fern to mitigate further declines in species and functional diversity, particularly among birds. Further research is needed to better understand the effects on reptiles.

1. Introduction

Invasive alien species are among the most significant threats to biodiversity worldwide (Butchart et al., 2010). Their impacts can be far-reaching and devastating. For instance, invasive plants often reduce the abundance and diversity of both flora (Hejda et al., 2009; Pyšek et al., 2012) and fauna (Schirmel et al., 2016; Fletcher et al., 2019). Further, invasive plants alter vegetation composition, often leading to the dominance of a few species (Castro-Díez et al., 2016). These changes are primarily driven by the reduction of habitat heterogeneity and structural complexity (Herrera & Dudley, 2003) which diminishes the range of ecological niches available to support a diversity of species. Addressing these impacts often requires substantial financial investment (Pimentel et al., 2002), making invasive plant species a persistent challenge for conservation and ecosystem management.

Protected areas have been designed to enhance the protection of biodiversity, and indeed they contribute positively to conservation (Leverington et al., 2010). They are effective at mitigating threats such as habitat fragmentation and land-use change. However, addressing biological invasions within protected areas is notably more complex (Foxcroft et al., 2017). The spread of invasive plants is often facilitated by human activities, such as the construction of access roads (Otto et al., 2014) and increased tourism (Pickering & Mount, 2010), which are integral to the operation and management of many protected areas. Consequently, simply setting aside land for protection often does not prevent the spread of invasive species. Instead, effective prevention by limiting the introduction and establishment of invasive species is recognized as the most effective approach to managing biological invasions (Leung et al., 2002).

The problem of invasive plant species is particularly pronounced in Africa, where their presence in protected areas has grown substantially over recent decades (Foxcroft et al., 2013). In Malawi, protected areas such as the Mulanje Mountain Forest Reserve and Nyika National Park are heavily impacted by invasive plants. Among these, bracken fern (*Pteridium aquilinum*) has emerged as one of the most problematic, especially in high-altitude grasslands. Although bracken fern is invasive, it is native to the Nyika National Park but its invasiveness poses a significant threat to the ecosystem and to the survival of native flora in general.

In the Nyika National Park invasion of bracken fern has become a growing concern, particularly because the grasslands it invades serve as critical feeding grounds for herbivores. Estimates suggest that bracken now covers over 20,000 hectares of the Nyika Plateau, with an annual expansion rate of approximately 37 hectares (Kanzunguze, 2018). This rapid growth underscores the urgency of understanding its ecological impacts. Previous studies have examined the ecology of bracken (Kanzunguze, 2019), quantified its spread (Kanzunguze, 2018), and identified factors associated with its invasion (Banda, 2022). However, its impacts on other taxa, particularly birds and reptiles, remain poorly understood.

Globally, the study of the impacts of invasive plants on birds and reptiles has received little focus, though in recent years there has been increasing attention to both birds (Catling, 2005; Davis, 2019; Grzędzicka & Reif, 2020) and reptiles (Martin & Murray, 2011; Bateman & Ostoja, 2012) in various countries. However, these studies have focused only on a subset of invasive plants, making it difficult to generalize their results to other areas invaded by different invasive plants with different ecological characteristics. This study explored how bracken fern invasion affects bird and reptile species, and specifically on bird and reptile diversity.

2. Methods

2.1 Study area

The study was conducted in the Nyika National Park, located between latitudes 11°0'0" and 10°10'0" and longitudes 33°0'0" and 34°0'0" (Figure 1). The park covers an area of approximately 3,200 km², with miombo woodlands dominating at altitudes below 1,800 m. At higher altitudes, grasslands prevail, interspersed with scattered forest patches. The dominant grass species above 1,800 m include *Loudetia simplex*, *Themeda triandra* and *Exotheca abyssinica* (Nyika-Vwaza Trust, 2024). This study focused on the montane region (>1900 m) as this area is the most severely affected by bracken invasion. Bracken primarily invades grasslands, making the montane grasslands more vulnerable than forest areas.

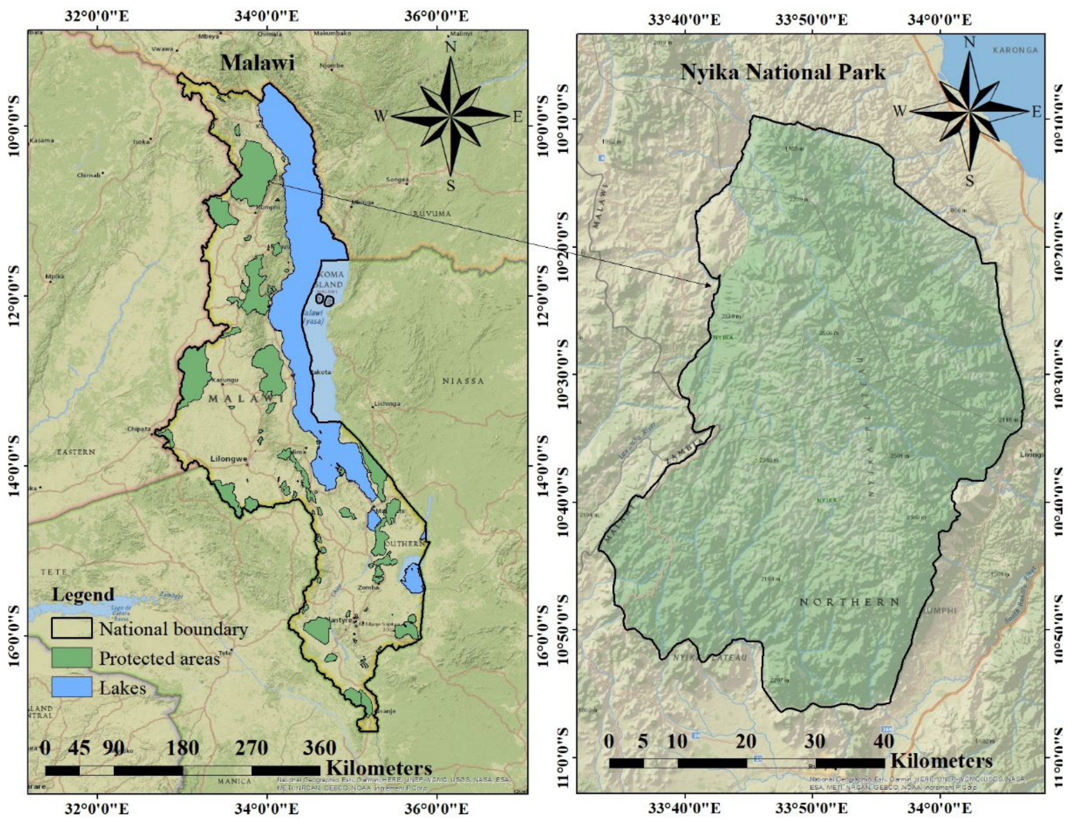

Figure 1: Location of the study area, Nyika National Park.

2.2 Bird and reptile surveys

Bird and reptile surveys were conducted in two habitat types within the study area – bracken-invaded habitats and non-invaded habitats. Bracken-invaded habitats consisted of patches where bracken had colonized grasslands, covering at least 70% of the habitat or target site. In contrast, non-invaded habitats were areas either free of bracken or where bracken invasion had only recently begun, covering less than 10% of the target patches. Both habitat types contained scattered trees that were utilized by various species, particularly birds. Some of the recorded bird species were not exclusively grassland or shrubland birds. In addition, for sites located near forest edges, there was notable exchange of bird species between grassland and forest.

Bird surveys were conducted in the mornings between sunrise and 11:00 am, and in the late afternoons, starting from around 16:00 pm until dusk (Bibby, 2000). In each habitat, transect walks were carried out, with transect lengths ranging from 0.6 to 2.1 km (Figure 2). During the surveys, all birds encountered – whether seen or heard – were recorded, along with their corresponding abundance, geographic location and perpendicular distance from the transect.

The study surveyed reptiles in both bracken-invaded and non-invaded habitats through searches on rocks, under logs and within piles of wood located within each habitat type. Figure 3 depicts field activities during reptile surveys. These surveys were conducted during both daytime and night-time to target specific species such as chameleons, which are active at night. Night surveys were extended beyond grassland areas to include forest edges to increase the likelihood of species detection. For all observed reptiles, the species name, abundance and geographic location were recorded.

Figure 2: Surveyors during the bird survey.

Figure 3: Surveyors conducting reptile searches during day and night.

2.3 Statistical analysis

Bird species diversity in bracken-invaded and non-invaded habitats was estimated using both Shannon and Simpson indices. Species diversity between the two habitats was compared using species accumulation curves, calculated with the iNEXT R package (Hsieh et al., 2016). The iNEXT package generates sampling curves along with confidence bands based on three orders of Hill numbers (q=0,1,2). These orders represent species richness (q=0), Shannon diversity (q=1), and Simpson diversity (q=2), respectively. Significance testing was based on confidence interval comparisons – overlapping confidence intervals indicate no statistically significant differences while non-overlapping intervals suggest significant differences.

Variation in bird species composition between bracken-invaded and non-invaded habitats was assessed using beta-diversity. Total dissimilarity in species composition was calculated using the Sørensen and Jaccard indices (Baselga & Orme, 2012). Using these, the study determined total beta diversity, nestedness, and turnover using the *betapart* R package (Baselga & Orme, 2012). Nestedness and turnover are particularly important as they help identify the causes of species dissimilarity – nestedness indicates whether there are core species shared among communities while turnover explains if dissimilarities result from species replacement (Dyderski & Jagodziński, 2021).

Functional diversity of bird species was estimated using three indices: functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv) (Villéger et al., 2008). Functional richness quantifies the functional space occupied by a community, while functional evenness reflects the distribution of species abundances within this space (Mason et al., 2005). Functional divergence measures the distribution of species abundances along a functional trait axis within the occupied range (Mason et al., 2005). Estimating functional diversity required gathering species-specific traits which were used to calculate the indices. The study collected 11 traits per bird species (Table 1), encompassing functional roles such as resource acquisition and habitat preference. All trait data were sourced from the AVONET database (Tobias et al., 2022).

Table 1: Traits used for estimation of bird functional diversity.

Trait Name	**Scale**	**Categories**
Beak culmen length	Continuous	NA
Beak nares length	Continuous	NA
Beak width	Continuous	NA
Beak depth	Continuous	NA
Tarsus length	Continuous	NA
Wing length	Continuous	NA
Tail length	Continuous	NA
Mass	Continuous	NA
Trophic niche	Categorical	frugivore, granivore, herbivore, invertivore, nectarivore & omnivore
Primary lifestyle	Categorical	aerial, generalist, insessorial & terrestrial
Habitat density	Categorical	dense, semi-open & open

To minimize redundancy among functional traits, continuous traits were subjected to principal components analysis (PCA). The first three principal components (PC1–PC3) were retained for further analysis (see Appendix). PC1 represented size-related variation across traits, PC2 highlighted proportional differences between leg/body mass and beak traits, and PC3 captured flight adaptations. Categorical trait variables were converted into dummy variables. The resulting PC1–PC3 components and dummy variables were used to estimate functional diversity indices using the "FD" R package (Laliberté et al., 2014).

For reptiles, the analyses were limited to descriptive statistics as the data did not meet the assumptions required for robust hypothesis testing. Consequently, the study focused on describing the abundance of different reptile species in bracken-invaded and non-invaded habitats.

3. Results

3.1 Bird species composition and diversity between habitats

The study recorded a total of 406 individual birds across both bracken-invaded and non-invaded habitats. Of these, 160 individuals were recorded in invaded habitats while 246 were observed in non-invaded habitats. Overall, 59 bird species were identified across the two habitat types, with 27 species in bracken-invaded habitats compared to 48 species in non-invaded habitats.

In bracken-invaded habitats the main bird species observed were the Cape Robin-Chat (*Cossypha caffra*), Churring Cisticola (*Cisticola njombe*), Black-lored Cisticola (*Cisticola nigriloris*), African Stonechat (*Saxicola torquatus*), Common Waxbill (*Estrilda astrild*), Cinnamon Bracken-warbler (*Bradypterus cinnamomeus*) and Hildebrandt's Spurfowl

(*Pternistis hildebrandti*) (Figure 4). The Cape Robin-Chat and African Stonechat were frequently seen perching on shrubs or small trees growing within the heavily bracken-invaded areas. The Churring Cisticola was often observed flying and moving actively within these areas. The Black-lored Cisticola and Cinnamon Bracken-warbler were notable for their loud and frequent calls in the bracken areas.

Hildebrandt's Spurfowl was most often seen walking along roads and trails passing through bracken thickets. It was also observed utilizing the bracken canopy and open spaces between stems within the thickets. Similar behavior was noted for other species, such as the Red-winged Francolin (*Scleroptila levaillantii*), Whyte's Francolin (*Scleroptila whytei*) and Common Quail (*Coturnix coturnix*), although these species were not observed in high abundance during the study period.

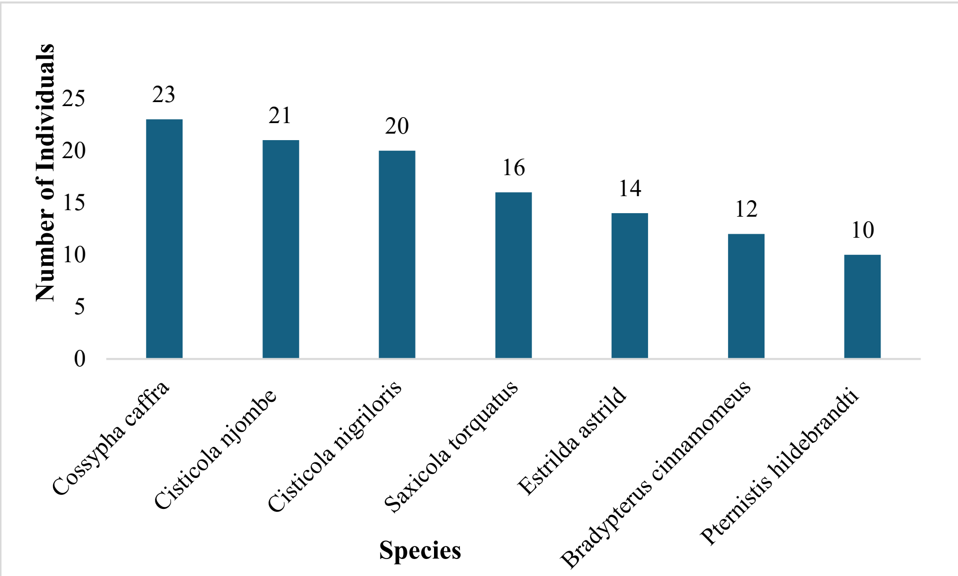

Figure 4: The main bird species in bracken-invaded habitats.

On the other hand, the main bird species in non-invaded habitats were the Churring Cisticola (*Cisticola njombe*), Yellow-mantled Widowbird (*Euplectes macroura*), Black-lored Cisticola (*Cisticola nigriloris*), Common Waxbill (*Estrilda astrild*), Fan-tailed Grassbird (*Schoenicola brevirostris*), Dark-capped Bulbul (*Pycnonotus tricolor*) and African Firefinch (*Lagonosticta rubricata*) (Figure 5). The Churring Cisticola was frequently observed flying in the grasslands, particularly at altitudes over 2000 m, but its activity declined noticeably at lower altitudes. Another commonly observed species was the Fan-tailed Grassbird, which was easily identified by its distinctive calls. The Common Waxbill, Dark-capped Bulbul and African Firefinch were primarily observed utilizing shrubs and small trees growing within the grasslands.

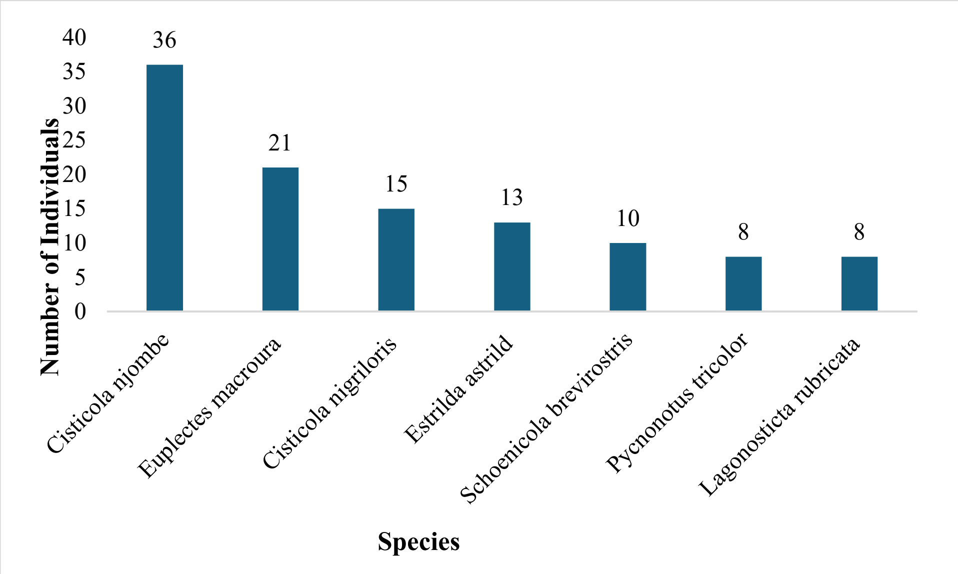

Figure 5: The main bird species in non-invaded habitats.

Despite the apparent difference in the number of bird species between bracken-invaded and non-invaded habitats, a statistical comparison based on Hill numbers showed no significant difference in species richness between the two habitats (Figure 6). However, significant differences were observed in the Shannon and Simpson diversity indices. Non-invaded habitats had consistently higher Shannon and Simpson diversity estimates (Figure 6). The Shannon and Simpson diversities for bracken-invaded habitats were 2.73 and 0.91, respectively, while non-invaded habitats had values of 3.38 and 0.95.

A beta diversity analysis between bracken-invaded and non-invaded habitats showed that bird communities in bracken habitats were distinct from those in non-invaded habitats. The total beta diversity estimates showed that the dissimilarity in species composition between the two habitats ranged from moderate (Sørensen index = 0.573**)** to high dissimilarity (Jaccard index = 0.729). Furthermore, the results revealed that the primary contributor to dissimilarity in species composition was species turnover rather than loss or gain (Table 2). The findings further revealed that bracken-invaded habitats do not simply represent a subset of bird species found in non-invaded habitats but rather support distinct bird communities. This interpretation is supported by the relatively low values of species nestedness compared to those of species turnover (Table 2).

Table 2: Bird beta diversity estimates.

Beta diversity component	**Sørensen index**	**Jaccard index**
Species turnover	0.407	0.579
Species nestedness	0.166	0.150
Total beta diversity	0.573	0.729

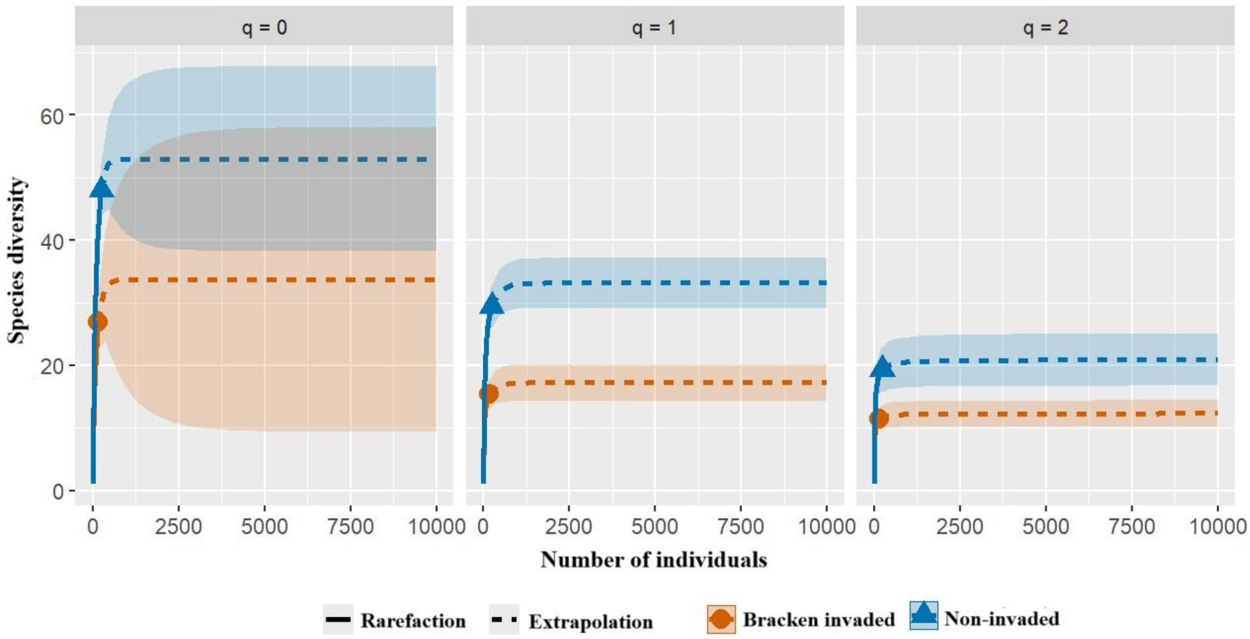

Figure 6: A comparison of bird species diversity in bracken invaded and non-invaded habitats. Shaded areas represent confidence intervals where overlapping confidence intervals indicate no significant differences. Hills numbers of order q are used: species richness (q=0), Shannon Diversity (q=1, the exponential of Shannon entropy) and Simpson Diversity (q=2, the inverse of Simpson concentration).

3.2 Bird functional diversity between invaded and non-invaded habitats

Overall, the results indicate that habitats invaded by bracken fern were characterized by reduced bird functional diversity. Non-invaded habitats consistently showed higher values across all three functional diversity indices (FRic, FEve and FDiv) compared to bracken-invaded habitats (Figure 7). Specifically, bird species in non-invaded habitats occupied a larger functional space and displayed greater trait variability, as reflected in the higher functional richness (FRic) values (Figure 7). In contrast, invaded habitats showed reduced trait variability and occupied a smaller functional space relative to non-invaded habitats.

Functional evenness (FEve) was also lower in invaded habitats, although the difference was marginal (Figure 7), indicating that species in non-invaded habitats were more evenly distributed within the functional space. Conversely, the lower FEve in invaded habitats suggests that bird species were more clustered around specific functional traits.

Similarly, functional divergence (FDiv) was slightly higher in non-invaded habitats, indicating greater variability in the distribution of species along extreme functional traits. In contrast, bracken-invaded habitats exhibited reduced functional trait space, less evenness and lower divergence, consistently highlighting a lower functional diversity compared to non-invaded habitats.

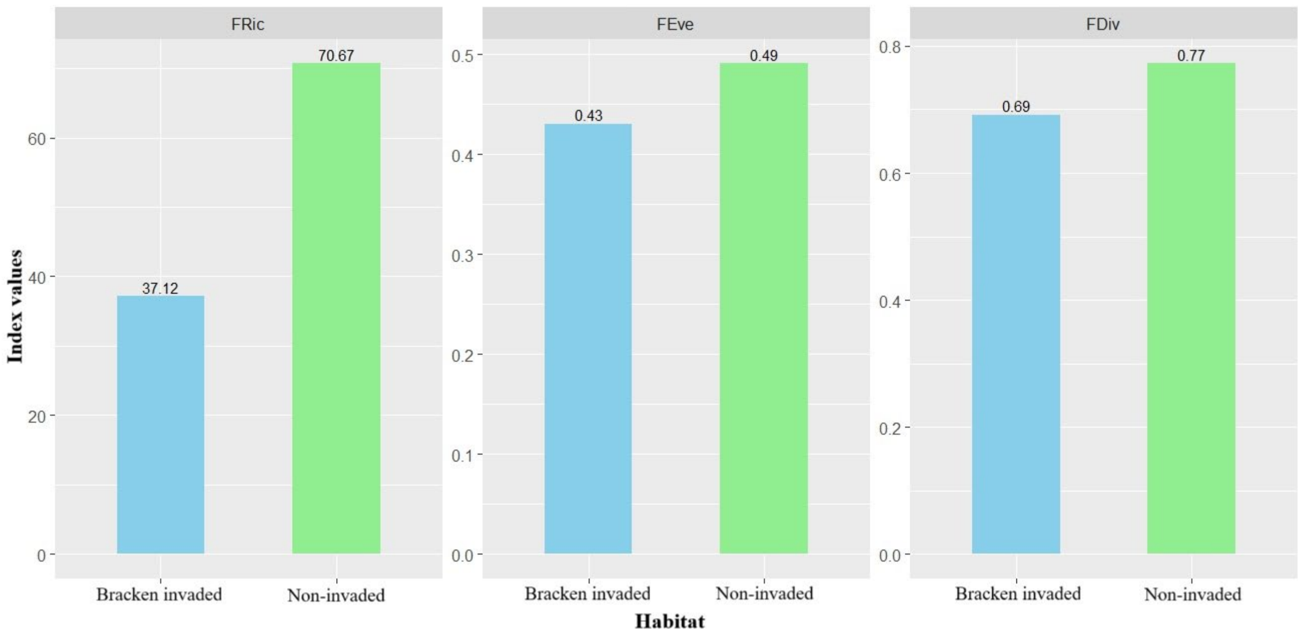

Figure 7: Functional diversity indices in bracken-invaded and non-invaded habitats. FRic represents functional richness, FEve represents functional evenness and FDiv represents functional divergence.

3.3 Reptile species diversity

The study recorded a limited number of reptile species in both bracken-invaded and non-invaded habitats. A total of six reptile species were observed across the two habitat types: two species in invaded habitats and four species in non-invaded habitats (Figure 8). In the invaded habitats, recorded species were the Grey-bellied Grass Snake (*Psammophylax variabilis*) and the Montane Three-striped Skink (*Trachlepis hildae*). In contrast, the non-invaded habitats seemed to have a higher species richness with records of the Eastern Yellow-bellied Sand Snake (*Psammophis orientalis*), Montane Three-striped Skink (*Trachlepis hildae*), Striped Skink (*Trachlepis striata*) and Variable Skink (*Trachlepis varia*). Among these, *Trachlepis hildae* was notably more abundant in the non-invaded habitats (Figure 8). Interestingly, opportunistic amphibians were recorded in both habitat types. Figure 9 shows pictures of some reptile species recorded in the study.

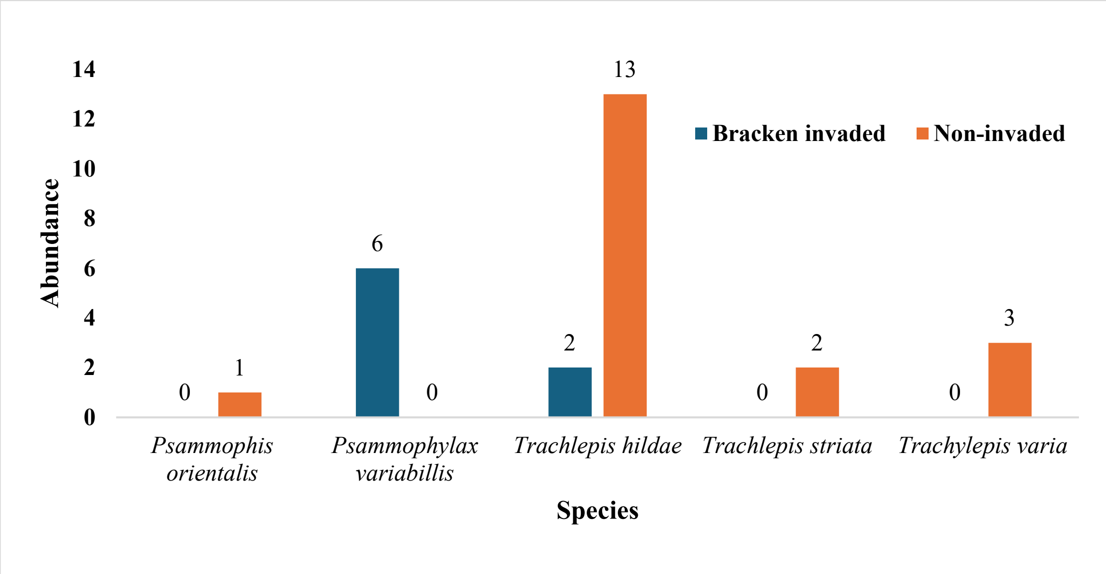

Figure 8: Abundance of reptile species in bracken-invaded and non-invaded habitats.

Figure 9: Some reptile species recorded during the study. (a) Grey-bellied Grass Snake (*Psammophylax variabilis*), (b) Striped Skink (*Trachlepis striata*), (c) Montane Three-striped Skink (*Trachlepis hildae*).

4. Discussion

4.1 The impact of bracken on bird species and functional diversity

This study highlights the significant ecological impacts of bracken fern invasion on bird communities. Bird species diversity was lower in bracken-invaded areas compared to non-invaded areas, suggesting that bracken invasion alters habitat quality and reduces resource availability. These findings align with previous research showing that invasive plants disrupt habitats by altering vegetation structure, food availability and predator communities (Nelson et al., 2017). The dominance of floristically uniform vegetation in bracken-invaded areas likely contributes to this reduced diversity, supporting the habitat heterogeneity hypothesis which predicts higher bird species diversity in more diverse habitats (MacArthur & MacArthur, 1961; Lorenzón et al., 2016; Cooper et al., 2020). In contrast, homogeneous habitats, like grassland monocultures, typically support fewer bird species (George et al., 2013).

Food availability is another key factor. Invasive plants often reduce arthropod abundance in invaded habitats (Litt et al., 2014), consequently insectivorous bird species may prefer uninvaded areas with higher arthropod abundance. While some invasive plants provide alternative food sources (Ortega et al., 2014), bracken offers limited food resources for birds as it is generally less attractive as food to both animals and insects.

Functional diversity analyses further emphasize the broader ecological impacts. Non-invaded habitats support higher functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv), suggesting they provide a broader array of ecological roles and trait combinations. This aligns with studies reporting reduced functional diversity in bird communities within invasive plant-dominated habitats (Schuldt et al., 2022; Grzędzicka et al., 2024). The lower functional diversity in bracken-invaded areas reflects a narrower ecological niche space, limiting the ecological functions available.

Despite these challenges, bracken may benefit certain bird species. Ground-dwelling birds, such as francolins and common quails, utilize bracken thickets for predator protection. Although their populations appeared low, it is possible they colonize these habitats in greater numbers but were difficult to detect due to the dense vegetation. Similarly, the Cape Robin-chat (*Cossypha caffra*) and African Stonechat (*Saxicola torquatus*) thrive in bracken-invaded habitats, suggesting their ability to adapt to or tolerate it. The Cape Robin-chat, in particular has been observed thriving in areas invaded by *Acacia* species (Rogers & Chown, 2014) indicating its ecological flexibility.

These findings suggest that while some bird species can adapt to bracken-invaded habitats, invasion significantly alters the overall bird community. Bracken habitats support distinct bird assemblages, as evidenced by higher species turnover values compared to nestedness. This indicates that such habitats host unique bird communities shaped by changes in habitat structure, resource availability and microclimatic conditions caused by dense bracken growth. Consistent with this, Grzędzicka (2022) found that invasive plants alter beta diversity in bird communities creating a distinct species composition.

While this study provides valuable insights, it is limited by the lack of direct testing for causal relationships and many conclusions are based on correlation. In addition, the study does not account for seasonal variation which could offer deeper insights into the influence of bracken on bird communities (Seoane et al., 2013; Katuwal et al., 2022). Despite such limitations, the findings serve as a foundation for further exploration of other hypotheses.

4.2 The impact of bracken on reptile species composition and diversity

The study could not clearly isolate differences between bracken-invaded and non-invaded habitats due to the low number of reptile species recorded in both. Only six species were observed, with two in bracken-invaded areas and four in non-invaded areas. The low reptile species richness is likely to be related to the high elevation of the sampling sites. Reptile capture rates and species richness tend to be higher at lower elevations, with declines above certain thresholds (Fischer et al., 2005). For instance, species richness for lizards and snakes tends to peak between 1000–1500 m and decreases significantly at higher elevations (Fu et al., 2007). This study surveyed sites at elevations ranging from 1971 m to 2486 m, with an average of 2229 m, which may explain the low species count. Reptile distribution is closely linked to temperature variations which are associated with elevation. Even small elevation differences, such as 50 m, can result in significant changes in species presence (Fischer et al., 2005).

Survey methods may have also influenced the low reptile capture rates. Different approaches for reptile surveys vary in effectiveness depending on habitat conditions (Ali et al., 2018). Visual searches, the approach used in this study, may have been less effective in the dense bracken and grass. While time-constrained searches are generally more efficient than trapping (Crosswhite et al., 1999), combining them with trapping methods could have improved species detection in both invaded and non-invaded habitats.

The two reptile species observed in bracken habitats suggest that invasion may not completely exclude reptiles but could limit the species that thrive there. In contrast, non-invaded habitats supported slightly higher species richness. Notably, *T. hildae*, the only species recorded in both habitat types, was significantly more abundant in non-invaded areas suggesting these areas offer more favorable conditions. However, the low number of reptile species and their corresponding abundance complicate the isolation of bracken fern invasion effects from other potential influencing factors, such as habitat structure, microclimate or prey availability.

4. Conclusions and Recommendations

This study explored the effects of bracken fern invasion on bird and reptile communities. For birds, findings show that bracken invasion is associated with lower species number and functional diversity, suggesting that bracken alters species composition. While bracken-invaded habitats may support some species, particularly mixed-feeding birds, the negative impacts seem to outweigh the benefits.

For reptiles, the results were inconclusive due to the low number of species recorded in both habitat types. However, the presence of a few species in bracken-invaded areas suggests these habitats may still offer resources or refuge for some reptiles. Further research is needed to assess how bracken-invaded habitats affect reptile diversity and abundance.

Based on these findings, the study recommends focusing conservation efforts on controlling bracken fern spread to protect species and functional diversity, especially amongst birds. Future studies should include more extensive surveys across seasons and times of day, as well as examine various microhabitats within invaded areas to better understand their ecological roles.

5. References

Ali, W., Javid, A., Bhukhari, S.M., Hussain, A., Hussain, S.M. & Rafique, H. (2018). Comparison of different trapping techniques used in herpetofaunal monitoring: a review. *Punjab University Journal of Zoology* 33(1), 57-68.

Banda, L.B. (2022). Measuring fire occurrence patterns and possible associations with the spread of bracken fern (*Pteridium aquilinum*) in Nyika National Park. Nyika-Vwaza Trust Research Study Report.

Baselga, A. & Orme, C.D.L. (2012). betapart: an R package for the study of beta diversity. *Methods in Ecology and Evolution* 3(5), 808-812.

Bateman, H.L. & Ostoja, S.M. (2012). Invasive woody plants affect the composition of native lizard and small mammal communities in riparian woodlands. *Animal Conservation* 15(3), 294-304.

Bibby, C., Burgess, N.D., Hill, D. & Mustoe, S. (2000). *Bird Census Techniques* (second edition). Academic Press, London.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Hernández Morcillo, M., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.C. & Watson, R. (2010). Global biodiversity: indicators of recent declines. *Science* 328(5982), 1164-1168.

Castro-Díez, P., Pauchard, A., Traveset, A. & Vilà, M. (2016). Linking the impacts of plant invasion on community functional structure and ecosystem properties. *Journal of Vegetation Science* 27(6), 1233-1242.

Catling, P.M. (2005). Effects of invasive alien plants on birds: some examples from North America. *Biodiversity* 6(3), 30-39.

Cooper, W.J., McShea, W.J., Forrester, T. & Luther, D.A. (2020). The value of local habitat heterogeneity and productivity when estimating avian species richness and species of concern. *Ecosphere* 11(5), e03107.

Crosswhite, D.L., Fox, S.F. & Thill R.E. (1999). Comparison of methods for monitoring reptiles and amphibians in upland forests of the Ouachita mountains.In: *Proceedings of the Oklahoma Academy of Science* 79, 45–50.

Davis, S.M. (2019). Impact of an invasive fern (*Dicranopteris pectinata*) on bird diversity and birdwatching in a Jamaican Ramsar site. *Journal of Caribbean Ornithology* 32, 57-64.

Dyderski, M.K., & Jagodziński, A.M. (2021). Impacts of invasive trees on alpha and beta diversity of temperate forest understories. *Biological Invasions* 23(1), 235-252.

Fischer, J. & Lindenmayer, D.B. (2005). The sensitivity of lizards to elevation: A case study from south-eastern Australia. *Diversity and Distributions* 11(3), 225-233.

Fletcher, R.A., Brooks, R.K., Lakoba, V.T., Sharma, G., Heminger, A.R., Dickinson, C.C. & Barney, J.N. (2019). Invasive plants negatively impact native, but not exotic, animals. *Global Change Biology* 25(11), 3694-3705.

Foxcroft, L.C., Pyšek, P., Richardson, D.M., Genovesi, P. & MacFadyen, S. (2017). Plant invasion science in protected areas: progress and priorities. *Biological Invasions* 19(5), 1353-1378.

Foxcroft, L.C., Witt, A. & Lotter, W.D. (2013). Icons in peril: Invasive alien plants in African protected areas. *Plant Invasions in Protected Areas: Patterns, Problems and Challenges*, 117-143. Elsevier.

Fu, C., Wang, J., Pu, Z., Zhang, S., Chen, H., Zhao, B., Chen, J. & Wu, J. (2007). Elevational gradients of diversity for lizards and snakes in the Hengduan Mountains, China. *Biodiversity and Conservation* 16, 707-726.

George, A.D., O'Connell, T.J., Hickman, K.R. & Leslie Jr, D.M. (2013). Food availability in exotic grasslands: a potential mechanism for depauperate breeding assemblages. *The Wilson Journal of Ornithology* 125(3), 526-533.

Grzędzicka, E. (2022). Impact of invasive weeds on the diversity and dissimilarity of bird communities in forested areas. *Diversity* 14(3), 229.

Grzędzicka, E., & Reif, J. (2020). Impacts of an invasive plant on bird communities differ along a habitat gradient. *Global Ecology and Conservation* 23, e01150.

Grzędzicka, E., Reif, J. & Hanzelka, J. (2024). Large invasive herbaceous plants decrease the taxonomic, functional and phylogenetic diversity of birds via their reproductive traits. *Functional Ecology* 38(12), 2595-2609.

Hejda, M., Hanzelka, J., Kadlec, T., Štrobl, M., Pyšek, P. & Reif, J. (2017). Impacts of an invasive tree across trophic levels: Species richness, community composition and resident species' traits. *Diversity and Distributions* 23(9), 997-1007.

Hejda, M., Pyšek, P. & Jarošík, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology* 97(3), 393-403.

Herrera, A.M. & Dudley, T.L. (2003). Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (*Arundo donax*) invasion. *Biological invasions* 5, 167-177.

Hsieh, T.C., Ma, K. & Chao, A. (2016). iNEXT: an R package for rarefaction and extrapolation of species diversity (H ill numbers). *Methods in Ecology and Evolution* 7(12), 1451-1456.

Kanzunguze, A. (2018). Mapping and remote detection of bracken fern invasion on the Nyika Plateau. Nyika-Vwaza Trust Research Study Report.

Kanzunguze, A. (2019). Ecology of bracken fern invasion in Nyika National Park: Assessment of its spatial-temporal distribution and potential threat to plant species diversity. Nyika-Vwaza Trust Research Study Report.

Katuwal, H.B., Rai, J., Tomlinson, K., Rimal, B., Sharma, H.P., Baral, H.S., Hughes, A.C. & Quan, R.C. (2022). Seasonal variation and crop diversity shape the composition of bird communities in agricultural landscapes in Nepal. *Agriculture, Ecosystems & Environment* 333, 107973.

Laliberté, E., Legendre, P., Shipley, B. & Laliberté, M.E. (2014). Package 'fd': Measuring functional diversity from multiple traits, and other tools for functional ecology. 28pp.

Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A. & Lamberti, G. (2002). An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society of London, Series B: Biological Sciences* 269(1508), 2407-2413.

Leverington, F., Costa, K.L., Pavese, H., Lisle, A. & Hockings, M. (2010). A global analysis of protected area management effectiveness. *Environmental Management* 46, 685-698.

Litt, A.R., Cord, E.E., Fulbright, T.E. & Schuster, G.L. (2014). Effects of invasive plants on arthropods. *Conservation Biology* 28(6), 1532-1549.

Lorenzón, R.E., Beltzer, A.H., Olguin, P.F. & Ronchi-Virgolini, A.L. (2016). Habitat heterogeneity drives bird species richness, nestedness and habitat selection by individual species in fluvial wetlands of the Paraná River, Argentina. *Austral Ecology* 41(7), 829-841.

MacArthur, R.H. & MacArthur, J.W. (1961). On bird species diversity. *Ecology* 42(3), 594-598.

Martin, L.J. & Murray, B.R. (2011). A predictive framework and review of the ecological impacts of exotic plant invasions on reptiles and amphibians. *Biological Reviews* 86(2), 407-419.

Mason, N.W., Mouillot, D., Lee, W.G. & Wilson, J.B. (2005). Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos* 111(1), 112-118.

Nelson, S.B., Coon, J.J., Duchardt, C.J., Fischer, J.D., Halsey, S.J., Kranz, A.J., Parker, C.M., Schneider, S.C., Swartz, T.M. & Miller, J.R. (2017). Patterns and mechanisms of invasive plant impacts on North American birds: a systematic review. *Biological Invasions* 19, 1547-1563.

Nyika-Vwaza Trust (2024). Nyika National Park. https://nyika-vwaza-trust.org/nyika-national-park/. Accessed 12th December 2024.

Ortega, Y.K., Greenwood, L.F., Callaway, R.M. & Pearson, D.E. (2014). Different responses of congeneric consumers to an exotic food resource: who gets the novel resource prize? *Biological Invasions* 16, 1757-1767.

Otto, R., Arteaga, M.A., Delgado, J.D., Arévalo, J.R., Blandino, C. & Fernández-Palacios, J.M. (2014). Road edge effect and elevation patterns of native and alien plants on an oceanic island (Tenerife, Canary Islands). *Folia Geobotanic* 49, 65-82.

Pickering, C. & Mount, A. (2010). Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism* 18(2), 239-256.

Pimentel, D., Lach, L., Zuniga, R. & Morrison, D. (2000). Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50(1), 53-65.

Pyšek, P., Jarošík, V., Hulme, P.E., Pergl, J., Hejda, M., Schaffner, U. & Vilà, M. (2012). A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. *Global Change Biology* 18(5), 1725-1737.

Rogers, A.M. & Chown, S.L. (2014). Novel ecosystems support substantial avian assemblages: the case of invasive alien Acacia thickets. *Diversity and Distributions* 20(1), 34-45.

Schirmel, J., Bundschuh, M., Entling, M.H., Kowarik, I. & Buchholz, S. (2016). Impacts of invasive plants on resident animals across ecosystems, taxa, and feeding types: a global assessment. *Global Change Biology* 22(2), 594-603.

Schuldt, A., Huke, P., Glatthorn, J., Hagge, J., Wildermuth, B. & Matevski, D. (2022). Tree mixtures mediate negative effects of introduced tree species on bird taxonomic and functional diversity. *Journal of Applied Ecology* 59(12), 3049-3060.

Seoane, J., Villen-Perez, S. & Carrascal, L.M. (2013). Environmental determinants of seasonal changes in bird diversity of Mediterranean oakwoods. *Ecological Research* 28, 435-445.

Tobias, J.A., Sheard, C., Pigot, A.L., Devenish, A.J.M., Yang, J., Sayol, F., Neate-Clegg, M.H.C., Alioravainen, N., Weeks, T.L., Barber, R.A., Walkden, P.A., MacGregor, H.E.A., Jones, S.E.I., Vincent, C., Phillips, A.G., Marples, N.M., Montaño-Centellas, F.A., Leandro-Silva, V., Claramunt, S., Darski, B., Freeman, B.G., Bregman, T.P., Cooney, C.R., Hughes, E.C., Capp, E.J.R., Varley, Z.K., Friedman, N.R., Korntheuer, H., Corrales-Vargas, A., Trisos, C.H., Weeks, B.C., Hanz, D.M., Töpfer, T., Bravo, G.A., Remeš, V., Nowak, L., Carneiro, L.S., Moncada R.A.J., Matysioková, B., Baldassarre, D.T., Martínez-Salinas, A., Wolfe, J.D., Chapman, P.M., Daly, B.G., Sorensen, M.C., Neu, A., Ford, M.A., Mayhew, R.J., Silveira, L.F., Kelly, D.J., Annorbah, N.N.D., Pollock, H.S., Grabowska-Zhang, A.M., McEntee, J.P., Gonzalez, J.C.T., Meneses, C.G., Muñoz, M.C., Powell, L.L., Jamie, G.A., Matthews, T.J., Johnson, O., Brito, G.R.R., Zyskowski, K., Crates, R., Harvey, M.G., Jurado Zevallos, M., Hosner, P.A., Bradfer-Lawrence, T., Maley, J.M., Stiles, F.G., Lima, H.S., Provost, K.L., Chibesa, M., Mashao, M., Howard, J.T., Mlamba, E., Chua, M.A.H., Li, B., Gómez, M.I., García, N.C., Päckert, M., Fuchs, J., Ali, J.R., Derryberry, E.P., Carlson, M.L., Urriza, R.C., Brzeski, K.E., Prawiradilaga, D.M., Rayner, M.J., Miller, E.T., Bowie, R.C.K., Lafontaine, R.-M., Scofield, R.P., Lou, Y., Somarathna, L., Lepage, D., Illif, M., Neuschulz, E.L., Templin, M., Dehling, D.M., Cooper, J.C., Pauwels, O.S.G., Analuddin, K., Fjeldså, J., Seddon, N., Sweet, P.R., DeClerck, F.A.J., Naka, L.N., Brawn, J.D., Aleixo, A., Böhning-Gaese, K., Rahbek, C., Fritz, S.A., Thomas, G.H. & Schleuning, M. (2022). AVONET: morphological, ecological and geographical data for all birds. *Ecology Letters* 25(3), 581-597.

Villéger, S., Mason, N.W. & Mouillot, D. (2008). New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89(8), 2290-2301.

6. Appendix: Summary of principle components analysis (PCA) of bird traits.

Importance of components:

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Standard deviation	2.469	1.1505	0.59811	0.31534	0.23602	0.20016	0.16085	0.04296
Proportion of Variance	0.762	0.1655	0.04472	0.01243	0.00696	0.00501	0.00323	0.00023
Cumulative Proportion	0.762	0.9274	0.97213	0.98456	0.99153	0.99654	0.99977	1.00000

Standard deviations (1, .., p=8):
[1] 2.46895902 1.15046479 0.59811488 0.31534065 0.23602415 0.20015981 0.16085388 0.04296125

Rotation (n x k) = (8 x 8):

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Beak.Length_Culmen	0.3918101	-0.1581003	-0.18691170	0.16175722	0.5033586	0.15887621	0.020424999	-0.69380046
Beak.Length_Nares	0.3620334	-0.3582753	-0.21064759	0.14317037	0.4417817	-0.17212413	0.119179350	0.66083199
Beak.Width	0.3790524	-0.2572600	-0.06342820	-0.34156213	-0.4599926	0.07059848	0.667207642	-0.08778071
Beak.Depth	0.3343858	-0.4717443	-0.03857874	0.02779216	-0.4523184	-0.04739927	-0.674136482	-0.04565170
Tarsus.Length	0.3326838	0.4569619	-0.27209109	0.09104975	-0.1231945	0.71202182	-0.119655547	0.24842360
Wing.Length	0.3629540	0.2653960	0.35602084	-0.72485551	0.2735790	-0.11854701	-0.234148843	0.04402759
Tail.Length	0.3510651	0.1150328	0.75431323	0.51913245	-0.0857005	-0.01865713	0.128844296	0.02720811
Mass	0.3070200	0.5152047	-0.38132311	0.18081951	-0.1946972	-0.64538689	0.003014079	-0.08808791